DIRETTIVE

DIRETTIVA 2010/75/UE DEL PARLAMENTO EUROPEO E DEL CONSIGLIO

del 24 novembre 2010

relativa alle emissioni industriali (prevenzione e riduzione integrate dell'inquinamento) (rifusione)

(Testo rilevante ai fini del SEE)

IL PARLAMENTO EUROPEO E IL CONSIGLIO DELL'UNIONE EUROPEA,

visto il trattato sul funzionamento dell'Unione europea, in particolare l'articolo 192, paragrafo 1,

vista la proposta della Commissione europea,

visto il parere del Comitato economico e sociale europeo ([1]),

visto il parere del Comitato delle regioni ([2]),

deliberando secondo la procedura legislativa ordinaria ([3]),

considerando quanto segue:

(1) Alla direttiva 78/176/CEE del Consiglio, del 20 febbraio 1978, relativa ai rifiuti provenienti dall'industria del biossido di titanio ([4]), alla direttiva 82/883/CEE del Consiglio, del 3 dicembre 1982, relativa alle modalità di vigilanza e di controllo degli ambienti interessati dagli scarichi dell'industria del biossido di titanio ([5]), alla direttiva 92/112/CEE del Consiglio, del 15 dicembre 1992, che fissa le modalità di armonizzazione dei programmi per la riduzione, al fine dell'eliminazione, dell'inquinamento provocato dai rifiuti dell'industria del biossido di titanio ([6]), alla direttiva 1999/13/CE del Consiglio, dell'11 marzo 1999, sulla limitazione delle emissioni di composti organici volatili dovute all'uso di solventi organici in talune attività e in taluni impianti ([7]), alla direttiva 2000/76/CE del Parlamento europeo e del Consiglio, del 4 dicembre 2000, sull'incenerimento dei rifiuti ([8]), alla direttiva 2001/80/CE del Parlamento europeo e del Consiglio, del 23 ottobre 2001, concernente la limitazione delle emissioni nell'atmosfera di taluni inquinanti originati dai grandi impianti di combustione ([9]), alla direttiva 2008/1/CE del Parlamento europeo e del Consiglio, del 15 gennaio 2008, sulla prevenzione e la riduzione integrate dell'inquinamento ([10]), devono essere apportate numerose modifiche sostanziali. Per motivi di chiarezza è opportuno procedere alla rifusione di dette direttive.

(2) Per prevenire, ridurre e, per quanto possibile, eliminare l'inquinamento dovuto alle attività industriali, nel rispetto del principio «chi inquina paga» e del principio della prevenzione dell'inquinamento, è necessario definire un quadro generale che disciplini le principali attività industriali, intervenendo innanzitutto alla fonte, nonché garantendo una gestione accorta delle risorse naturali e tenendo presente, se del caso, la situazione socioeconomica e le specifiche caratteristiche locali del sito in cui si svolge l'attività industriale.

(3) Approcci distinti nel controllo delle emissioni nell'atmosfera, nelle acque o nel terreno possono incoraggiare il trasferimento dell'inquinamento da una matrice ambientale all'altra anziché proteggere l'ambiente nel suo complesso. È pertanto appropriato assicurare un approccio integrato alla prevenzione e alla riduzione delle emissioni nell'aria, nell'acqua e nel terreno, alla gestione dei rifiuti, all'efficienza energetica e alla prevenzione degli incidenti. Tale approccio contribuirà altresì al conseguimento di condizioni di parità nell'Unione, uniformando i requisiti in materia di prestazioni ambientali per le installazioni industriali.

([1]) GU C 182 del 4.8.2009, pag. 46.
([2]) GU C 325 del 19.12.2008, pag. 60.
([3]) Posizione del Parlamento europeo del 10 marzo 2009 (GU C 87 E dell'1.4.2010, pag. 191) e posizione del Consiglio in prima lettura del 15 febbraio 2010 (GU C 107 E del 27.4.2010, pag. 1). Posizione del Parlamento europeo del 7 luglio 2010 (non ancora pubblicata nella Gazzetta ufficiale) e decisione del Consiglio dell'8 novembre 2010.
([4]) GU L 54 del 25.2.1978, pag. 19.
([5]) GU L 378 del 31.12.1982, pag. 1.
([6]) GU L 409 del 31.12.1992, pag. 11.
([7]) GU L 85 del 29.3.1999, pag. 1.
([8]) GU L 332 del 28.12.2000, pag. 91.
([9]) GU L 309 del 27.11.2001, pag. 1.
([10]) GU L 24 del 29.1.2008, pag. 8.

(4) È opportuno rivedere la legislazione relativa alle installazioni industriali per semplificare e chiarire le disposizioni esistenti, ridurre i vincoli amministrativi inutili ed attuare le conclusioni delle comunicazioni della Commissione, del 21 settembre 2005, sulla strategia tematica sull'inquinamento atmosferico («la strategia tematica sull'inquinamento atmosferico»), del 22 settembre 2006 sulla strategia tematica per la protezione del suolo e del 21 dicembre 2005 sulla strategia tematica sulla prevenzione e il riciclaggio dei rifiuti adottate come seguito alla decisione n. 1600/2002/CE del Parlamento europeo e del Consiglio, del 22 luglio 2002, che istituisce il sesto programma comunitario di azione in materia di ambiente ([1]). Tali comunicazioni fissano obiettivi di tutela della salute umana e dell'ambiente che non possono essere raggiunti senza nuove riduzioni delle emissioni che provengono dalle attività industriali.

(5) Per assicurare la prevenzione e la riduzione dell'inquinamento, le singole installazioni dovrebbero operare esclusivamente se sono in possesso di un'autorizzazione oppure, nel caso di talune attività e di talune installazioni che utilizzano solventi organici, esclusivamente se detengono un'autorizzazione oppure se sono registrate.

(6) Spetta agli Stati membri determinare l'approccio per assegnare le responsabilità ai gestori delle installazioni purché sia assicurato il rispetto della presente direttiva. Gli Stati membri possono scegliere di rilasciare l'autorizzazione ad un gestore responsabile per ciascuna installazione ovvero specificare la responsabilità tra diversi gestori di differenti parti di un'installazione. Qualora l'attuale regolamentazione nazionale preveda un solo gestore responsabile per ciascuna installazione, gli Stati membri possono decidere di mantenere tale sistema.

(7) Per facilitare il rilascio delle autorizzazioni, è opportuno che gli Stati membri possano fissare requisiti per talune categorie di installazioni in norme generali vincolanti.

(8) È importante prevenire inconvenienti e incidenti e limitarne le conseguenze. La responsabilità per le conseguenze ambientali degli inconvenienti e incidenti è disciplinata dalla pertinente normativa nazionale e, se del caso, da altra pertinente normativa dell'Unione.

(9) Per evitare la duplicazione della regolamentazione, è opportuno che l'autorizzazione rilasciata per un'installazione contemplata dalla direttiva 2003/87/CE del Parlamento europeo e del Consiglio, del 13 ottobre 2003, che istituisce un sistema per lo scambio delle quote di emissioni di gas a effetto serra nella Comunità ([2]), non contenga un valore limite per le emissioni dirette di gas a effetto serra di cui all'allegato I di tale direttiva, salvo ove ciò sia indispensabile per evitare un rilevante inquinamento locale o quando un'installazione sia esclusa da tale sistema.

(10) Conformemente all'articolo 193 del trattato sul funzionamento dell'Unione europea (TFUE), la presente direttiva non impedisce agli Stati membri di mantenere o adottare misure di protezione più rigorose, ad esempio prescrizioni in materia di emissioni di gas a effetto serra, purché tali misure siano compatibili con i trattati e siano state notificate alla Commissione.

(11) I gestori dovrebbero presentare domande d'autorizzazione contenenti le informazioni necessarie affinché l'autorità competente definisca le condizioni per il rilascio dell'autorizzazione. È opportuno che, quando presentano le domande d'autorizzazione, i gestori possano utilizzare le informazioni derivanti dall'applicazione della direttiva 85/337/CEE del Consiglio, del 27 giugno 1985, sulla valutazione dell'impatto ambientale di determinati progetti pubblici e privati ([3]), e della direttiva 96/82/CE del Consiglio, del 9 dicembre 1996, sul controllo dei pericoli di incidenti rilevanti connessi con determinate sostanze pericolose ([4]).

(12) L'autorizzazione dovrebbe definire tutte le misure necessarie per assicurare un elevato livello di protezione dell'ambiente nel suo complesso e per assicurare che l'installazione sia gestita conformemente ai principi generali degli obblighi fondamentali del gestore. L'autorizzazione dovrebbe fissare inoltre valori limite di emissione per le sostanze inquinanti, ovvero parametri o misure tecniche equivalenti, requisiti adeguati per la protezione del suolo e delle acque sotterranee e prescrizioni in materia di monitoraggio. È opportuno che le condizioni di autorizzazione siano definite sulla base delle migliori tecniche disponibili.

(13) Per definire le migliori tecniche disponibili e limitare le disparità a livello dell'Unione relativamente al livello di emissioni delle attività industriali, è opportuno elaborare documenti di riferimento sulle migliori tecniche disponibili («documenti di riferimento sulle BAT»), i quali dovrebbero essere riesaminati e, ove necessario, aggiornati attraverso uno scambio di informazioni tra le parti interessate e gli elementi fondamentali dei documenti di riferimento sulle BAT («conclusioni sulle BAT») dovrebbero essere adottati attraverso la procedura di comitato. A tale riguardo la Commissione, attraverso la procedura di comitato, dovrebbe stabilire linee guida sulla raccolta dei dati, sull'elaborazione dei documenti di riferimento sulle BAT e sull'assicurazione della loro qualità. Le conclusioni sulle BAT dovrebbero fungere da riferimento per stabilire le condizioni di autorizzazione e possono essere integrate da altre fonti. La Commissione dovrebbe mirare all'aggiornamento dei documenti di riferimento sulle BAT entro e non oltre otto anni dalla pubblicazione della versione precedente.

([1]) GU L 242 del 10.9.2002, pag. 1.
([2]) GU L 275 del 25.10.2003, pag. 32.
([3]) GU L 175 del 5.7.1985, pag. 40.
([4]) GU L 10 del 14.1.1997, pag. 13.

(14) Al fine di garantire uno scambio di informazioni efficace ed attivo da cui derivino documenti di riferimento sulle BAT di alta qualità, la Commissione dovrebbe istituire un forum dal funzionamento trasparente. Si dovrebbero stabilire modalità pratiche per lo scambio di informazioni e l'accesso ai documenti di riferimento sulle BAT, in particolare per garantire che gli Stati membri e le parti interessate forniscano dati di qualità e quantità sufficiente in base agli orientamenti stabiliti per consentire di determinare le migliori tecniche disponibili e le tecniche emergenti.

(15) È importante offrire alle autorità competenti una flessibilità sufficiente per fissare valori limite di emissione atti ad assicurare che, in condizioni di esercizio normali, le emissioni non superino i livelli di emissione associati alle migliori tecniche disponibili indicati nelle conclusioni sulle BAT. A tal fine, l'autorità competente può fissare limiti di emissione diversi dai livelli di emissione associati alle migliori tecniche disponibili in termini di valori, periodi di tempo e condizioni di riferimento applicati, purché sia possibile dimostrare, attraverso i risultati del controllo delle emissioni, che le emissioni non hanno superato i livelli di emissione associati alle migliori tecniche disponibili. L'osservanza dei valori limite di emissione fissati nelle autorizzazioni dà luogo a emissioni inferiori a detti valori limite.

(16) Per tenere conto di talune circostanze particolari in cui l'applicazione dei livelli di emissione associati alle migliori tecniche disponibili comporterebbe costi sproporzionatamente elevati rispetto ai benefici ambientali, è opportuno che le autorità competenti possano fissare valori limite d'emissione che si discostino da detti livelli. Tali discostamenti dovrebbero basarsi su una valutazione che tenga conto di criteri ben definiti. I valori limite di emissione fissati nella presente direttiva non dovrebbero essere superati. In ogni caso, non dovrebbero essere causati inquinamenti significativi e dovrebbe essere conseguito un livello elevato di protezione dell'ambiente nel suo complesso.

(17) Per permettere ai gestori di sperimentare tecniche nuove che potrebbero garantire un più elevato livello di protezione dell'ambiente nel suo complesso o almeno lo stesso livello di protezione dell'ambiente e maggiori risparmi di spesa rispetto alle migliori tecniche disponibili esistenti, le autorità competenti dovrebbero poter accordare deroghe temporanee ai livelli di emissione associati alle migliori tecniche disponibili.

(18) Le modifiche apportate ad un'installazione possono provocare un aumento dei livelli di inquinamento. È opportuno che gli operatori notifichino all'autorità competente tutte le modifiche previste che potrebbero avere ripercussioni sull'ambiente. Non dovrebbero essere apportate a un'installazione modifiche sostanziali che possano avere significativi effetti negativi sulla salute umana o sull'ambiente senza un'autorizzazione concessa conformemente alla presente direttiva.

(19) Lo spandimento di effluenti di allevamento contribuisce significativamente alle emissioni di inquinanti nell'atmosfera e nell'acqua. Al fine di conseguire gli obiettivi fissati nella strategia tematica sull'inquinamento atmosferico e nella normativa dell'Unione in materia di tutela delle acque, è necessario che la Commissione riesamini la necessità di stabilire i controlli più adatti di dette emissioni mediante le migliori tecniche disponibili.

(20) L'allevamento intensivo di pollame e di bovini contribuisce in modo significativo alle emissioni di inquinanti nell'atmosfera e nell'acqua. Al fine di conseguire gli obiettivi fissati nella strategia tematica sull'inquinamento atmosferico e nella normativa dell'Unione in materia di tutela delle acque, è necessario che la Commissione riesamini la necessità di fissare valori soglia di capacità differenziati per le diverse specie di pollame per definire l'ambito di applicazione della presente direttiva, nonché rivedere la necessità di stabilire i controlli più adatti sulle emissioni prodotte dalle installazioni di allevamento di bovini.

(21) Per tenere conto dei progressi delle migliori tecniche disponibili o di altri cambiamenti di un'installazione, è opportuno riesaminare regolarmente e, se necessario, aggiornare le condizioni di autorizzazione, in particolare quando vengono adottate conclusioni sulle BAT nuove o aggiornate.

(22) In casi specifici in cui il riesame e l'aggiornamento dell'autorizzazione indicano che potrebbe essere necessario un periodo superiore a quattro anni dopo la pubblicazione di una decisione relativa alle conclusioni sulle BAT per introdurre nuove migliori tecniche disponibili, le autorità competenti possono stabilire nelle condizioni di autorizzazione un periodo più lungo qualora ciò sia giustificato in base ai criteri stabiliti nella presente direttiva.

(23) È necessario assicurare che l'esercizio di un'installazione non comporti un deterioramento della qualità del suolo e delle acque sotterranee. È pertanto opportuno che le condizioni di autorizzazione prevedano anche misure adeguate per prevenire emissioni nel suolo e nelle acque sotterranee, nonché la periodica verifica di tali misure per evitare che abbiano luogo perdite, fuoriuscite, inconvenienti o incidenti durante l'uso di attrezzature e durante lo stoccaggio. Al fine di rilevare precocemente un eventuale inquinamento del suolo e delle acque sotterranee e, di conseguenza, adottare adeguate misure correttive prima che l'inquinamento si diffonda, è altresì necessario procedere al monitoraggio del suolo e delle acque sotterranee per verificare la presenza di sostanze pericolose pertinenti. In sede di determinazione della frequenza del monitoraggio si può tener conto del tipo di misure di prevenzione e della portata e della cadenza della loro verifica.

(24) Al fine di assicurare che l'esercizio di un'installazione non comporti un deterioramento della qualità del suolo e delle acque sotterranee è necessario stabilire lo stato della contaminazione del suolo e delle acque sotterranee attraverso una relazione di riferimento. La relazione di riferimento dovrebbe essere uno strumento pratico atto a consentire, per quanto possibile, un raffronto in termini quantitativi tra lo stato del sito descritto in tale relazione e lo stato del sito al momento della cessazione definitiva delle attività, al fine di accertare se si è verificato un aumento significativo dell'inquinamento del suolo o delle acque sotterranee. La relazione di riferimento dovrebbe pertanto contenere informazioni che si avvalgano dei dati esistenti sulle misurazioni effettuate sul suolo e sulle acque sotterranee, nonché dei dati storici relativi agli usi passati del sito.

(25) Conformemente al principio «chi inquina paga», in sede di valutazione del livello di significatività dell'inquinamento del suolo e delle acque sotterranee causato dal gestore che farebbe scattare l'obbligo di ripristinare il sito allo stato descritto nella relazione di riferimento, è opportuno che gli Stati membri tengano conto delle condizioni di autorizzazione applicate nel corso dell'attività interessata, delle misure di prevenzione dell'inquinamento adottate per l'installazione e dell'aumento relativo dell'inquinamento rispetto al carico di contaminazione indicato nella relazione di riferimento. La responsabilità per l'inquinamento non causato dal gestore è disciplinata dalla pertinente normativa nazionale e, se del caso, da altra pertinente normativa dell'Unione.

(26) Per garantire l'attuazione e l'esecuzione efficaci della presente direttiva, è opportuno che i gestori riferiscano periodicamente all'autorità competente in merito al rispetto delle condizioni di autorizzazione. È opportuno che gli Stati membri facciano in modo che il gestore e l'autorità competente adottino entrambi le misure necessarie in caso di inosservanza della presente direttiva, prevedano un sistema di ispezioni ambientali e garantiscano la disponibilità di risorse umane sufficienti, dotate delle competenze e delle qualifiche necessarie per lo svolgimento efficace di tali ispezioni.

(27) Conformemente alla convenzione di Aarhus sull'accesso alle informazioni, la partecipazione del pubblico ai processi decisionali e l'accesso alla giustizia in materia ambientale [1], è necessario che i cittadini possano partecipare effettivamente al processo decisionale, esprimendo in merito ad esso pareri e preoccupazioni dei quali i responsabili decisionali devono tenere conto; ciò permetterà di rafforzare la responsabilizzazione delle istanze decisionali ed aumenterà la trasparenza del processo decisionale, contribuendo in tal modo a sensibilizzare i cittadini in merito ai problemi ambientali e ad ottenere il loro sostegno relativamente alle decisioni prese. È opportuno che i cittadini interessati abbiano accesso alla giustizia per potere contribuire alla salvaguardia del diritto di ognuno a vivere in un ambiente atto a garantire la sua salute ed il suo benessere.

(28) La combustione di carburante nelle installazioni con potenza termica nominale totale inferiore a 50 MW contribuisce significativamente alle emissioni di inquinanti nell'atmosfera e nell'acqua. Al fine di conseguire gli obiettivi fissati nella strategia tematica sull'inquinamento atmosferico, è necessario che la Commissione riesamini la necessità di stabilire i controlli più adatti delle emissioni di tali installazioni. Tale riesame dovrebbe tener conto delle specificità degli impianti di combustione utilizzati in strutture sanitarie, con particolare riferimento al loro impiego eccezionale in situazioni di emergenza.

(29) I grandi impianti di combustione contribuiscono considerevolmente all'emissione di sostanze inquinanti nell'atmosfera, che hanno gravi ripercussioni sulla salute umana e sull'ambiente. Per ridurre tale impatto e contribuire al rispetto delle prescrizioni contenute nella direttiva 2001/81/CE del Parlamento europeo e del Consiglio, del 23 ottobre 2001, relativa ai limiti nazionali di emissione di alcuni inquinanti atmosferici [2] e al conseguimento degli obiettivi fissati nella strategia tematica sull'inquinamento atmosferico, è necessario stabilire valori limite di emissione più severi a livello dell'Unione per talune categorie di impianti di combustione e di sostanze inquinanti.

(30) La Commissione dovrebbe riesaminare la necessità di stabilire valori limite di emissione su scala dell'Unione e di modificare i valori limite di emissione indicati nell'allegato V per taluni grandi impianti di combustione, tenendo conto del riesame e dell'aggiornamento dei documenti di riferimento sulle BAT pertinenti In tale contesto, la Commissione dovrebbe considerare la specificità dei sistemi energetici delle raffinerie.

(31) A causa delle caratteristiche di taluni combustibili solidi indigeni, è appropriato applicare gradi minimi di desolforazione piuttosto che valori limite di emissione per l'anidride solforosa agli impianti di combustione che bruciano tali combustibili. Inoltre, poiché le caratteristiche specifiche degli scisti bituminosi potrebbero non consentire l'applicazione delle stesse tecniche di abbattimento dello zolfo o il conseguimento della stessa efficienza di desolforazione ottenuta con gli altri combustibili, è appropriato un grado minimo di desolforazione leggermente inferiore per gli impianti alimentati con tale combustibile.

(32) È opportuno che, nel caso di un'improvvisa interruzione della fornitura di combustibile o di gas a basso tenore di zolfo dovuta a una situazione di penuria grave, l'autorità competente possa accordare deroghe temporanee che autorizzino gli impianti di combustione interessati a superare i valori limite di emissione fissati dalla presente direttiva.

[1] GU L 124 del 17.5.2005, pag. 4.

[2] GU L 309 del 27.11.2001, pag. 22.

(33) È opportuno che il gestore interessato non lasci in funzione l'impianto per oltre 24 ore dopo un guasto o un cattivo funzionamento del dispositivo di abbattimento e che la durata complessiva del funzionamento in assenza di abbattimento non ecceda le 120 ore nell'arco di 12 mesi, per limitare gli effetti negativi dell'inquinamento sull'ambiente. Tuttavia, nel caso vi sia l'assoluta necessità di continuare le forniture di energia o sia necessario evitare un aumento complessivo delle emissioni derivante dalla messa in funzione di un altro impianto di combustione, le autorità competenti dovrebbero poter autorizzare una deroga a tali limitazioni temporali.

(34) Per garantire un livello elevato di tutela dell'ambiente e della salute umana, e per evitare gli spostamenti transfrontalieri di rifiuti verso impianti soggetti a norme ambientali meno rigorose, è opportuno definire e fare rispettare valori limite di emissione, condizioni di esercizio e prescrizioni tecniche rigorosi per gli impianti d'incenerimento o di coincenerimento di rifiuti nell'Unione.

(35) L'uso di solventi organici in determinate attività e in determinate installazioni provoca emissioni di composti organici nell'atmosfera che possono contribuire alla formazione locale e transfrontaliera di ossidanti fotochimici che causano danni alle risorse naturali e hanno effetti nocivi per la salute umana. È pertanto necessario adottare misure preventive per limitare l'uso di solventi organici ed esigere il rispetto dei valori limite di emissione di composti organici e di condizioni di esercizio adeguate. Ai gestori dovrebbe essere consentito rispettare i requisiti di un piano di riduzione invece dei valori limite di emissione di cui alla presente direttiva quando altre misure, come l'utilizzo di prodotti o di tecniche senza solventi o a basso tenore di solventi, permettono di ridurre in modo equivalente le emissioni.

(36) Le installazioni che producono biossido di titanio possono dare origine a importanti tassi di inquinamento atmosferico e idrico. Per ridurre tali ripercussioni è necessario fissare valori limite di emissione più severi per determinate sostanze inquinanti a livello dell'Unione.

(37) Per quanto riguarda l'inclusione nell'ambito di applicazione delle norme nazionali, dei regolamenti e delle disposizioni amministrative messe in vigore al fine di adeguare alla presente direttiva gli impianti per la fabbricazione di prodotti ceramici mediante cottura, sulla base delle caratteristiche del comparto industriale nazionale, e al fine di garantire una chiara interpretazione dell'ambito di applicazione, è opportuno che gli Stati decidano se applicare entrambi i criteri di capacità produttiva e capacità del forno o uno solo dei due criteri.

(38) Al fine di semplificare le relazioni e ridurre gli oneri amministrativi superflui, la Commissione dovrebbe individuare metodi per snellire il modo in cui sono messi a disposizione i dati ai sensi della presente direttiva in base agli altri requisiti della normativa dell'Unione e in particolare al regolamento (CE) n. 166/2006 del Parlamento europeo e del Consiglio, del 18 gennaio 2006, relativo all'istituzione di un registro europeo delle emissioni e dei trasferimenti di sostanze inquinanti [1].

(39) Al fine di garantire condizioni uniformi di attuazione, la Commissione dovrebbe avere competenze di esecuzione al fine di adottare orientamenti sulla raccolta di dati, sulla stesura dei documenti di riferimento sulle BAT e sulla loro garanzia di qualità, compresa l'adeguatezza del loro contenuto e formato, di adottare decisioni riguardo alle conclusioni sulle BAT, di stabilire norme dettagliate per la determinazione dei periodi di avvio e di arresto e per i piani nazionali transitori per i grandi impianti di combustione, nonché di stabilire il tipo, il formato e la frequenza delle informazioni che gli Stati membri devono trasmettere alla Commissione. In conformità dell'articolo 291 TFUE, le norme e i principi generali relativi ai meccanismi di controllo, da parte degli Stati membri, dell'esercizio delle competenze di esecuzione della Commissione sono stabiliti preventivamente mediante un regolamento adottato secondo la procedura legislativa ordinaria. In attesa dell'adozione di tale nuovo regolamento, continua ad applicarsi la decisione 1999/468/CE del Consiglio, del 28 giugno 1999, recante modalità per l'esercizio delle competenze di esecuzione conferite alla Commissione [2], (fatta salva la procedura di regolamentazione con controllo, che non è applicabile).

(40) La Commissione dovrebbe avere la facoltà di adottare atti delegati ai sensi dell'articolo 290 TFUE relativamente alla fissazione della data a decorrere da cui devono essere effettuate le misurazioni continue delle emissioni di metalli pesanti, diossine e furani nell'atmosfera e all'adeguamento di alcune parti degli allegati V, VI e VII al progresso scientifico e tecnico. Nel caso degli impianti di incenerimento dei rifiuti e degli impianti di coincenerimento dei rifiuti, ciò può comprendere anche la definizione di criteri in base ai quali ammettere deroghe al monitoraggio in continuo delle emissioni di polveri totali. È particolarmente importante che durante i lavori preparatori la Commissione svolga consultazioni adeguate, anche a livello di esperti.

(41) Per far fronte a gravi episodi di inquinamento ambientale, imputabile ad esempio a metalli pesanti, diossine e furani, è opportuno che la Commissione, in base a una valutazione dell'applicazione delle migliori tecniche disponibili da parte di determinate attività o dell'impatto di tali attività sull'ambiente nel suo insieme, presenti proposte concernenti prescrizioni minime valide in tutta l'Unione per i valori limite di emissione e per le norme in materia di monitoraggio e conformità.

(42) È opportuno che gli Stati membri fissino norme relative alle sanzioni applicabili in caso di violazione delle disposizioni nazionali adottate conformemente alla presente direttiva e ne assicurino l'applicazione. Tali sanzioni dovrebbero essere effettive, proporzionate e dissuasive.

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[1] GU L 33 del 4.2.2006, pag. 1.

[2] GU L 184 del 17.7.1999, pag. 23.

(43) Per concedere alle installazioni esistenti un tempo sufficiente per adeguarsi, sul piano tecnico, alle nuove prescrizioni della presente direttiva, è opportuno che alcune di queste nuove prescrizioni si applichino alle installazioni esistenti dopo un periodo di tempo determinato a partire dalla data d'applicazione della presente direttiva. Gli impianti di combustione necessitano di un periodo di tempo sufficiente per attuare le misure di abbattimento delle emissioni richieste per conformarsi ai valori limite di emissione indicati nell'allegato V.

(44) Poiché gli obiettivi della presente direttiva, in particolare garantire un elevato livello di tutela dell'ambiente e migliorare la qualità dell'ambiente, non possono essere realizzati in misura sufficiente dagli Stati membri e possono dunque, a causa del carattere transfrontaliero dell'inquinamento provocato dalle attività industriali, essere realizzati meglio a livello dell'Unione, l'Unione può intervenire in base al principio di sussidiarietà sancito dall'articolo 5 del trattato sull'Unione europea. La presente direttiva si limita a quanto necessario per conseguire tali obiettivi in ottemperanza al principio di proporzionalità enunciato nello stesso articolo.

(45) La presente direttiva rispetta i diritti fondamentali e osserva i principi sanciti in particolare dalla Carta dei diritti fondamentali dell'Unione europea. In particolare, la presente direttiva mira a promuovere l'applicazione dell'articolo 37 della predetta Carta.

(46) L'obbligo di attuare la presente direttiva nel diritto nazionale dovrebbe limitarsi alle disposizioni che rappresentano un cambiamento sostanziale rispetto alle direttive precedenti. L'obbligo di attuare le disposizioni rimaste immutate nella sostanza discende dalle direttive precedenti.

(47) Conformemente al punto 34 dell'accordo interistituzionale «Legiferare meglio» ([1]), gli Stati membri sono incoraggiati a redigere e a rendere pubblici, nell'interesse proprio e dell'Unione, prospetti indicanti, per quanto possibile, la concordanza tra la presente direttiva e i provvedimenti di recepimento.

(48) La presente direttiva dovrebbe far salvi gli obblighi degli Stati membri relativi ai termini di recepimento nel diritto nazionale e di applicazione delle direttive indicate nell'allegato IX, parte B,

HANNO ADOTTATO LA PRESENTE DIRETTIVA:

CAPO I

DISPOSIZIONI COMUNI

Articolo 1

Oggetto

La presente direttiva stabilisce norme riguardanti la prevenzione e la riduzione integrate dell'inquinamento proveniente da attività industriali.

([1]) GU C 321 del 31.12.2003, pag. 1.

Essa fissa inoltre norme intese a evitare oppure, qualora non sia possibile, ridurre le emissioni delle suddette attività nell'aria, nell'acqua e nel terreno e ad impedire la produzione di rifiuti, per conseguire un livello elevato di protezione dell'ambiente nel suo complesso.

Articolo 2

Ambito di applicazione

1. La presente direttiva si applica alle attività industriali che causano inquinamento di cui ai capi da II a VI.

2. La presente direttiva non si applica alle attività di ricerca, alle attività di sviluppo o alla sperimentazione di nuovi prodotti e processi.

Articolo 3

Definizioni

Ai fini della presente direttiva si intende per:

1) «sostanze», gli elementi chimici e loro composti, ad eccezione delle seguenti sostanze:

   a) le sostanze radioattive come definite all'articolo 1della direttiva 96/29/Euratom del Consiglio, del 13 maggio 1996, che stabilisce le norme fondamentali di sicurezza relative alla protezione sanitaria della popolazione e dei lavoratori contro i pericoli derivanti dalle radiazioni ionizzanti ([2]);

   b) i microrganismi geneticamente modificati come definiti all'articolo 2, lettera b), della direttiva 2009/41/CE del Parlamento europeo e del Consiglio, del 6 maggio 2009, sull'impiego confinato di microrganismi geneticamente modificati ([3]);

   c) gli organismi geneticamente modificati come definiti all'articolo 2, punto 2, della direttiva 2001/18/CE del Parlamento europeo e del Consiglio, del 12 marzo 2001, sull'emissione deliberata nell'ambiente di organismi geneticamente modificati ([4]);

2) «inquinamento», l'introduzione diretta o indiretta, a seguito di attività umana, di sostanze, vibrazioni, calore o rumore nell'aria, nell'acqua o nel terreno, che potrebbero nuocere alla salute umana o alla qualità dell'ambiente, causare il deterioramento di beni materiali, oppure danni o perturbazioni a valori ricreativi dell'ambiente o ad altri suoi legittimi usi;

([2]) GU L 159 del 29.6.1996, pag. 1.
([3]) GU L 125 del 21.5.2009, pag. 75.
([4]) GU L 106 del 17.4.2001, pag. 1.

3) «installazione», l'unità tecnica permanente in cui sono svolte una o più attività elencate nell'allegato I o nell'allegato VII, parte I, e qualsiasi altra attività accessoria presso lo stesso luogo, che sono tecnicamente connesse con le attività elencate nei suddetti allegati e possono influire sulle emissioni e sull'inquinamento;

4) «emissione», lo scarico diretto o indiretto, da fonti puntiformi o diffuse dell'installazione, di sostanze, vibrazioni, calore o rumore nell'aria, nell'acqua o nel terreno;

5) «valori limite di emissione», la massa espressa in rapporto a determinati parametri specifici, la concentrazione e/o il livello di un'emissione che non possono essere superati in uno o più periodi di tempo.

6) «norma di qualità ambientale», la serie di requisiti che devono sussistere in un dato momento in un determinato ambiente o in una specifica parte di esso, come stabilito nella normativa dell'Unione;

7) «autorizzazione», l'autorizzazione scritta all'esercizio di un'installazione o di parte di essa oppure di un impianto di combustione, di un impianto di incenerimento dei rifiuti o di un impianto di coincenerimento dei rifiuti;

8) «disposizioni generali vincolanti», valori limite di emissione o altri requisiti, almeno a livello settoriale, adottati al fine di essere utilizzati direttamente per determinare le condizioni di autorizzazione;

9) «modifica sostanziale», una modifica delle caratteristiche o del funzionamento ovvero un potenziamento di un'installazione o di un impianto di combustione, di un impianto di incenerimento dei rifiuti o di un impianto di coincenerimento dei rifiuti che potrebbe avere effetti negativi e significativi per la salute umana o per l'ambiente;

10) «migliori tecniche disponibili», la più efficiente e avanzata fase di sviluppo di attività e relativi metodi di esercizio indicanti l'idoneità pratica di determinate tecniche a costituire la base dei valori limite di emissione e delle altre condizioni di autorizzazione intesi ad evitare oppure, ove ciò si riveli impraticabile, a ridurre le emissioni e l'impatto sull'ambiente nel suo complesso:

   a) per «tecniche» sia le tecniche impiegate sia le modalità di progettazione, costruzione, manutenzione, esercizio e chiusura dell'installazione;

   b) per «tecniche disponibili» le tecniche sviluppate su una scala che ne consenta l'applicazione in condizioni economicamente e tecnicamente attuabili nell'ambito del pertinente comparto industriale, prendendo in considerazione i costi e i vantaggi, indipendentemente dal fatto che siano o meno applicate o prodotte nello Stato membro di cui si tratta, purché il gestore possa avervi accesso a condizioni ragionevoli;

   c) per «migliori», si intendono le tecniche più efficaci per ottenere un elevato livello di protezione dell'ambiente nel suo complesso;

11) «documento di riferimento sulle BAT», un documento risultante dallo scambio di informazioni organizzato a norma dell'articolo 13 elaborato per attività definite e che riporta, in particolare, le tecniche applicate, i livelli attuali di emissione e di consumo, le tecniche considerate per la determinazione delle migliori tecniche disponibili nonché le conclusioni sulle BAT e ogni tecnica emergente, con particolare attenzione ai criteri di cui all'allegato III;

12) «conclusioni sulle BAT», un documento contenente le parti di un documento di riferimento sulle BAT riguardanti le conclusioni sulle migliori tecniche disponibili, la loro descrizione, le informazioni per valutarne l'applicabilità, i livelli di emissione associati alle migliori tecniche disponibili, il monitoraggio associato, i livelli di consumo associati e, se del caso, le pertinenti misure di bonifica del sito;

13) «livelli di emissione associati alle migliori tecniche disponibili», intervalli di livelli di emissione ottenuti in condizioni di esercizio normali utilizzando una migliore tecnica disponibile o una combinazione di migliori tecniche disponibili, come indicato nelle conclusioni sulle BAT, espressi come media in un determinato arco di tempo e nell'ambito di condizioni di riferimento specifiche;

14) «tecnica emergente», una tecnica innovativa per un'attività industriale che, se sviluppata commercialmente, potrebbe assicurare un più elevato livello di protezione dell'ambiente nel suo complesso o almeno lo stesso livello di protezione dell'ambiente e maggiori risparmi di spesa rispetto alle migliori tecniche disponibili esistenti;

15) «gestore», qualsiasi persona fisica o giuridica che detiene o gestisce, nella sua totalità o in parte, l'installazione o l'impianto di combustione, l'impianto di incenerimento dei rifiuti o l'impianto di coincenerimento dei rifiuti oppure, se previsto dalla normativa nazionale, dispone di un potere economico determinante sull'esercizio tecnico dei medesimi;

16) «pubblico», una o più persone fisiche o giuridiche nonché, ai sensi della normativa o prassi nazionale, le associazioni, le organizzazioni o i gruppi di tali persone;

17) «pubblico interessato», il pubblico che subisce o può subire gli effetti dell'adozione di una decisione relativa alla concessione o all'aggiornamento di un'autorizzazione o delle condizioni di autorizzazione, o che ha un interesse rispetto a tale decisione; ai fini della presente definizione le organizzazioni non governative che promuovono la protezione dell'ambiente e che soddisfano i requisiti di diritto nazionale si considerano portatrici di un siffatto interesse;

18) «sostanze pericolose», sostanze o miscele pericolose come definite all'articolo 2, punti 7 e 8 del regolamento (CE) n. 1272/2008, del Parlamento europeo e del Consiglio, del 16 dicembre 2008, relativo alla classificazione, all'etichettatura e all'imballaggio delle sostanze e delle miscele [1];

19) «relazione di riferimento», informazioni sullo stato di contaminazione del suolo e delle acque sotterranee da parte di sostanze pericolose pertinenti;

20) «acque sotterranee», acque sotterranee quali definite all'articolo 2, punto 2, della direttiva 2000/60/CE del Parlamento europeo e del Consiglio, del 23 ottobre 2000, che istituisce un quadro per l'azione comunitaria in materia di acque [2];

21) «suolo», lo strato più superficiale della crosta terrestre situato tra il substrato roccioso e la superficie. Il suolo è costituito da componenti minerali, materia organica, acqua, aria e organismi viventi;

22) «ispezione ambientale», tutte le azioni, ivi compresi visite in loco, controllo delle emissioni e controlli delle relazioni interne e dei documenti di follow-up, verifica dell'autocontrollo, controllo delle tecniche utilizzate e adeguatezza della gestione ambientale dell'installazione, intraprese dall'autorità competente o per suo conto al fine di verificare e promuovere il rispetto delle condizioni di autorizzazione da parte delle installazioni, nonché, se del caso, monitorare l'impatto ambientale di queste ultime;

23) «pollame», il pollame quale definito all'articolo 2, punto 1, della direttiva 90/539/CEE del Consiglio, del 15 ottobre 1990, relativa alle norme di polizia sanitaria per gli scambi intracomunitari e le importazioni in provenienza dai paesi terzi di pollame e uova da cova [3];

24) «combustibile», qualsiasi materia combustibile solida, liquida o gassosa;

25) «impianto di combustione», qualsiasi dispositivo tecnico in cui sono ossidati combustibili al fine di utilizzare il calore così prodotto;

26) «camino», una struttura contenente una o più canne di scarico che forniscono un condotto attraverso il quale lo scarico gassoso viene disperso nell'atmosfera;

27) «ore operative», il tempo, espresso in ore, durante cui un impianto di combustione, in tutto o in parte, è in funzione e scarica emissioni nell'atmosfera, esclusi i periodi di avvio e di arresto;

28) «grado di desolforazione», il rapporto per un determinato periodo di tempo tra la quantità di zolfo non emessa nell'atmosfera da un impianto di combustione e la quantità di zolfo contenuta nel combustibile solido introdotto nei dispositivi dell'impianto di combustione e utilizzata nell'impianto per lo stesso periodo di tempo;

29) «combustibile solido indigeno», un combustibile solido presente in natura impiegato per alimentare un impianto di combustione specificamente concepito per tale combustibile ed estratto a livello locale;

30) «combustibile determinante», il combustibile che, di tutti combustibili utilizzati in un impianto di combustione multicombustibile che utilizza i residui di distillazione e di conversione della raffinazione del petrolio greggio, da soli o con altri combustibili, per il proprio consumo, ha il valore limite di emissione più elevato di cui all'allegato V, parte 1, o, nel caso di più combustibili aventi il medesimo valore limite, quello tra essi che fornisce la quantità più elevata di calore;

31) per «biomassa» si intendono:

a) prodotti costituiti di materia vegetale di provenienza agricola o forestale, utilizzabili come combustibile per recuperarne il contenuto energetico;

b) i rifiuti seguenti:

i) rifiuti vegetali derivanti da attività agricole e forestali;

ii) rifiuti vegetali derivanti dalle industrie alimentari di trasformazione, se l'energia termica generata è recuperata;

iii) rifiuti vegetali fibrosi della produzione di pasta di carta grezza e di produzione di carta dalla pasta, se sono coinceneriti sul luogo di produzione e se l'energia termica generata è recuperata;

iv) rifiuti di sughero;

v) rifiuti di legno ad eccezione di quelli che possono contenere composti organici alogenati o metalli pesanti, a seguito di un trattamento o di rivestimento inclusi in particolare i rifiuti di legno di questo genere derivanti dai rifiuti edilizi e di demolizione;

32) «impianto di combustione multicombustibile», qualsiasi impianto di combustione che possa essere alimentato simultaneamente o alternativamente da due o più tipi di combustibile;

33) «turbina a gas», qualsiasi macchina rotante che trasforma energia termica in meccanica e costituita principalmente da un compressore, un dispositivo termico in cui il combustibile è ossidato per riscaldare il fluido motore e la turbina;

34) «motore a gas», un motore a combustione interna che funziona secondo il ciclo Otto ed utilizza l'accensione comandata o, nel caso dei motori a doppia alimentazione, l'accensione spontanea, per bruciare il combustibile;

[1] GU L 353 del 31.12.2008, pag. 1.
[2] GU L 327 del 22.12.2000, pag. 1.
[3] GU L 303 del 31.10.1990, pag. 6.

35) «motore diesel», un motore a combustione interna che funziona secondo il ciclo diesel ed utilizza l'accensione spontanea per bruciare il combustibile;

36) «piccolo sistema isolato», un piccolo sistema isolato quale definito all'articolo articolo 2, punto 26, della direttiva 2003/54/CE del Parlamento europeo e del Consiglio, del 26 giugno 2003, relativa a norme comuni per il mercato interno dell'energia elettrica ([1]);

37) «rifiuto», i rifiuti quali definiti all'articolo 3, punto 1, della direttiva 2008/98/CE del Parlamento europeo e del Consiglio, del 19 novembre 2008, relativa ai rifiuti ([2]);

38) «rifiuto pericoloso», i rifiuti pericolosi quali definiti all'articolo 3, punto 2, della direttiva 2008/98/CE;

39) «rifiuti urbani misti», i rifiuti domestici o derivanti da attività commerciali, industriali o amministrative che, per natura e composizione, sono analoghi ai rifiuti domestici, ad esclusione degli elementi menzionati al punto 20 01 dell'allegato della decisione 2000/532/CE ([3]) che sono raccolti separatamente alla fonte e degli altri rifiuti di cui al punto 20 02 di tale allegato;

40) «impianto di incenerimento dei rifiuti», qualsiasi unità e attrezzatura tecnica fissa o mobile destinata al trattamento termico dei rifiuti con o senza recupero del calore prodotto dalla combustione attraverso l'incenerimento mediante ossidazione dei rifiuti nonché altri processi di trattamento termico, quali ad esempio la pirolisi, la gassificazione o il processo al plasma, a condizione che le sostanze risultanti dal trattamento siano successivamente incenerite;

41) «impianto di coincenerimento dei rifiuti», qualsiasi unità tecnica fissa o mobile la cui funzione principale consiste nella produzione di energia o di prodotti materiali e che utilizza rifiuti come combustibile normale o accessorio o in cui i rifiuti sono sottoposti a un trattamento termico a fini di smaltimento attraverso l'incenerimento mediante ossidazione dei rifiuti nonché altri procedimenti di trattamento termico, quali ad esempio la pirolisi, la gassificazione o il processo al plasma sempre che le sostanze risultanti dal trattamento siano successivamente incenerite;

42) «capacità nominale», la somma delle capacità di incenerimento dei forni che costituiscono un impianto di incenerimento dei rifiuti o un impianto di coincenerimento dei rifiuti, secondo quanto dichiarato dal costruttore e confermato dal gestore, tenuto conto del valore calorifico dei rifiuti, espresso in quantità oraria di rifiuti inceneriti;

43) «diossine e furani», tutte le dibenzo-p-diossine e i dibenzofurani policlorurati di cui all'allegato VI, parte 2;

44) «composto organico», qualsiasi composto contenente almeno l'elemento carbonio e uno o più degli elementi seguenti: idrogeno, alogeni, ossigeno, zolfo, fosforo, silicio o azoto, ad eccezione degli ossidi di carbonio e dei carbonati e bicarbonati inorganici;

45) «composto organico volatile», qualsiasi composto organico, nonché la frazione di creosoto, che abbia a 293,15 K una pressione di vapore di 0,01 kPa o superiore, oppure che abbia una volatilità corrispondente in condizioni particolari di uso;

46) «solvente organico», qualsiasi composto organico volatile usato:

a) da solo o in combinazione con altri agenti e senza subire una trasformazione chimica al fine di dissolvere materie prime, prodotti o materiali di rifiuto;

b) come agente di pulizia per dissolvere contaminanti;

c) come dissolvente;

d) come mezzo di dispersione;

e) come correttore di viscosità;

f) come correttore di tensione superficiale;

g) come plastificante;

h) come conservante;

47) «rivestimento», rivestimento quale definito all'articolo 2, punto 8, della direttiva 2004/42/CE del Parlamento europeo e del Consiglio, del 21 aprile 2004, relativa alla limitazione delle emissioni di composti organici volatili dovute all'uso di solventi organici in talune pitture e vernici e in taluni prodotti per carrozzeria ([4]).

Articolo 4

Obbligo di detenere un'autorizzazione

1. Gli Stati membri adottano le misure necessarie per garantire che nessuna installazione o nessun impianto di combustione, nessun impianto di incenerimento dei rifiuti o nessun impianto di coincenerimento dei rifiuti operi senza autorizzazione.

In deroga al primo comma, gli Stati membri possono fissare una procedura per la registrazione delle installazioni contemplate esclusivamente al capo V.

La procedura di registrazione è specificata in un atto vincolante e comprende almeno la notifica all'autorità competente, da parte del gestore, della sua intenzione di gestire un'installazione.

([1]) GU L 176 del 15.7.2003, pag. 37.

([2]) GU L 312 del 22.11.2008, pag. 3.

([3]) Decisione 2000/532/CE della Commissione, del 3 maggio 2000, che sostituisce la decisione 94/3/CE che istituisce un elenco di rifiuti conformemente all'articolo 1, lettera c), della direttiva 75/442/CE del Consiglio, relativa ai rifiuti, e la decisione 94/904/CE del Consiglio che istituisce un elenco di rifiuto pericolosi ai sensi dell'articolo 1, paragrafo 4, della direttiva 91/689/CE del Consiglio, relativa ai rifiuti pericolosi (GU L 226 del 6.9.2000, pag. 3).

([4]) GU L 143 del 30.4.2004, pag. 87.

2. Gli Stati membri possono scegliere di far valere un'autorizzazione per due o più installazioni o parti di esse, e gestiti dal medesimo gestore sullo stesso sito.

Nel caso in cui riguardi due o più installazioni, l'autorizzazione deve contenere condizioni atte a garantire che ogni installazione sia conforme ai requisiti contenuti nella presente direttiva.

3. Gli Stati membri possono scegliere di far valere un'autorizzazione per diverse parti di un'installazione gestite da gestori differenti. In tali casi, l'autorizzazione specifica le responsabilità di ciascun gestore.

Articolo 5

Rilascio di un'autorizzazione

1. Fatti salvi gli altri requisiti prescritti dalle normative nazionali o dell'Unione, l'autorità competente rilascia l'autorizzazione se l'installazione è conforme ai requisiti previsti dalla presente direttiva.

2. Gli Stati membri adottano le misure necessarie per il pieno coordinamento delle procedure e delle condizioni per il rilascio dell'autorizzazione quando sono coinvolti più autorità competenti o più gestori oppure è concessa più di un'autorizzazione, al fine di garantire un approccio integrato effettivo di tutte le autorità competenti per questa procedura.

3. In caso di nuova installazione o di modifica sostanziale cui si applica l'articolo 4 della direttiva 85/337/CEE, le informazioni o conclusioni pertinenti risultanti dall'applicazione degli articoli 5, 6, 7 e 9 di tale direttiva sono esaminate e utilizzate per il rilascio dell'autorizzazione.

Articolo 6

Disposizioni generali vincolanti

Fatto salvo l'obbligo di possedere un'autorizzazione, gli Stati membri possono inserire requisiti per talune categorie di installazioni, impianti di combustione, impianti di incenerimento dei rifiuti o impianti di coincenerimento dei rifiuti sotto forma di disposizioni generali vincolanti.

Ove siano adottate disposizioni generali vincolanti, l'autorizzazione può contenere semplicemente un riferimento alle disposizioni stesse.

Articolo 7

Incidenti o inconvenienti

Fatta salva la direttiva 2004/35/CE del Parlamento europeo e del Consiglio, del 21 aprile 2004, sulla responsabilità ambientale in materia di prevenzione e riparazione del danno ambientale ([1]), in caso di incidenti o inconvenienti che incidano in modo significativo sull'ambiente, gli Stati membri adottano le misure necessarie per garantire che:

a) il gestore informi l'autorità competente immediatamente;

b) il gestore adotti immediatamente le misure per limitare le conseguenze ambientali e a prevenire ulteriori eventuali incidenti o inconvenienti;

c) l'autorità competente imponga al gestore di adottare ogni misura complementare appropriata che l'autorità stessa ritenga necessaria per limitare le conseguenze ambientali e prevenire ulteriori eventuali incidenti o inconvenienti.

Articolo 8

Violazioni

1. Gli Stati membri adottano le misure necessarie affinché le condizioni di autorizzazione siano rispettate.

2. In caso di violazione delle condizioni di autorizzazione, gli Stati membri provvedono affinché:

a) il gestore informi immediatamente l'autorità competente;

b) il gestore adotti immediatamente le misure necessarie per garantire il ripristino della conformità nel più breve tempo possibile;

c) l'autorità competente imponga al gestore di adottare ogni misura complementare appropriata che l'autorità stessa ritenga necessaria per ripristinare la conformità.

Laddove la violazione delle condizioni di autorizzazione presenti un pericolo immediato per la salute umana o minacci di provocare ripercussioni serie ed immediate sull'ambiente e sino a che la conformità non venga ripristinata conformemente alle lettere b) e c) del primo comma, è sospeso l'esercizio dell'installazione, dell'impianto di combustione, dell'impianto di incenerimento dei rifiuti, dell'impianto di coincenerimento dei rifiuti o della relativa parte interessata.

Articolo 9

Emissioni di gas a effetto serra

1. Quando le emissioni di un gas a effetto serra provenienti da un'installazione sono indicate nell'allegato I della direttiva 2003/87/CE in relazione a un'attività esercitata in tale installazione, l'autorizzazione contiene valori limite per le emissioni dirette di questo gas solo quando ciò risulti indispensabile per evitare un rilevante inquinamento locale.

2. Per le attività elencate all'allegato I della direttiva 2003/87/CE, gli Stati membri possono decidere di non imporre alcun requisito di efficienza energetica con riguardo alle unità di combustione o altre unità che emettono biossido di carbonio sul sito.

([1]) GU L 143 del 30.4.2004, pag. 56.

3. Se necessario, le autorità competenti modificano l'autorizzazione nel modo opportuno.

4. I paragrafi da 1 a 3 non si applicano alle installazioni che sono temporaneamente escluse dal sistema per lo scambio di quote di emissioni di gas a effetto serra nell'Unione ai sensi dell'articolo 27 della direttiva 2003/87/CE.

CAPO II

DISPOSIZIONI PER LE ATTIVITÀ ELENCATE NELL'ALLEGATO I

Articolo 10

Ambito di applicazione

Il presente capo si applica a tutte le attività elencate nell'allegato I e che, se del caso, raggiungono i valori soglia di capacità fissati nello stesso allegato.

Articolo 11

Principi generali degli obblighi fondamentali del gestore

Gli Stati membri adottano le misure necessarie affinché l'installazione sia gestita in modo conforme ai principi che seguono:

a) sono adottate tutte le opportune misure di prevenzione dell'inquinamento;

b) sono applicate le migliori tecniche disponibili;

c) non si verificano fenomeni di inquinamento significativi;

d) è prevenuta la produzione di rifiuti, a norma della direttiva 2008/98/CE;

e) nel caso si producano rifiuti, questi ultimi, in ordine di priorità e conformemente alla direttiva 2008/98/CE, sono riutilizzati, riciclati, ricuperati o, ove ciò sia tecnicamente ed economicamente impossibile, sono smaltiti evitando e riducendo ogni loro impatto sull'ambiente;

f) l'energia è utilizzata in modo efficiente;

g) sono adottate le misure necessarie per prevenire gli incidenti e limitarne le conseguenze;

h) si provvede affinché sia evitato qualsiasi rischio di inquinamento al momento della cessazione definitiva delle attività ed il sito stesso sia ripristinato conformemente allo stato soddisfacente di cui all'articolo 22.

Articolo 12

Domande di autorizzazione

1. Gli Stati membri adottano le misure necessarie affinché una domanda di autorizzazione contenga la descrizione:

a) dell'installazione e delle sue attività;

b) delle materie prime e secondarie, delle sostanze e dell'energia usate o prodotte dall'installazione;

c) delle fonti di emissione dell'installazione;

d) dello stato del sito di ubicazione dell'installazione;

e) se del caso, una relazione di riferimento ai sensi dell'articolo 22, paragrafo 2;

f) del tipo e dell'entità delle prevedibili emissioni dell'installazione in ogni comparto ambientale nonché un'identificazione degli effetti significativi delle emissioni sull'ambiente;

g) della tecnologia prevista e delle altre tecniche per prevenire le emissioni dall'installazione oppure, qualora ciò non fosse possibile, per ridurle;

h) delle misure di prevenzione, di preparazione per il riutilizzo, di riciclaggio e di recupero dei rifiuti prodotti dall'installazione;

i) delle altre misure previste per ottemperare agli obblighi fondamentali del gestore di cui all'articolo 11;

j) delle misure previste per controllare le emissioni nell'ambiente;

k) delle principali alternative alla tecnologia, alle tecniche e alle misure proposte, prese in esame dal richiedente in forma sommaria.

La domanda di autorizzazione contiene anche una sintesi non tecnica dei dati di cui al primo comma.

2. Se i dati forniti secondo i requisiti previsti dalla direttiva 85/337/CEE oppure un rapporto di sicurezza elaborato secondo la direttiva 96/82/CE o altre informazioni fornite secondo qualunque altra normativa rispettano uno dei requisiti di cui al paragrafo 1, tali informazioni possono essere incluse nella domanda di autorizzazione o essere ad essa allegate.

Articolo 13

Documenti di riferimento sulle BAT e scambio di informazioni

1. Al fine di elaborare, riesaminare e, se necessario, aggiornare i documenti di riferimento sulle BAT, la Commissione organizza uno scambio di informazioni tra gli Stati membri, le industrie interessate, le organizzazioni non governative che promuovono la protezione ambientale e la Commissione.

2. Lo scambio di informazioni riguarda in particolare:

a) le prestazioni delle installazioni e delle tecniche in termini di emissioni espresse come medie a breve e lungo termine, ove appropriato, e le condizioni di riferimento associate, consumo e natura delle materie prime ivi compresa l'acqua, uso dell'energia e produzione di rifiuti;

b) le tecniche usate, il monitoraggio associato, gli effetti incrociati, la fattibilità economica e tecnica e i loro sviluppi;

c) le migliori tecniche disponibili e le tecniche emergenti individuate dopo aver esaminato gli elementi di cui alle lettere a) e b).

3. La Commissione istituisce e convoca periodicamente un forum composto dai rappresentanti degli Stati membri, delle industrie interessate e delle organizzazioni non governative che promuovono la protezione ambientale.

La Commissione chiede il parere del forum in merito alle modalità pratiche dello scambio di informazioni e in particolare per quanto riguarda:

a) il regolamento interno del forum;

b) il programma di lavoro per lo scambio di informazioni;

c) le linee guida sulla raccolta dei dati;

d) le linee guida relative all'elaborazione di documenti di riferimento sulle BAT e all'assicurazione di qualità, ivi compresa l'adeguatezza del loro contenuto e formato.

Le linee guida di cui al secondo comma, lettere c) e d) del presente paragrafo tengono conto del parere del forum e sono adottate secondo la procedura di regolamentazione di cui all'articolo 75, paragrafo 2.

4. La Commissione richiede e rende pubblico il parere del forum in merito al contenuto proposto dei documenti di riferimento sulle BAT e tiene conto di tale parere per le procedure di cui al paragrafo 5.

5. Decisioni sulle conclusioni sulle BAT sono adottate secondo la procedura di regolamentazione di cui all'articolo 75, paragrafo 2.

6. A seguito dell'adozione di una decisione ai sensi del paragrafo 5, la Commissione rende pubblico senza indugio il documento di riferimento sulle BAT e provvede affinché le conclusioni sulle BAT siano rese disponibili in tutte le lingue ufficiali dell'Unione.

7. In attesa dell'adozione di una decisione pertinente ai sensi del paragrafo 5, le conclusioni sulle migliori tecniche disponibili tratte dai documenti di riferimento sulle BAT adottati della Commissione precedentemente alla data di cui all'articolo 83 valgono come conclusioni sulle BAT ai fini del presente capo, ad eccezione dell'articolo 15, paragrafi 3 e 4.

Articolo 14

Condizioni di autorizzazione

1. Gli Stati membri si accertano che l'autorizzazione includa tutte le misure necessarie per soddisfare le relative condizioni di cui agli articoli 11 e 18.

Tali misure includono almeno:

a) valori limite di emissione fissati per le sostanze inquinanti elencate nell'allegato II e per le altre sostanze inquinanti che possono essere emesse dall'installazione interessata in quantità significativa, in considerazione della loro natura e delle loro potenzialità di trasferimento dell'inquinamento da un elemento ambientale all'altro;

b) disposizioni adeguate che garantiscono la protezione del suolo e delle acque sotterranee e le disposizioni per il controllo e la gestione dei rifiuti prodotti dall'installazione;

c) opportuni requisiti di controllo delle emissioni, che specificano:

   i) la metodologia di misurazione, la frequenza, nonché la procedura di valutazione; e

   ii) quando si applica l'articolo 15, paragrafo 3, lettera b), che i risultati del controllo delle emissioni sono disponibili per gli stessi periodi e alle stesse condizioni di riferimento dei livelli di emissione associati alle migliori tecniche disponibili;

d) l'obbligo di comunicare all'autorità competente periodicamente ed almeno una volta l'anno:

   i) informazioni in base ai risultati del controllo delle emissioni di cui alla lettera c) e altri dati richiesti che consentano all'autorità competente di verificare la conformità con le condizioni di autorizzazione; e

   ii) quando si applica l'articolo 15, paragrafo 3, lettera b), una sintesi di detti risultati espressi in un formato che consenta un confronto con i livelli di emissione associati alle migliori tecniche disponibili;

e) disposizioni adeguate per la manutenzione e la verifica periodiche delle misure adottate per prevenire le emissioni nel suolo e nelle acque sotterranee ai sensi della lettera b) e disposizioni adeguate relative al controllo periodico del suolo e delle acque sotterranee in relazione alle sostanze pericolose che possono essere presenti nel sito e tenuto conto della possibilità di contaminazione del suolo e delle acque sotterranee presso il sito dell'installazione;

f) misure relative alle condizioni di esercizio diverse dalle condizioni di esercizio normali, quali le operazioni di avvio e di arresto, le perdite, le disfunzioni, gli arresti temporanei e l'arresto definitivo dell'impianto;

g) disposizioni per ridurre al minimo l'inquinamento a grande distanza o attraverso le frontiere;

h) condizioni per valutare la conformità con i valori limite di emissione o un riferimento alle prescrizioni applicabili indicate altrove.

2. Ai fini del paragrafo 1, lettera a), i valori limite di emissione possono essere integrati o sostituiti con altri parametri o misure tecniche equivalenti che garantiscano un livello equivalente di protezione ambientale.

3. Le conclusioni sulle BAT fungono da riferimento per stabilire le condizioni di autorizzazione.

4. Fatto salvo l'articolo 18, l'autorità competente può stabilire condizioni di autorizzazione più rigide di quelle ottenibili utilizzando le migliori tecniche disponibili descritte nelle conclusioni sulle BAT. Gli Stati membri possono stabilire norme in forza delle quali l'autorità competente può fissare dette condizioni più rigide.

5. Se l'autorità competente stabilisce condizioni di autorizzazione sulla base di una migliore tecnica disponibile non descritta in alcuna delle pertinenti conclusioni sulle BAT, essa provvede affinché:

a) tale tecnica sia determinata prestando particolare attenzione ai criteri di cui all'allegato III; e

b) siano rispettati i requisiti di cui all'articolo 15.

Qualora le conclusioni sulle BAT di cui al primo comma non contengano livelli di emissione associati alle migliori tecniche disponibili, l'autorità competente provvede affinché la tecnica di cui al primo comma garantisca un livello di protezione dell'ambiente equivalente alle migliori tecniche descritte disponibili nelle conclusioni sulle BAT.

6. Se un'attività, o un tipo di processo di produzione svolto all'interno di un'installazione non è previsto da alcuna delle conclusioni sulle BAT o se queste conclusioni non prendono in considerazione tutti gli effetti potenziali dell'attività o del processo sull'ambiente, l'autorità competente, previa consultazione con il gestore, stabilisce le condizioni di autorizzazione in base alle migliori tecniche disponibili che ha determinato per le attività o i processi interessati prestando particolare attenzione ai criteri di cui all'allegato III.

7. Nel caso delle installazioni di cui al punto 6.6 dell'allegato I, i paragrafi da 1 a 6 del presente articolo si applicano fatta salva la normativa in materia di benessere degli animali.

Articolo 15

Valori limite delle emissioni, parametri e misure tecniche equivalenti

1. I valori limite di emissione delle sostanze inquinanti si applicano nel punto di fuoriuscita delle emissioni dall'installazione e la determinazione di tali valori è effettuata al netto di ogni eventuale diluizione che avvenga prima di quel punto.

Per quanto concerne gli scarichi indiretti di sostanze inquinanti nell'acqua, l'effetto di una stazione di depurazione può essere preso in considerazione nella determinazione dei valori limite di emissione dell'installazione interessata, a condizione di garantire un livello equivalente di protezione dell'ambiente nel suo insieme e di non portare a carichi inquinanti maggiori nell'ambiente.

2. Fatto salvo l'articolo 18, i valori limite di emissione, i parametri e le misure tecniche equivalenti di cui all'articolo 14, paragrafi 1 e 2, si basano sulle migliori tecniche disponibili, senza l'obbligo di utilizzare una tecnica o una tecnologia specifica.

3. L'autorità competente fissa valori limite di emissione che garantiscano che, in condizioni di esercizio normali, le emissioni non superino i livelli di emissione associati alle migliori tecniche disponibili indicati nelle decisioni sulle conclusioni sulle BAT di cui all'articolo 13, paragrafo 5, attraverso una delle due opzioni seguenti:

a) fissando valori limite di emissione che non superano i livelli di emissione associati alle migliori tecniche disponibili. Detti valori limite di emissione sono espressi per lo stesso periodo di tempo o per periodi più brevi e per le stesse condizioni di riferimento dei livelli di emissione associati alle migliori tecniche disponibili; o

b) fissando valori limite di emissione diversi da quelli di cui alla lettera a) in termini di valori, periodi di tempo e condizioni di riferimento.

Quando si applica la lettera b), l'autorità competente valuta almeno annualmente i risultati del controllo delle emissioni al fine di garantire che le emissioni in condizioni di esercizio normali non hanno superato i livelli di emissione associati alle migliori tecniche disponibili.

4. In deroga al paragrafo 3 e fatto salvo l'articolo 18, in casi specifici l'autorità competente può fissare valori limite di emissione meno severi. Tale deroga può applicarsi unicamente ove una valutazione dimostri che il conseguimento dei livelli di emissione associati alle migliori tecniche disponibili di cui alle conclusioni sulle BAT comporterebbe una maggiorazione sproporzionata dei costi rispetto ai benefici ambientali, in ragione:

a) dell'ubicazione geografica e delle condizioni ambientali locali dell'istallazione interessata o

b) delle caratteristiche tecniche dell'istallazione interessata.

L'autorità competente documenta in un allegato alle condizioni di autorizzazione le ragioni dell'applicazione del primo comma, ivi compreso il risultato della valutazione e la giustificazione delle condizioni imposte.

I valori limite di emissione fissati a norma del primo comma non superano, in ogni caso, i valori limite di emissione di cui agli allegati della presente direttiva, laddove applicabili.

L'autorità competente garantisce comunque che non si verifichino eventi inquinanti di rilievo e che si realizzi nel complesso un elevato grado di tutela ambientale.

In base alle informazioni fornite dagli Stati membri in conformità dell'articolo 72, paragrafo 1, e in particolare in relazione all'applicazione del presente paragrafo, la Commissione può eventualmente valutare e precisare ulteriormente, mediante linee guida, i criteri da tenere in considerazione per l'applicazione del presente paragrafo.

Le autorità competenti riesaminano l'applicazione del primo comma quale parte di ciascun riesame delle condizioni di autorizzazione ai sensi dell'articolo 21.

5. L'autorità competente può accordare deroghe temporanee alle disposizioni dei paragrafi 2 e 3 del presente articolo e dell'articolo 11, punti a) e b), in caso di sperimentazione e utilizzo di tecniche emergenti per un periodo complessivo non superiore a nove mesi, a condizione che dopo il periodo specificato tale tecnica sia sospesa o che le emissioni dell'attività raggiungano almeno i livelli di emissione associati alle migliori tecniche disponibili.

Articolo 16

Disposizioni in materia di controllo

1. Le disposizioni in materia di controllo di cui all'articolo 14, paragrafo 1, lettera c), sono basate, se del caso, sulle conclusioni del controllo descritto nelle conclusioni sulle BAT.

2. La frequenza del controllo periodico di cui all'articolo 14, paragrafo 1, lettera e), è determinata dall'autorità competente nell'autorizzazione rilasciata ad ogni installazione o in norme generali vincolanti.

Fatto salvo il primo comma, il controllo periodico è effettuato almeno una volta ogni cinque anni per le acque sotterranee e almeno una volta ogni dieci anni per il suolo, a meno che tale controllo non sia basato su una valutazione sistematica del rischio di contaminazione.

Articolo 17

Disposizioni generali vincolanti per le attività elencate nell'allegato I

1. Quando adottano disposizioni generali vincolanti, gli Stati membri assicurano un approccio integrato e un'elevata protezione dell'ambiente equivalente a quella che si potrebbe conseguire con le condizioni contenute nelle singole autorizzazioni.

2. Le disposizioni generali vincolanti si basano sulle migliori tecniche disponibili, senza prescrivere l'utilizzo di alcuna tecnica o tecnologia specifica, al fine di garantire la conformità con gli articoli 14 e 15.

3. Gli Stati membri provvedono affinché le disposizioni generali vincolanti siano aggiornate al fine di tener conto dei progressi delle migliori tecniche disponibili e garantire la conformità con l'articolo 21.

4. Le disposizioni generali vincolanti adottate conformemente ai paragrafi 1, 2 e 3 contengono un riferimento alla presente direttiva o sono corredate di un siffatto riferimento all'atto della pubblicazione ufficiale.

Articolo 18

Norme di qualità ambientale

Qualora una norma di qualità ambientale richieda condizioni più rigorose di quelle ottenibili con le migliori tecniche disponibili, l'autorizzazione contiene misure supplementari, fatte salve le altre misure che possono essere adottate per rispettare le norme di qualità ambientale.

Articolo 19

Sviluppi delle migliori tecniche disponibili

Gli Stati membri garantiscono che l'autorità competente si tenga informata o venga informata sugli sviluppi delle migliori tecniche disponibili e sulla pubblicazione delle conclusioni sulle BAT nuove o aggiornate, e rendono disponibili tali informazioni al pubblico interessato.

Articolo 20

Modifica delle installazioni da parte dei gestori

1. Gli Stati membri adottano le misure necessarie affinché il gestore comunichi all'autorità competente le eventuali modifiche o ampliamenti che intenda apportare alla natura o al funzionamento dell'installazione che possano produrre conseguenze sull'ambiente. Ove necessario, l'autorità competente aggiorna l'autorizzazione.

2. Gli Stati membri adottano le misure necessarie affinché nessuna modifica sostanziale progettata dal gestore sia effettuata senza un'autorizzazione concessa conformemente alla presente direttiva.

La domanda di autorizzazione e la decisione dell'autorità competente si riferiscono alle parti dell'installazione e agli aspetti di cui all'articolo 12 che possono essere oggetto della modifica sostanziale.

3. Le modifiche riguardanti la natura, il funzionamento o un ampliamento dell'installazione sono ritenuti sostanziali se le modifiche o gli ampliamenti di per sé raggiungono le soglie di cui all'allegato I.

Articolo 21

Riesame e aggiornamento delle condizioni di autorizzazione da parte dell'autorità competente

1. Gli Stati membri adottano le misure necessarie affinché l'autorità competente riesamini periodicamente, conformemente ai paragrafi da 2 a 5, tutte le condizioni di autorizzazione e, se necessario per assicurare la conformità alla presente direttiva, aggiornino le condizioni stesse.

2. Su richiesta dell'autorità competente, il gestore presenta tutte le informazioni necessarie ai fini del riesame delle condizioni di autorizzazione, ivi compresi in particolare i risultati del controllo delle emissioni e altri dati, che consentano un confronto tra il funzionamento dell'installazione e le migliori tecniche disponibili descritti nelle conclusioni sulle BAT applicabili e i livelli di emissione associati alle migliori tecniche disponibili.

In occasione del riesame delle condizioni di autorizzazione, l'autorità competente utilizza tutte le informazioni provenienti dai controlli o dalle ispezioni.

3. Entro quattro anni dalla data di pubblicazione delle decisioni sulle conclusioni sulle BAT ai sensi dell'articolo 13, paragrafo 5, relative all'attività principale di un'installazione, l'autorità competente garantisce che:

a) tutte le condizioni di autorizzazione per l'installazione interessata siano riesaminate e, se necessario, aggiornate per assicurare il rispetto della presente direttiva, in particolare, se applicabile, dell'articolo 15, paragrafi 3 e 4;

b) l'installazione sia conforme a tali condizioni di autorizzazione.

Il riesame tiene conto di tutte le conclusioni sulle BAT, nuove o aggiornate, applicabili all'installazione e adottate ai sensi dell'articolo 13, paragrafo 5, da quando l'autorizzazione è stata concessa o da ultimo riesaminata.

4. Se un'installazione non è contemplata da alcuna delle conclusioni sulle BAT, le condizioni di autorizzazione sono riesaminate e, ove necessario, aggiornate qualora gli sviluppi nelle migliori tecniche disponibili consentano una notevole riduzione delle emissioni.

5. Le condizioni di autorizzazione sono riesaminate e, ove necessario, aggiornate almeno nei seguenti casi:

a) l'inquinamento provocato dall'installazione è tale da rendere necessaria la revisione dei valori limite di emissione esistenti nell'autorizzazione o l'inserimento in quest'ultima di nuovi valori limite;

b) la sicurezza di esercizio richiede l'impiego di altre tecniche;

c) ove sia necessario rispettare una norma di qualità ambientale nuova o riveduta conformemente all'articolo 18.

Articolo 22

Chiusura del sito

1. Fatta salva la direttiva 2000/60/CE, la direttiva 2004/35/CE, la direttiva 2006/118/CE del Parlamento europeo e del Consiglio, del 12 dicembre 2006, sulla protezione delle acque sotterranee dall'inquinamento e dal deterioramento ([1]), e della pertinente normativa dell'Unione sulla protezione del suolo, l'autorità competente stabilisce condizioni di autorizzazione volte a garantire l'osservanza dei paragrafi 3 e 4 del presente articolo al momento della cessazione definitiva delle attività.

([1]) GU L 372 del 27.12.2006, pag. 19.

2. Quando l'attività comporta l'utilizzo, la produzione o lo scarico di sostanze pericolose e, tenuto conto della possibilità di contaminazione del suolo e delle acque sotterranee nel sito dell'installazione, il gestore elabora e trasmette all'autorità competente una relazione di riferimento prima della messa in servizio dell'installazione o prima dell'aggiornamento dell'autorizzazione rilasciata per l'installazione, per la prima volta dopo il 7 gennaio 2013.

La relazione di riferimento contiene le informazioni necessarie per determinare lo stato di contaminazione del suolo e delle acque sotterranee al fine di effettuare un raffronto in termini quantitativi con lo stato al momento della cessazione definitiva delle attività ai sensi del paragrafo 3.

La relazione di riferimento contiene almeno le seguenti informazioni:

a) informazioni sull'uso attuale e, se disponibili, sugli usi passati del sito;

b) se disponibili, le informazioni esistenti relative alle misurazioni effettuate sul suolo e sulle acque sotterranee che ne illustrino lo stato al momento dell'elaborazione della relazione o, in alternativa, relative a nuove misurazioni effettuate sul suolo e sulle acque sotterranee tenendo conto della possibilità di una contaminazione del suolo e delle acque sotterranee da parte delle sostanze pericolose usate, prodotte o rilasciate dall'installazione interessata.

Se le informazioni fornite in virtù di altre normative nazionali o dell'Unione soddisfano i requisiti di cui al presente paragrafo, tali informazioni possono essere incluse o allegate alla relazione di riferimento presentata.

La Commissione può fissare linee guida in merito al contenuto della relazione di riferimento.

3. Al momento della cessazione definitiva delle attività, il gestore valuta lo stato di contaminazione del suolo e delle acque sotterranee da parte di sostanze pericolose pertinenti usate, prodotte o rilasciate dall'installazione. Se l'installazione ha provocato un inquinamento significativo del suolo o delle acque sotterranee con sostanze pericolose pertinenti rispetto allo stato constatato nella relazione di riferimento di cui al paragrafo 2, il gestore adotta le misure necessarie per rimediare a tale inquinamento in modo da riportare il sito a tale stato. A tal fine si può tener conto della fattibilità tecnica di dette misure.

Fatto salvo il primo comma, al momento della cessazione definitiva delle attività, e se la contaminazione del suolo e delle acque sotterranee nel sito comporta un rischio significativo per la salute umana o per l'ambiente in conseguenza delle attività autorizzate svolte dal gestore anteriormente al primo aggiornamento dell'autorizzazione per l'installazione successivo al 7 gennaio 2013 e tenendo conto dello stato del sito di ubicazione dell'installazione stabilito ai sensi dell'articolo 12, paragrafo 1, lettera d), il gestore esegue gli interventi necessari finalizzati ad eliminare, controllare, contenere o ridurre le sostanze pericolose pertinenti in modo che il sito, tenuto conto dell'uso attuale o dell'uso futuro approvato del medesimo, cessi di comportare detto rischio.

4. Se non è tenuto ad elaborare la relazione di riferimento di cui al paragrafo 2, al momento della cessazione definitiva delle attività, il gestore esegue gli interventi necessari finalizzati ad eliminare, controllare, contenere o ridurre le sostanze pericolose pertinenti in modo che il sito, tenuto conto dell'uso attuale o dell'uso futuro approvato del medesimo cessi di comportare un rischio significativo per la salute umana o per l'ambiente a causa della contaminazione del suolo o delle acque sotterranee in conseguenza delle attività autorizzate, tenendo conto dello stato del sito di ubicazione dell'installazione stabilito ai sensi dell'articolo 12, paragrafo 1, lettera d).

Articolo 23

Ispezioni ambientali

1. Gli Stati membri organizzano un sistema di ispezioni delle installazioni che prevedono l'esame di tutta la gamma degli effetti ambientali indotti dalle installazioni interessate.

Gli Stati membri provvedono affinché i gestori forniscano alle autorità competenti tutta l'assistenza necessaria per permettere a tali autorità di svolgere qualsiasi visita del sito, di prelevare campioni e raccogliere qualsiasi informazione necessaria allo svolgimento dei loro compiti, ai fini della presente direttiva.

2. Gli Stati membri provvedono affinché tutte le installazioni siano considerate in un piano d'ispezione ambientale a livello nazionale, regionale o locale e garantiscono che tale piano sia periodicamente riveduto e, se del caso, aggiornato.

3. Ogni piano d'ispezione ambientale contiene i seguenti elementi:

a) un'analisi generale dei principali problemi ambientali pertinenti;

b) la zona geografica coperta dal piano d'ispezione;

c) un registro delle installazioni coperte dal piano;

d) le procedure per l'elaborazione dei programmi per le ispezioni ambientali ordinarie conformemente al paragrafo 4;

e) le procedure per le ispezioni straordinarie conformemente al paragrafo 5;

f) se necessario, le disposizioni riguardanti la cooperazione tra le varie autorità d'ispezione.

4. Sulla base dei piani d'ispezione, l'autorità redige periodicamente i programmi delle ispezioni ordinarie comprendenti la frequenza delle visite in loco per i vari tipi di installazioni.

Il periodo tra due visite in loco è basato su una valutazione sistematica dei rischi ambientali delle installazioni interessate e non supera un anno per le installazioni che presentano i rischi più elevati, e tre anni per le installazioni che presentano i rischi meno elevati.

Se da un'ispezione emerge una grave inosservanza delle condizioni di autorizzazione, è effettuato un ulteriore sopralluogo entro sei mesi da detta ispezione.

La valutazione sistematica dei rischi ambientali è basata almeno sui criteri seguenti:

a) gli impatti potenziali e reali delle installazioni interessate sulla salute umana e sull'ambiente tenendo conto dei livelli e dei tipi di emissioni, della sensibilità dell'ambiente locale e del rischio di incidenti;

b) il livello di osservanza delle condizioni di autorizzazione;

c) la partecipazione del gestore al sistema dell'Unione di ecogestione e audit (EMAS) (a norma del regolamento (CE) n. 1221/2009 [1]).

La Commissione può adottare linee guida sui criteri relativi alla valutazione dei rischi ambientali.

5. Le ispezioni ambientali straordinarie sono effettuate per indagare nel più breve tempo possibile e, se necessario, prima della concessione, del riesame o dell'aggiornamento di un'autorizzazione, le denunce ed i casi gravi di incidenti, di guasti e di infrazione in materia ambientale.

6. Dopo ogni visita in loco l'autorità competente redige una relazione che contiene i pertinenti riscontri in merito alla conformità dell'installazione alle condizioni di autorizzazione e le conclusioni riguardanti eventuali azioni da intraprendere.

La relazione è notificata al gestore interessato entro due mesi dalla visita in loco ed è resa disponibile al pubblico dall'autorità competente conformemente alla direttiva 2003/4/CE del Parlamento europeo e del Consiglio, del 28 gennaio 2003, sull'accesso del pubblico all'informazione ambientale [2], entro quattro mesi dalla visita in loco.

Fatto salvo l'articolo 8, paragrafo 2, l'autorità competente provvede affinché il gestore adotti tutte le misure necessarie contenute nella relazione entro un termine ragionevole.

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[1] Regolamento (CE) n. 1221/2009 del Parlamento europeo e del Consiglio, del 25 novembre 2009, sull'adesione volontaria delle organizzazioni a un sistema comunitario di ecogestione e audit (EMAS) (GU L 342 del 22.12.2009, pag. 1).

[2] GU L 41 del 14.2.2003, pag. 26.

Articolo 24

Accesso all'informazione e partecipazione del pubblico alla procedura di autorizzazione

1. Gli Stati membri provvedono affinché al pubblico interessato siano offerte tempestive ed effettive opportunità di partecipazione alle seguenti procedure:

a) la concessione di un'autorizzazione per nuove installazioni;

b) la concessione di un'autorizzazione per modifiche sostanziali;

c) la concessione o aggiornamento di un'autorizzazione per un'installazione in cui si propone l'applicazione dell'articolo 15, paragrafo 4;

d) l'aggiornamento di un'autorizzazione o delle condizioni di autorizzazione relative a un'installazione a norma dell'articolo 21, paragrafo 5, lettera a).

A tale partecipazione si applica la procedura stabilita nell'allegato IV.

2. Non appena sia stata adottata una decisione in merito al rilascio, al riesame o all'aggiornamento di un'autorizzazione, l'autorità competente rende disponibili al pubblico, anche mediante internet per quanto riguarda le lettere a), b) ed f), le seguenti informazioni:

a) il contenuto della decisione, compresa una copia dell'autorizzazione e degli eventuali successivi aggiornamenti;

b) i motivi su cui è basata la decisione;

c) i risultati delle consultazioni condotte prima dell'adozione della decisione e una spiegazione della modalità con cui se ne è tenuto conto nella decisione;

d) il titolo dei documenti di riferimento sulle BAT pertinenti per l'installazione o l'attività interessati;

e) il metodo utilizzato per determinare le condizioni di autorizzazione di cui all'articolo 14, ivi compresi i valori limite di emissione, in relazione alle migliori tecniche disponibili e ai livelli di emissione ivi associati;

f) se è concessa una deroga ai sensi dell'articolo 15, paragrafo 4, i motivi specifici della deroga sulla base dei criteri indicati in detto paragrafo e le condizioni imposte.

3. L'autorità competente rende altresì disponibili al pubblico, anche tramite Internet, quanto meno per quanto riguarda la lettera a):

a) le informazioni pertinenti sulle misure adottate dal gestore, in applicazione dell'articolo 22, al momento della cessazione definitiva delle attività;

b) i risultati del controllo delle emissioni, richiesti dalle condizioni di autorizzazione e in possesso dell'autorità competente.

4. I paragrafi 1, 2 e 3 del presente articolo si applicano nel rispetto delle restrizioni previste dall'articolo 4, paragrafi 1 e 2, della direttiva 2003/4/CE.

Articolo 25

Accesso alla giustizia

1. Gli Stati membri provvedono, nel quadro del proprio ordinamento giuridico nazionale, affinché il pubblico interessato abbia accesso a una procedura di ricorso dinanzi ad un organo giurisdizionale o ad un altro organo indipendente ed imparziale istituito dalla legge, per contestare la legittimità sostanziale o procedurale di decisioni, atti od omissioni soggetti alle disposizioni dell'articolo 24 quando è rispettata una delle seguenti condizioni:

a) essi vantano un interesse sufficiente;

b) essi fanno valere la violazione di un diritto, nei casi in cui il diritto processuale amministrativo di uno Stato membro esiga tale presupposto.

2. Gli Stati membri stabiliscono in quale fase possono essere contestati le decisioni, gli atti o le omissioni.

3. Gli Stati membri determinano ciò che costituisce un interesse sufficiente e una violazione di un diritto, compatibilmente con l'obiettivo di offrire al pubblico interessato un ampio accesso alla giustizia.

A tal fine, l'interesse di qualsiasi organizzazione non governativa che promuove la protezione ambientale e che rispetta i requisiti della legislazione nazionale è considerato sufficiente ai fini del paragrafo 1, lettera a).

Si considera inoltre che tali organizzazioni siano titolari di diritti suscettibili di essere lesi ai fini del paragrafo 1, lettera b).

4. I paragrafi 1, 2 e 3 non escludono la possibilità di procedimenti di ricorso preliminare dinanzi all'autorità amministrativa e non incidono sul requisito dell'esaurimento dei procedimenti di ricorso amministrativo quale presupposto per l'esperimento di procedimenti di ricorso giurisdizionale ove siffatto requisito sia prescritto dal diritto nazionale.

Tali procedimenti sono giusti, equi, tempestivi e non eccessivamente onerosi.

5. Gli Stati membri provvedono a mettere a disposizione del pubblico informazioni pratiche sull'accesso alle procedure di ricorso amministrativo e giurisdizionale.

Articolo 26

Effetti transfrontalieri

1. Qualora uno Stato membro constati che il funzionamento di un'installazione può avere effetti negativi significativi sull'ambiente di un altro Stato membro, oppure qualora uno Stato membro che potrebbe subire tali effetti significativi presenti domanda in tal senso, lo Stato membro in cui è stata richiesta l'autorizzazione ai sensi dell'articolo 4 o dell'articolo 20, paragrafo 2, comunica all'altro Stato membro le eventuali informazioni che devono essere fornite o rese disponibili ai sensi dell'allegato IV, nel momento stesso in cui le mette a disposizione del pubblico.

Tali informazioni servono da base per le consultazioni necessarie nel quadro dei rapporti bilaterali tra i due Stati membri, secondo il principio della reciprocità e della parità di trattamento.

2. Gli Stati membri provvedono, nel quadro dei loro rapporti bilaterali, affinché nei casi di cui al paragrafo 1 le domande siano accessibili anche al pubblico dello Stato membro eventualmente interessato, per un periodo di tempo adeguato che consenta una presa di posizione prima della decisione dell'autorità competente.

3. I risultati delle consultazioni condotte ai sensi dei paragrafi 1 e 2 sono presi in considerazione dall'autorità competente al momento della decisione sulla domanda.

4. L'autorità competente informa ogni Stato membro consultato ai sensi del paragrafo 1 della decisione adottata in merito alla domanda e gli trasmette le informazioni di cui all'articolo 24, paragrafo 2. Tale Stato membro adotta le misure necessarie affinché le suddette informazioni siano rese disponibili in modo appropriato al pubblico interessato nel proprio territorio.

Articolo 27

Tecniche emergenti

1. Se del caso, gli Stati membri incoraggiano lo sviluppo e l'applicazione di tecniche emergenti, in particolare delle tecniche emergenti individuate nei documenti di riferimento sulle BAT.

2. La Commissione stabilisce orientamenti per aiutare gli Stati membri ad incoraggiare lo sviluppo e l'applicazione di tecniche emergenti, come previsto al paragrafo 1.

CAPO III

DISPOSIZIONI PARTICOLARI PER GLI IMPIANTI DI COMBUSTIONE

Articolo 28

Ambito di applicazione

Il presente capo si applica agli impianti di combustione aventi una potenza termica nominale totale pari o superiore a 50 MW, indipendentemente dal tipo di combustibile utilizzato.

Il presente capo non si applica ai seguenti impianti di combustione:

a) impianti in cui i prodotti della combustione sono utilizzati per il riscaldamento diretto, l'essiccazione o qualsiasi altro trattamento degli oggetti o dei materiali;

b) impianti di postcombustione destinati alla depurazione dello scarico gassoso mediante combustione, che non siano gestiti come impianti indipendenti di combustione;

c) dispositivi di rigenerazione dei catalizzatori di cracking catalitico;

d) dispositivi di conversione del solfuro di idrogeno in zolfo;

e) reattori utilizzati nell'industria chimica;

f) batteria di forni per il coke;

g) cowpers degli altiforni;

h) qualsiasi apparecchio tecnico usato per la propulsione di un veicolo, una nave o un aeromobile;

i) turbine a gas e motori a gas usati su piattaforme off-shore;

j) impianti che utilizzano come combustibile qualsiasi rifiuto solido o liquido diverso dai rifiuti di cui all'articolo 3, punto 31, lettera b).

Articolo 29

Norme di aggregazione

1. Quando gli scarichi gassosi di due o più impianti di combustione distinti sono emessi attraverso un camino comune, l'insieme formato da questi impianti è considerato un impianto di combustione unico e se ne sommano le capacità ai fini del calcolo della potenza termica nominale totale.

2. Nel caso in cui due o più singoli impianti di combustione che hanno ottenuto un'autorizzazione per la prima volta il 1° luglio 1987 o successivamente, o i cui gestori hanno presentato una domanda completa di autorizzazione in tale data o successivamente, siano installati in maniera tale che gli scarichi gassosi, tenuto conto delle condizioni tecniche ed economiche, possano a giudizio delle autorità competenti essere convogliati verso un unico camino, la combinazione degli impianti è considerata come un impianto di combustione unico e le capacità dei singoli impianti sono sommate ai fini del calcolo della potenza termica nominale totale.

3. Ai fini del calcolo della potenza termina nominale totale di una combinazione di impianti di combustione di cui ai paragrafi 1 e 2, i singoli impianti di combustione con potenza termica nominale inferiore a 15 MWth non sono considerati.

Articolo 30

Valori limite di emissione

1. Gli scarichi gassosi degli impianti di combustione sono smaltiti in modo controllato attraverso un camino contenente uno o più canne di scarico, la cui altezza è calcolata in modo da salvaguardare la salute umana e l'ambiente.

2. Tutte le autorizzazioni per installazioni contenenti impianti di combustione che hanno ottenuto un'autorizzazione prima del 7 gennaio 2013, o i cui gestori hanno presentato una domanda completa per un'autorizzazione entro tale data, a condizione che detti impianti siano messi in servizio al più tardi entro il 7 gennaio 2014, contengono condizioni che assicurano che le emissioni nell'atmosfera di tali impianti non superino i valori limite di emissione di cui all'allegato V, parte 1.

Tutte le autorizzazioni per installazioni contenenti impianti di combustione che hanno ottenuto un'esenzione di cui all'articolo 4, paragrafo 4, della direttiva 2001/80/CE, e fatti funzionare dopo il 1º gennaio 2016, comprendono condizioni intese ad assicurare che le emissioni nell'atmosfera di tali impianti non superino i valori limite di emissione di cui all'allegato V, parte 2.

3. Tutte le autorizzazioni per installazioni contenenti impianti di combustione non coperti dal paragrafo 2 contengono condizioni che garantiscono che le emissioni nell'atmosfera di tali impianti non superino i valori limite di emissione di cui all'allegato V, parte 2.

4. I valori limite di emissione che figurano nell'allegato V, parti 1 e 2, nonché i gradi minimi di desolforazione di cui nella parte 5 di tale allegato si applicano alle emissioni di ogni camino comune in funzione della potenza termica nominale totale dell'intero impianto di combustione. Se l'allegato V prevede che possono essere applicati valori limite di emissione per una parte di un impianto di combustione con un numero limitato di ore operative, tali valori limite si applicano alle emissioni di detta parte dell'impianto, ma sono fissate in relazione della potenza termica nominale totale dell'intero impianto di combustione.

5. L'autorità competente può accordare una deroga per un massimo di sei mesi dall'obbligo di osservanza dei valori limite di emissione di cui ai paragrafi 2 e 3, per l'anidride solforosa in impianti di combustione che a tale scopo normalmente utilizzano un combustibile a basso tenore di zolfo se il gestore si trova nell'impossibilità di rispettare tali valori limite, a causa dell'interruzione delle forniture del combustibile summenzionato dovuta ad una situazione di grave penuria.

Gli Stati membri comunicano immediatamente alla Commissione ogni deroga concessa a norma del primo comma.

6. L'autorità competente può accordare una deroga all'obbligo di rispettare i valori limite di emissione di cui ai paragrafi 2 e 3, qualora un impianto di combustione, che utilizza esclusivamente combustibile gassoso debba ricorrere eccezionalmente all'uso di altri combustibili a causa di un'improvvisa interruzione della fornitura di gas e per tale motivo dovrebbe essere dotato di un dispositivo di depurazione degli scarichi gassosi. Tale deroga è concessa per un periodo non superiore a 10 giorni, salvo che non vi sia la necessità assoluta di continuare le forniture di energia.

Il gestore informa immediatamente l'autorità competente di ogni caso specifico di cui al primo comma.

Gli Stati membri informano immediatamente la Commissione in merito a ogni deroga concessa a norma del primo comma.

7. Qualora un impianto di combustione sia ampliato, i valori limite di emissione di cui all'allegatoV, parte 2, è applicato alla parte ampliata dell'impianto interessata dalla modifica ed è fissato in funzione della potenza termica nominale totale dell'intero impianto di combustione. Nel caso di una modifica di un impianto di combustione che può avere conseguenze per l'ambiente e che riguarda una parte dell'impianto con potenza termica nominale pari o superiore a 50 MW, i valori limite di emissione di cui all'allegato V, parte 2, si applicano alla parte modificata dell'impianto in funzione della potenza termica nominale totale dell'intero impianto di combustione.

8. I valori limite di emissione di cui all'allegato V, parti 1 e 2, non si applicano ai seguenti impianti di combustione:

a) motori diesel;

b) caldaie di recupero nelle installazioni per la produzione della pasta di legno.

9. Per i seguenti impianti di combustione, in base alle migliori tecniche disponibili, la Commissione riesamina la necessità di stabilire valori limite di emissione su scala dell'Unione e di modificare i valori limite di emissione di cui all'allegato V:

a) gli impianti di combustione di cui al paragrafo 8;

b) gli impianti di combustione all'interno di raffinerie alimentati con i residui di distillazione e di conversione della raffinazione del petrolio greggio, da soli o con altri combustibili, per il loro proprio consumo, tenuto conto della specificità dei sistemi energetici delle raffinerie;

c) gli impianti di combustione alimentati con gas diversi dal gas naturale;

d) impianti di combustione in installazioni chimiche che utilizzano residui di produzione liquidi come combustibile non commerciale per il loro proprio consumo.

Entro il 31 dicembre 2013, la Commissione riferisce i risultati di tale riesame al Parlamento europeo e al Consiglio corredandoli, se del caso, di una proposta legislativa.

Articolo 31

Grado di desolforazione

1. Per gli impianti di combustione che bruciano combustibili solidi indigeni, i quali non possono rispettare i valori limite di emissione per l'anidride solforosa, di cui all'articolo 30, paragrafi 2 e 3, a causa delle caratteristiche di tale combustibile, gli Stati membri possono applicare in alternativa i gradi minimi di desolforazione di cui all'allegato V, parte 5, secondo le norme sulla conformità stabilite alla parte 6 di tale allegato, e previa convalida da parte dell'autorità competente della relazione tecnica di cui all'articolo 72, paragrafo 4, lettera a).

2. Per gli impianti di combustione brucianti combustibile solido indigeno in cui sono coinceneriti anche rifiuti e che non possono rispettare i valori $C_{processo}$ per il biossido di zolfo di cui all'allegato VI, parte 4, punti 3.1 o 3.2, a causa delle caratteristiche del combustibile solido indigeno, gli Stati membri possono applicare, in alternativa, i gradi minimi di desolforazione di cui all'allegato V, parte 5, secondo le norme slla conformità di cui alla parte 6 di tale allegato. Se gli Stati membri applicano il presente paragrafo, il valore $C_{rifiuti}$ di cui all'allegato VI, parte 4, punto 1, è pari a 0 mg/Nm^3.

3. Entro il 31 dicembre 2019 la Commissione riesamina la possibilità di applicare i gradi minimi di desolforazione di cui all'allegato V, parte 5, tenendo conto in particolare delle migliori tecniche disponibili e dei vantaggi ottenuti dalla riduzione delle emissioni di ossido di zolfo.

Articolo 32

Piano nazionale transitorio

1. Nel periodo dal 1° gennaio 2016 al 30 giugno 2020 gli Stati membri possono elaborare ed attuare un piano nazionale transitorio relativo agli impianti di combustione che hanno ottenuto la prima autorizzazione anteriormente al 27 novembre 2002, o i cui gestori hanno presentato una domanda completa di autorizzazione prima di tale data, a condizione che l'impianto sia stato messo in funzione entro il 27 novembre 2003. Per ogni impianto di combustione contemplato dal piano, quest'ultimo riguarda le emissioni di uno o più dei seguenti inquinanti: ossidi di azoto, anidride solforosa e polveri. Per le turbine a gas il piano contempla solo le emissioni di ossido di azoto.

Il piano nazionale transitorio non comprende nessuno dei seguenti impianti di combustione:

a) impianti ai quali si applica l'articolo 33, paragrafo 1;

b) impianti all'interno di raffinerie alimentate con gas a basso potere calorifico originati dalla gassificazione dei residui delle raffinerie o dei residui di distillazione e di conversione della raffinazione del petrolio greggio, da soli o con altri combustibili, per il loro proprio consumo;

c) impianti ai quali si applica l'articolo 35;

d) impianti che hanno ottenuto un'esenzione di cui all'articolo 4, paragrafo 4, della direttiva 2001/80/CE.

2. Gli impianti di combustione contemplati dal piano possono essere esentati dall'obbligo di osservare i valori limite di emissione di cui all'articolo 30, paragrafo 2, per gli inquinanti soggetti al piano o, se del caso, i gradi di desolforazione di cui all'articolo 31.

I valori limite di emissione di ossido di zolfo, ossido di azoto e polveri fissati nell'autorizzazione dell'impianto di combustione applicabili il 31 dicembre 2015, in particolare ai sensi delle disposizioni delle direttive 2001/80/CE e 2008/1/CE, sono almeno mantenuti.

Gli impianti di combustione con potenza termica nominale totale superiore a 500 MW alimentati con combustibili solidi, che hanno ottenuto la prima autorizzazione dopo il 1° luglio 1987, osservano i valori limite di emissione di ossido di azoto di cui all'allegato V, parte 1.

3. Per ogni inquinante da esso contemplato, il piano nazionale transitorio stabilisce un massimale che definisce le emissioni annuali totali massime per tutti gli impianti contemplati dal piano in base alla potenza termica nominale totale di ciascun impianto al 31 dicembre 2010, alle effettive ore di funzionamento annuali e al combustibile utilizzato, secondo la media degli ultimi dieci anni di funzionamento fino al 2010 compreso.

Il massimale per l'anno 2016 è calcolato in base ai valori limite di emissione pertinenti di cui agli allegati da III a VII della direttiva 2001/80/CE o, se del caso, in base ai gradi di desolforazione di cui all'allegato III della direttiva 2001/80/CE. Nel caso di turbine a gas, sono utilizzati i valori limite di emissione di ossido di azoto fissati per tali impianti all'allegato VI, parte B, della direttiva 2001/80/CE. I massimali per gli anni 2019 e 2020 sono calcolati in base ai valori limite di emissione pertinenti di cui all'allegato V, parte 1, della presente direttiva o, se del caso, ai gradi di desolforazione pertinenti di cui all'allegato V, parte 5, della presente direttiva. I massimali per gli anni 2017 e 2018 sono fissati stabilendo un decremento lineare dei massimali tra il 2016 e il 2019.

Se un impianto compreso nel piano nazionale transitorio viene chiuso o non rientra più nell'ambito di applicazione del capo III, ciò non comporta l'aumento delle emissioni nazionali totali annue dei restanti impianti del piano.

4. Il piano nazionale transitorio contiene inoltre disposizioni in materia di monitoraggio e comunicazione dei dati conformi alle norme di attuazione stabilite ai sensi dell'articolo 41, lettera b), nonché le misure previste per ciascun impianto al fine di garantire il tempestivo rispetto dei valori limite di emissione che si applicheranno a decorrere dal 1° luglio 2020.

5. Entro il 1° gennaio 2013 gli Stati membri comunicano alla Commissione i loro piani nazionali transitori.

La Commissione valuta i piani e, se essa non solleva alcuna obiezione entro dodici mesi dalla ricezione del piano, lo Stato membro interessato lo considera approvato.

Se ritiene che un piano non sia conforme alle norme di attuazione stabilite ai sensi dell'articolo 41, lettera b), la Commissione informa lo Stato membro interessato che il suo piano non può essere approvato. Per la valutazione di una nuova versione di un piano comunicata da uno Stato membro alla Commissione, il termine di cui al secondo comma è di sei mesi.

6. Gli Stati membri informano la Commissione di ogni successiva modifica del piano.

Articolo 33

Deroga in caso di arco di vita limitato

1. Nel periodo dal 1° gennaio 2016 al 31 dicembre 2023 gli impianti di combustione possono essere esentati dall'obbligo di osservare i valori limite di emissione di cui all'articolo 30, paragrafo 2, e i gradi di desolforazione di cui all'articolo 31, se del caso, e di essere inclusi nel piano nazionale transitorio di cui all'articolo 32 purché siano soddisfatte le seguenti condizioni:

a) il gestore dell'impianto di combustione si impegna, con una dichiarazione scritta presentata entro il 1° gennaio 2014 all'autorità competente, a non far funzionare l'impianto per più di 17 500 ore operative a partire dal 1° gennaio 2016 e non oltre il 31 dicembre 2023;

b) il gestore è tenuto a presentare ogni anno all'autorità competente un documento in cui è registrato il numero di ore operative dal 1° gennaio 2016;

c) i valori limite di emissione di ossido di zolfo, ossido di azoto e polveri fissati nell'autorizzazione dell'impianto di combustione applicabili il 31 dicembre 2015, in particolare ai sensi delle disposizioni delle direttive 2001/80/CE e 2008/1/CE, sono almeno mantenuti durante il restante periodo di funzionamento dell'impianto di combustione. Gli impianti di combustione con potenza termica nominale totale superiore a 500 MWth alimentati con combustibili solidi, che hanno ottenuto la prima autorizzazione dopo il 1° luglio 1987, osservano i valori limite di emissione di ossido di azoto di cui all'allegato V, parte 1; e

d) l'impianto di combustione non ha ottenuto un'esenzione ai sensi dell'articolo 4, paragrafo 4, della direttiva 2001/80/CE.

2. Al più tardi il 1° gennaio 2016 ogni Stato membro comunica alla Commissione un elenco di tutti gli impianti di combustione cui si applica il paragrafo 1, compresi la potenza termica nominale totale, i tipi di combustibili usati e i valori limite di emissione di ossido di zolfo, ossido di azoto e polveri applicabili. Per gli impianti soggetti al paragrafo 1 gli Stati membri trasmettono annualmente alla Commissione un documento in cui è registrato il numero di ore operative dal 1° gennaio 2016.

3. Nel caso di impianti di combustione che, alla data del 6 gennaio 2011, fanno parte di un piccolo sistema isolato e producono almeno il 35 % dell'elettricità fornita all'interno di tale sistema, e che, per le loro caratteristiche tecniche, non possono rispettare i valori limite di emissione di cui all'articolo 30, paragrafo 2, il numero di ore operative di cui al paragrafo 1, lettera a), del presente articolo è di 18 000 a partire dal 1° gennaio 2020 e non oltre il 31 dicembre 2023, e la data di cui al paragrafo 1, lettera b), e al paragrafo 2 del presente articolo è fissata al 1° gennaio 2020.

4. Nel caso di impianti di combustione con potenza termica nominale totale superiore a 1 500 MW, entrati in funzione anteriormente al 31 dicembre 1986 e alimentati a combustile solido indigeno, con valore calorifico netto inferiore a 5 800 kJ/kg, un contenuto di umidità superiore al 45 % in peso, un contenuto combinato di umidità e ceneri superiore al 60 % in peso e un contenuto di ossido di calcio in ceneri superiore al 10 %, il numero di ore operative di cui al paragrafo 1, lettera a) è fissato a 32 000.

Articolo 34

Piccoli sistemi isolati

1. Fino al 31 dicembre 2019 gli impianti di combustione che, alla data del 6 gennaio 2011, fanno parte di un piccolo sistema isolato possono essere esentati dall'obbligo di osservare i valori limite di emissione di cui all'articolo 30, paragrafo 2, e, se del caso, i gradi di desolforazione di cui all'articolo 31. Fino al 31 dicembre 2019 i valori limite di emissione fissati nelle autorizzazioni di tali impianti di combustione, in particolare ai sensi delle disposizioni delle direttive 2001/80/CE e 2008/1/CE, sono almeno mantenuti.

2. Gli impianti di combustione con potenza termica nominale totale superiore a 500 MW alimentati con combustibili solidi, che hanno ottenuto la prima autorizzazione dopo il 1° luglio 1987, osservano i valori limite di emissione di ossido di azoto di cui all'allegato V, parte 1.

3. Gli Stati membri sul cui territorio sono presenti impianti di combustione contemplati dal presente capo, che fanno parte di un piccolo sistema isolato, comunicano alla Commissione, entro il 7 gennaio 2013, un elenco di tali impianti di combustione, il consumo energetico totale annuo del piccolo sistema isolato e la quantità di energia ottenuta dall'interconnessione con altri sistemi.

Articolo 35

Impianti di teleriscaldamento

1. Fino al 31 dicembre 2022, gli impianti di combustione possono essere esentati dall'obbligo di osservare i valori limite di emissione di cui all'articolo 30, paragrafo 2, e i gradi di desolforazione di cui all'articolo 31 purché siano soddisfatte le seguenti condizioni:

a) la potenza termica nominale totale dell'impianto di combustione non è superiore a 200 MW;

b) l'impianto ha ottenuto la prima autorizzazione anteriormente al 27 novembre 2002 o il gestore di tale impianto ha presentato una domanda completa di autorizzazione prima di tale data, a condizione che sia stato messo in funzione entro il 27 novembre 2003;

c) almeno il 50 % della produzione di calore utile dell'impianto, calcolata in media mobile su un periodo di cinque anni, è fornito ad una rete pubblica di teleriscaldamento sotto forma di vapore o di acqua calda; e

d) i valori limite di emissione di ossido di zolfo, ossido di azoto e polveri fissati nell'autorizzazione applicabili il 31 dicembre 2015, in particolare ai sensi delle disposizioni delle direttive 2001/80/CE e 2008/1/CE, sono almeno mantenuti fino al 31 dicembre 2022.

2. Al più tardi il 1° gennaio 2016 ogni Stato membro comunica alla Commissione un elenco di tutti gli impianti di combustione cui si applica il paragrafo 1, compresi la potenza termica nominale totale, i tipi di combustibili usati e i valori limite di emissione di ossido di zolfo, ossido di azoto e polveri applicabili. Inoltre gli Stati membri, per ogni impianto di combustione cui si applica il paragrafo 1 e durante il periodo ivi indicato, informano annualmente la Commissione della proporzione di produzione di calore utile di ogni impianto che è stata fornita ad una rete pubblica di teleriscaldamento sotto forma di vapore o di acqua calda, espressa come media mobile sui cinque anni precedenti.

Articolo 36

Stoccaggio geologico di anidride carbonica

1. Gli Stati membri provvedono affinché i gestori di tutti gli impianti di combustione con una produzione di energia elettrica stimata pari o superiore a 300 megawatt che ottengono la licenza edilizia iniziale o, in assenza di tale procedura, la licenza di esercizio iniziale dopo l'entrata in vigore della direttiva 2009/31/CE del Parlamento europeo e del Consiglio, del 23 aprile 2009, relativa allo stoccaggio geologico di biossido di carbonio ([1]), abbiano accertato che le seguenti condizioni siano soddisfatte:

a) disponibilità di siti di stoccaggio appropriati;

b) fattibilità tecnica ed economica di strutture di trasporto;

c) possibilità tecnica ed economica di installare a posteriori le strutture per la cattura di anidride carbonica.

2. Se le condizioni stabilite al paragrafo 1 sono soddisfatte, l'autorità competente provvede a che sia riservata un'area sufficiente all'interno del sito dell'installazione per installare le strutture necessarie alla cattura e alla compressione di anidride carbonica. L'autorità competente determina se le condizioni sono soddisfatte sulla base della valutazione di cui al paragrafo 1 e di altre informazioni disponibili, in particolare per quanto riguarda la tutela dell'ambiente e della salute umana.

Articolo 37

Cattivo funzionamento o guasto degli impianti di abbattimento

1. Gli Stati membri provvedono affinché le autorizzazioni prevedano disposizioni relative al cattivo funzionamento o al guasto degli impianti di abbattimento.

2. L'autorità competente chiede al gestore, nell'ipotesi di un guasto, di ridurre o cessare l'attività se il funzionamento normale non viene ripristinato entro ventiquattro ore, oppure di far funzionare l'impianto usando combustibili poco inquinanti.

Il gestore informa l'autorità competente entro quarantotto ore dal cattivo funzionamento o dal guasto dell'impianto di abbattimento.

([1]) GU L 140 del 5.6.2009, pag. 114.

La durata complessiva del funzionamento privo di abbattimento non eccede mai le centoventi ore nell'arco di dodici mesi.

L'autorità competente può consentire deroghe al limite temporale di cui al primo e al terzo comma nei casi seguenti:

a) vi è la necessità assoluta di mantenere la fornitura energetica;

b) l'impianto di combustione guasto sarebbe sostituito per un periodo limitato con un altro che causerebbe un aumento generale delle emissioni.

Articolo 38

Controllo delle emissioni nell'atmosfera

1. Gli Stati membri provvedono affinché il controllo delle sostanze inquinanti per l'atmosfera sia effettuato conformemente all'allegato V, parte 3.

2. L'installazione e il funzionamento del dispositivo automatico di controllo sono sottoposti al monitoraggio e ai test annuali di verifica di cui all'allegato V, parte 3.

3. L'autorità competente stabilisce la localizzazione dei punti di campionamento o di misurazione da utilizzare per il controllo delle emissioni.

4. Tutti i risultati dei controlli sono registrati, elaborati e presentati in modo tale da consentire all'autorità competente di verificare l'osservanza delle condizioni di funzionamento e dei valori limite di emissione contenuti nell'autorizzazione.

Articolo 39

Conformità ai valori limite di emissione

I valori limite di emissione in atmosfera sono considerati rispettati se sono soddisfatte le condizioni di cui all'allegato V, parte 4.

Articolo 40

Impianti di combustione multicombustibile

1. Per gli impianti di combustione multicombustibile che comportano l'impiego simultaneo di due o più combustibili, l'autorità competente stabilisce i valori limite conformemente alla procedura che segue:

a) prendere il valore limite di emissione relativo a ciascun combustibile e a ciascun inquinante, corrispondente alla potenza termica nominale totale dell'intero impianto di combustione quale è stabilita nell'allegato V, parti 1 e 2;

b) determinare i valori limite di emissione ponderati per combustibile; detti valori si ottengono moltiplicando ciascuno dei valori limite di emissione di cui alla lettera a) per la potenza termica fornita da ciascun combustibile e dividendo il risultato di ciascuna moltiplicazione per la somma delle potenze termiche fornite da tutti i combustibili;

c) addizionare i valori limite di emissione ponderati per combustibile.

2. Per gli impianti di combustione multicombustibile previsti all'articolo 30, paragrafo 2, che usano i residui di distillazione e di conversione della raffinazione del petrolio greggio, da soli o con altri combustibili, per il loro proprio consumo, si possono applicare i seguenti valori limite di emissione invece dei valori limite di emissione fissati a norma del paragrafo 1:

a) laddove durante il funzionamento dell'impianto la proporzione di calore fornita dal combustibile determinante sia pari o superiore al 50 % rispetto alla somma delle potenze termiche fornite da tutti i combustibili, il valore limite di emissione di cui all'allegato V, parte 1, per il combustibile determinante;

b) laddove la proporzione di calore fornita dal combustibile determinante sia inferiore al 50 % rispetto alla somma delle potenze termiche fornite da tutti i combustibili, il valore limite di emissione determinato conformemente alla procedura che segue:

   i) prendere i valori limite di emissione di cui all'allegato V, parte 1, per ciascuno dei combustibili utilizzati, corrispondenti alla potenza termica nominale totale dell'impianto di combustione;

   ii) calcolare il valore limite di emissione del combustibile determinante, moltiplicando per due il valore limite di emissione determinato per tale combustibile conformemente al punto i) e sottraendo dal risultato il valore limite di emissione relativo al combustibile utilizzato con il valore limite di emissione meno elevato di cui all'allegato V, parte 1, corrispondente alla potenza termica nominale totale dell'impianto di combustione;

   iii) determinare i valori limite di emissione ponderati per ogni combustibile utilizzato moltiplicando i valori limite di emissione di cui ai punti i) e ii) per la potenza termica del combustibile in questione e dividendo il risultato di tale moltiplicazione per la somma delle potenze termiche fornite da tutti i combustibili;

   iv) addizionare i valori limite di emissione ponderati per combustibile determinati al punto iii).

3. Per gli impianti di combustione multicombustibile previsti all'articolo 30, paragrafo 2, che usano i residui di distillazione e di conversione della raffinazione del petrolio greggio, da soli o con altri combustibili, per il loro proprio consumo, si possono applicare i valori limite medi di emissione di anidride solforosa di cui all'allegato V, parte 7, invece dei valori limite di emissione fissati a norma del paragrafo 1 o 2 del presente articolo.

Articolo 41

Norme di attuazione

Sono stabilite norme di attuazione riguardanti:

a) la determinazione dei periodi di avvio e di arresto di cui all'articolo 3, punto 27, e all'allegato V, parte 4, punto 1; e

b) i piani nazionali transitori di cui all'articolo 32 e, in particolare, la fissazione di massimali di emissione e relativi monitoraggio e comunicazione.

Tali norme di attuazione sono adottate secondo la procedura di regolamentazione di cui all'articolo 75, paragrafo 2. La Commissione presenta opportune proposte entro il 7 luglio 2011.

CAPO IV

DISPOSIZIONI PARTICOLARI PER GLI IMPIANTI DI INCENERIMENTO E DI COINCENERIMENTO DEI RIFIUTI

Articolo 42

Ambito di applicazione

1. Il presente capo si applica agli impianti di incenerimento dei rifiuti e agli impianti di coincenerimento dei rifiuti destinati all'incenerimento o al coincenerimento di rifiuti solidi o liquidi.

Il presente capo non si applica agli impianti di gassificazione o di pirolisi, se i gas prodotti da siffatto trattamento termico dei rifiuti sono purificati in misura tale da non costituire più rifiuti prima del loro incenerimento e da poter provocare emissioni non superiori a quelle derivanti dalla combustione di gas naturale.

Ai fini del presente capo gli impianti di incenerimento dei rifiuti e gli impianti di coincenerimento dei rifiuti comprendono tutte le linee di incenerimento o di coincenerimento, i luoghi di ricezione e di stoccaggio, le installazioni di pretrattamento in loco, i sistemi di alimentazione in rifiuti, in combustibile e in aria, le caldaie, le installazioni di trattamento degli scarichi gassosi, le installazioni di trattamento o stoccaggio in loco dei residui e delle acque reflue, i camini, i dispositivi e i sistemi di controllo delle operazioni di incenerimento o di coincenerimento, di registrazione e di sorveglianza delle condizioni di incenerimento o di coincenerimento.

Se per il trattamento termico dei rifiuti sono utilizzati processi diversi dall'ossidazione, quali ad esempio la pirolisi, la gassificazione o il processo al plasma, l'impianto di incenerimento o di coincenerimento dei rifiuti include sia il processo di trattamento termico che il successivo processo di incenerimento.

Se il coincenerimento dei rifiuti avviene in modo che la funzione principale dell'impianto non consiste nella produzione di energia o di prodotti materiali bensì nel trattamento termico dei rifiuti, l'impianto è considerato un impianto di incenerimento dei rifiuti.

2. Il presente capo non si applica ai seguenti impianti:

a) impianti che trattano unicamente i seguenti rifiuti:

   i) i rifiuti di cui all'articolo 3, punto 31, lettera b);

   ii) rifiuti radioattivi;

   iii) rifiuti animali, come regolati dal regolamento (CE) n. 1774/2002 del Parlamento europeo e del Consiglio del 3 ottobre 2002, recante norme sanitarie relative ai sottoprodotti di origine animale non destinati al consumo umano [1];

[1] GU L 273 del 10.10.2002, pag. 1.

iv) rifiuti derivanti dalla prospezione e dallo sfruttamento delle risorse petrolifere e di gas nelle installazioni offshore e inceneriti a bordo di queste ultime;

b) impianti sperimentali utilizzati a fini di ricerca, sviluppo e sperimentazione per migliorare il processo di incenerimento che trattano meno di 50 t di rifiuti all'anno.

Articolo 43

Definizione di residuo

Ai fini del presente capo, si intende per «residuo» qualsiasi rifiuto liquido o solido generato da un impianto di incenerimento dei rifiuti o da un impianto di coincenerimento dei rifiuti.

Articolo 44

Domande di autorizzazione

La domanda di autorizzazione relativa a un impianto di incenerimento o di coincenerimento di rifiuti contiene una descrizione delle misure previste per garantire che siano rispettate le seguenti prescrizioni:

a) l'impianto è progettato e attrezzato e sarà gestito e sottoposto a manutenzione in maniera conforme ai requisiti di cui al presente capo, tenendo conto delle categorie di rifiuti da incenerire o da coincenerire;

b) il calore generato durante il processo di incenerimento e di coincenerimento è recuperato per quanto praticabile attraverso la produzione di calore, vapore o energia;

c) i residui saranno ridotti al minimo in quantità e nocività e riciclati ove opportuno;

d) lo smaltimento dei residui che non possono essere evitati, limitati o riciclati sarà effettuato conformemente alla normativa nazionale e dell'Unione.

Articolo 45

Condizioni di autorizzazione

1. L'autorizzazione contiene quanto segue:

a) un elenco di tutti i tipi di rifiuti che possono essere trattati che si serve almeno dei tipi di rifiuti contemplati nell'elenco di rifiuti europeo istituito dalla decisione 2000/532/CE laddove possibile, e contiene informazioni sulla quantità di ciascun tipo di rifiuti, se del caso;

b) la capacità complessiva di incenerimento o di coincenerimento di rifiuti dell'impianto;

c) i valori limite per le emissioni nell'atmosfera e nell'acqua;

d) le prescrizioni relative al pH, alla temperatura e al flusso degli scarichi di acque reflue;

e) le procedure e la frequenza di campionamento e misurazione da utilizzare per rispettare le condizioni fissate per il controllo delle emissioni;

f) il periodo massimo durante il quale, a causa di disfunzionamenti, guasti dei dispositivi di depurazione e di misurazione o arresti tecnicamente inevitabili, le emissioni nell'atmosfera e gli scarichi di acque reflue possono superare i valori limite di emissione previsti.

2. In aggiunta alle prescrizioni di cui al paragrafo 1, l'autorizzazione rilasciata per un impianto di incenerimento di rifiuti o per un impianto di coincenerimento di rifiuti che utilizza rifiuti pericolosi contiene:

a) un elenco delle quantità delle diverse categorie di rifiuti pericolosi che possono essere trattati;

b) i flussi di massa minimi e massimi di tali rifiuti pericolosi, i loro valori calorifici minimi e massimi e il loro contenuto massimo di policlorobifenile, pentaclorofenolo, cloro, fluoro, zolfo, metalli pesanti e altre sostanze inquinanti.

3. Gli Stati membri hanno la facoltà di stabilire un elenco delle categorie di rifiuti da inserire nell'autorizzazione che possono essere coinceneriti in talune categorie di impianti di coincenerimento di rifiuti.

4. L'autorità competente riesamina periodicamente e aggiorna, ove necessario, le condizioni di autorizzazione.

Articolo 46

Controllo delle emissioni

1. Gli scarichi gassosi sono evacuati in modo controllato dagli impianti di incenerimento dei rifiuti e dagli impianti di coincenerimento dei rifiuti mediante un camino, la cui altezza sia tale da salvaguardare la salute umana e l'ambiente.

2. Le emissioni nell'atmosfera degli impianti di incenerimento dei rifiuti e degli impianti di coincenerimento dei rifiuti non superano i valori limite di emissione di cui all'allegato VI, parti 3 e 4, oppure determinati conformemente allo stesso allegato, parte 4.

Qualora più del 40 % del calore liberato in un impianto di coincenerimento dei rifiuti sia prodotto da rifiuti pericolosi, qualora l'impianto coincenerisca rifiuti urbani misti non trattati, si applicano i valori limite di emissione di cui all'allegato VI, parte 3, della presente direttiva.

3. L'evacuazione in ambiente idrico di acque reflue provenienti dalla depurazione degli scarichi gassosi è limitata per quanto possibile e le concentrazioni di sostanze inquinanti non superano i valori limite di emissione di cui all'allegato VI, parte 5.

4. I valori limite di emissione si applicano al punto in cui le acque reflue, provenienti dalla depurazione degli scarichi gassosi sono evacuate dall'impianto di incenerimento dei rifiuti o dall'impianto di coincenerimento dei rifiuti.

Qualora le acque reflue provenienti dalla depurazione degli scarichi gassosi siano trattate al di fuori dell'impianto di incenerimento dei rifiuti o dell'impianto di coincenerimento dei rifiuti in un impianto di trattamento destinato esclusivamente al trattamento di questo tipo di acque reflue, i valori limite di emissione di cui all'allegato VI, parte 5, si applicano al punto in cui le acque reflue fuoriescono dall'impianto di trattamento. Qualora le acque reflue provenienti dalla depurazione di scarichi gassosi siano trattate congiuntamente ad acque reflue provenienti da altre fonti, il loco o al di fuori del sito, il gestore effettua gli opportuni calcoli del bilancio di massa, utilizzando i risultati delle misure di cui all'allegato VI, punto 2, parte 6, ai fini di stabilire i livelli di emissione che nello scarico finale delle acque reflue possono essere attribuiti alla depurazione degli scarichi gassosi.

In nessun caso si procede alla diluizione delle acque reflue per farle rientrare nei valori limite di emissione di cui all'allegato VI, parte 5.

5. Il sito dell'impianto di incenerimento dei rifiuti e il sito dell'impianto di coincenerimento dei rifiuti, ivi comprese le aree di stoccaggio dei rifiuti, è progettato e gestito in modo da evitare l'immissione non autorizzata e accidentale di qualsiasi inquinante nel suolo, nelle acque superficiali e nelle acque sotterranee.

È prevista una capacità di stoccaggio per le acque piovane contaminate che defluiscano dal sito dell'impianto di incenerimento dei rifiuti o dal sito dell'impianto di coincenerimento o per l'acqua contaminata derivante da spandimenti o da operazioni di estinzione di incendi. La capacità di stoccaggio deve essere sufficiente per garantire che tali acque possano, se necessario, essere analizzate e, se necessario, trattate prima dello scarico.

6. Fatto salvo l'articolo 50, paragrafo 4, lettera c), per nessun motivo l'impianto di incenerimento dei rifiuti o l'impianto di coincenerimento dei rifiuti o i singoli forni che fanno parte di un impianto di incenerimento dei rifiuti o di un impianto di coincenerimento dei rifiuti possono continuare ad incenerire rifiuti ininterrottamente per un tempo superiore a quattro ore in caso di superamento dei valori limite di emissione.

La durata cumulativa del funzionamento in tali condizioni in un anno non supera le 60 ore.

Il limite temporale di cui al secondo comma si applica ai forni che sono collegati allo stesso dispositivo di lavaggio degli scarichi gassosi.

Articolo 47

Guasti

In caso di guasto il gestore riduce o arresta l'attività appena possibile, finché sia ristabilito il normale funzionamento.

Articolo 48

Controllo delle emissioni

1. Gli Stati membri assicurano che il controllo delle emissioni sia effettuato conformemente alle parti 6 e 7 dell'allegato VI.

2. L'installazione e il funzionamento dei sistemi di misurazione automatici sono sottoposti a controllo e test annuale di verifica come prescritto nell'allegato VI, parte 6, punto 1.

3. L'autorità competente stabilisce la localizzazione dei punti di campionamento o di misurazione da utilizzare per il controllo delle emissioni.

4. Tutti i risultati dei controlli sono registrati, elaborati e presentati in modo tale da consentire all'autorità competente di verificare l'osservanza delle condizioni di funzionamento e dei valori limite di emissione contenuti nell'autorizzazione.

5. Non appena siano disponibili nell'Unione tecniche di misurazione opportune, la Commissione, mediante atti delegati conformemente all'articolo 76 e fatte salve le condizioni stabilite dagli articoli 77 e 78, fissa la data a decorrere dalla quale devono essere effettuate le misurazioni in continuo relative alle emissioni nell'atmosfera di diossine, metalli pesanti e furani.

Articolo 49

Conformità ai valori limite di emissione

I valori limite di emissione per l'atmosfera e per l'acqua si considerano rispettati se sono rispettate le condizioni descritte nella parte 8 dell'allegato VI.

Articolo 50

Condizioni di esercizio

1. Gli impianti di incenerimento dei rifiuti sono gestiti in modo da raggiungere un livello di incenerimento tale che il tenore di carbonio organico totale delle scorie e delle ceneri pesanti sia inferiore al 3 % o la loro perdita per ignizione sia inferiore al 5 % del peso a secco del materiale. Se necessario sono utilizzate tecniche di pretrattamento dei rifiuti.

2. Gli impianti di incenerimento dei rifiuti sono progettati, costruiti, attrezzati e fatti funzionare in maniera che i gas prodotti dall'incenerimento o dal coincenerimento dei rifiuti siano portati, dopo l'ultima immissione di aria di combustione, in modo controllato e omogeneo persino nelle condizioni più sfavorevoli, a una temperatura di almeno 850 °C per almeno due secondi.

Gli impianti di coincenerimento dei rifiuti sono progettati, costruiti, attrezzati e fatti funzionare in maniera che i gas prodotti dal coincenerimento dei rifiuti siano portati, in modo controllato e omogeneo persino nelle condizioni più sfavorevoli, a una temperatura di almeno 850 °C per almeno due secondi.

Se sono inceneriti o coinceneriti rifiuti pericolosi contenenti oltre l'1 % di sostanze organiche alogenate, espresse in cloro, la temperatura necessaria per osservare il disposto del primo e del secondo comma è pari ad almeno 1 100 °C.

Negli impianti di incenerimento dei rifiuti, le temperature di cui al primo e al terzo comma sono misurate vicino alla parete interna della camera di combustione. L'autorità competente può autorizzare misurazioni effettuate presso un altro punto rappresentativo della camera di combustione.

3. Ciascuna camera di combustione di un impianto di incenerimento dei rifiuti è dotata di almeno un bruciatore di riserva che entra in funzione automaticamente non appena la temperatura dei gas di combustione, dopo l'ultima immissione di aria di combustione, scende al di sotto delle temperature di cui al paragrafo 2. Tale bruciatore è utilizzato anche nelle operazioni di avvio e di arresto dell'impianto per garantire che tali temperature siano sempre mantenute costanti durante tali operazioni e fintantoché vi siano rifiuti nella camera di combustione.

Il bruciatore di riserva non è alimentato con combustibili che provochino emissioni superiori a quelle derivanti dalla combustione di gasolio, quale definito all'articolo 2, punto 2, della direttiva 1999/32/CE del Consiglio, del 26 aprile 1999, relativa alla riduzione del tenore di zolfo di alcuni combustibili liquidi ([1]), di gas liquefatto o di gas naturale.

4. Gli impianti di incenerimento dei rifiuti e gli impianti di coincenerimento dei rifiuti fanno funzionare un sistema automatico per impedire l'introduzione di rifiuti nelle seguenti situazioni:

a) all'avvio, fino al raggiungimento della temperatura di cui al paragrafo 2 del presente articolo oppure la temperatura specificata ai sensi dell'articolo 51, paragrafo 1;

b) ogniqualvolta la temperatura scenda al di sotto della temperature di cui al paragrafo 2 del presente articolo oppure della temperatura specificata ai sensi dell'articolo 51, paragrafo 1;

c) ogniqualvolta le misurazioni in continuo indichino che uno qualsiasi dei valori limite di emissione è superato a causa del cattivo funzionamento o di un guasto dei dispositivi di depurazione degli scarichi gassosi.

5. Il calore generato dagli impianti di incenerimento dei rifiuti o dagli impianti di coincenerimento dei rifiuti è recuperato per quanto praticabile.

6. I rifiuti ospedalieri infetti sono introdotti direttamente nel forno, senza essere prima mescolati con altre categorie di rifiuti e senza manipolazione diretta.

7. Gli Stati membri provvedono affinché l'impianto di incenerimento dei rifiuti o l'impianto di coincenerimento dei rifiuti sia gestito e controllato da una persona fisica competente a gestire l'impianto.

([1]) GU L 121 dell'11.5.1999, pag. 13.

Articolo 51

Autorizzazione a modificare le condizioni di esercizio

1. Per determinate categorie di rifiuti o per determinati processi termici l'autorità competente può autorizzare l'applicazione di condizioni diverse da quelle di cui all'articolo 50, paragrafi 1, 2 e 3, nonché, per quanto riguarda la temperatura, di cui al paragrafo 4 di tale articolo, specificandole nell'autorizzazione, sempreché siano rispettate le altre prescrizioni del presente capo. Gli Stati membri possono definire le norme che disciplinano tali autorizzazioni.

2. Per gli impianti di incenerimento dei rifiuti la modifica delle condizioni di esercizio non dà luogo a una maggiore quantità di residui o a residui con un più elevato tenore di sostanze inquinanti organiche rispetto ai residui che si otterrebbero applicando le condizioni di cui all'articolo 50, paragrafi 1, 2 e 3.

3. Le emissioni di carbonio organico totale e monossido di carbonio degli impianti di coincenerimento dei rifiuti, autorizzati a modificare le condizioni di esercizio conformemente al paragrafo 1 rispettano inoltre i valori limite di emissione di cui alla parte 3 dell'allegato VI.

Le emissioni di monossido di carbonio organico totale dei bollitori per corteccia utilizzati nelle industrie della pasta di legno e della carta che coinceneriscono i rifiuti nel luogo di produzione che erano in funzione e avevano un'autorizzazione prima del 28 dicembre 2002, e che erano autorizzati a modificare le condizioni di esercizio conformemente al paragrafo 1, rispettano inoltre i valori limite di emissione di cui alla parte 3 dell'allegato VI.

4. Gli Stati membri comunicano alla Commissione tutte le condizioni di esercizio autorizzate ai sensi dei paragrafi 1, 2 e 3 e i risultati delle verifiche effettuate nell'ambito delle informazioni fornite in conformità dei previsti obblighi di relazione a norma dell'articolo 72.

Articolo 52

Consegna e ricezione dei rifiuti

1. Il gestore dell'impianto di incenerimento dei rifiuti o dell'impianto di coincenerimento dei rifiuti adotta tutte le precauzioni necessarie riguardo alla consegna e alla ricezione dei rifiuti per evitare o limitare per quanto praticabile l'inquinamento dell'aria, del suolo, delle acque superficiali e sotterranee nonché altri effetti negativi sull'ambiente, odori e rumore e i rischi diretti per la salute umana.

2. Prima dell'accettazione dei rifiuti nell'impianto di incenerimento dei rifiuti o nell'impianto di coincenerimento dei rifiuti, il gestore determina la massa di ciascun tipo di rifiuti, possibilmente in base all'elenco europeo dei rifiuti istituito dalla decisione 2000/532/CE.

3. Prima dell'accettazione dei rifiuti pericolosi nell'impianto di incenerimento dei rifiuti o nell'impianto di coincenerimento dei rifiuti, il gestore raccoglie informazioni sui rifiuti al fine di verificare l'osservanza dei requisiti previsti dall'autorizzazione e specificati all'articolo 45, paragrafo 2.

Tali informazioni comprendono quanto segue:

a) tutti i dati di carattere amministrativo sul processo produttivo contenuti nei documenti di cui al paragrafo 4, lettera a);

b) la composizione fisica e, se possibile, chimica dei rifiuti e tutte le altre informazioni necessarie per valutarne l'idoneità ai fini del previsto processo di incenerimento;

c) le caratteristiche di pericolosità dei rifiuti, le sostanze con le quali non possono essere mescolati e le precauzioni da adottare nella manipolazione dei rifiuti.

4. Prima dell'accettazione dei rifiuti pericolosi nell'impianto di incenerimento dei rifiuti o nell'impianto di coincenerimento dei rifiuti il gestore applica almeno le seguenti procedure:

a) controllo dei documenti prescritti dalla direttiva 2008/98/CE e, se del caso, di quelli prescritti dal regolamento (CE) n. 1013/2006 del Parlamento europeo e del Consiglio, del 14 giugno 2006, relativo alla spedizione di rifiuti [1] e dalla legislazione in materia di trasporto di merci pericolose;

b) prelievo di campioni rappresentativi, a meno che ciò non risulti inopportuno, per quanto possibile prima dello scarico, per verificarne mediante controlli la conformità alla descrizione di cui al paragrafo 3 e per consentire all'autorità competente di determinare la natura dei rifiuti trattati.

I campioni di cui alla lettera b) sono conservati per almeno un mese dopo l'incenerimento o il coincenerimento dei rifiuti in questione.

5. L'autorità competente può concedere deroghe ai paragrafi 2, 3 e 4 per gli impianti di incenerimento dei rifiuti o per gli impianti di coincenerimento dei rifiuti che sono parte di un'installazione di cui al capo II e inceneriscono o coinceneriscono esclusivamente i rifiuti prodotti all'interno di tale installazione.

Articolo 53

Residui

1. La quantità e la nocività dei residui sono ridotte al minimo. I residui sono riciclati, se del caso, direttamente nell'impianto o al di fuori di esso.

2. Il trasporto e lo stoccaggio intermedio dei residui secchi sotto forma di polveri sono effettuati in modo tale da evitare la dispersione nell'ambiente di tali residui.

3. Prima di determinare le modalità per lo smaltimento o il riciclaggio dei residui, sono effettuate opportune prove per stabilire le caratteristiche fisiche e chimiche, nonché il potenziale inquinante, dei residui. Tali prove concernono l'intera frazione solubile e la frazione solubile dei metalli pesanti.

Articolo 54

Modifica sostanziale

La modifica dell'attività di un impianto di incenerimento dei rifiuti o di un impianto di coincenerimento dei rifiuti che tratta esclusivamente rifiuti non pericolosi in un'installazione di cui al capo II che comporta l'incenerimento o il coincenerimento di rifiuti pericolosi è considerata sostanziale.

Articolo 55

Relazioni e informazioni al pubblico circa gli impianti di incenerimento dei rifiuti e gli impianti di coincenerimento dei rifiuti

1. Le domande di nuove autorizzazioni per impianti di incenerimento dei rifiuti e per impianti di coincenerimento dei rifiuti sono messi a disposizione del pubblico in uno o più luoghi per un periodo adeguato di tempo affinché il pubblico possa esprimere le proprie osservazioni sulle domande prima della decisione dell'autorità competente. La decisione, comprendente almeno una copia dell'autorizzazione e di qualsiasi suo successivo aggiornamento, è parimenti accessibile al pubblico.

2. Per gli impianti di incenerimento dei rifiuti o impianti di coincenerimento dei rifiuti aventi una capacità nominale di due o più Mg l'ora la relazione di cui all'articolo 72 contiene informazioni relative al funzionamento ed alla sorveglianza dell'impianto, illustra il funzionamento del processo di incenerimento e di coincenerimento e raffronta il livello delle emissioni nell'atmosfera e nell'acqua con i valori limite di emissione. Tali informazioni sono rese accessibili al pubblico.

3. L'autorità competente redige un elenco degli impianti di incenerimento dei rifiuti e degli impianti di coincenerimento dei rifiuti aventi una capacità nominale inferiore a due Mg l'ora, che è reso accessibile al pubblico.

CAPO V

DISPOSIZIONI PARTICOLARI PER INSTALLAZIONI ED ATTIVITÀ CHE UTILIZZANO SOLVENTI ORGANICI

Articolo 56

Ambito di applicazione

Il presente capo si applica alle attività elencate nell'allegato VII, parte 1, e, se del caso, che raggiungono le soglie di consumo di cui alla parte 2 del medesimo allegato.

[1] GU L 190 del 12.7.2006, pag. 1.

Articolo 57

Definizioni

Ai fini del presente capo, si intende per:

1) «installazione esistente», un'installazione in funzione al 29 marzo 1999 o che è stata autorizzata o registrata prima del 1° aprile 2001 o il cui gestore ha presentato una domanda completa di autorizzazione prima del 1° aprile 2001, a condizione che l'installazione sia stata messa in funzione entro il 1° aprile 2002;

2) «scarichi gassosi», gli effluenti gassosi finali contenenti composti organici volatili o altri inquinanti emessi nell'aria da un camino o da un dispositivo di abbattimento;

3) «emissioni diffuse», qualsiasi emissione nell'aria, nel suolo e nell'acqua, non contenuta negli scarichi gassosi di composti organici volatili nonché i solventi contenuti in qualsiasi prodotto, tranne se altrimenti indicato nella parte 2 dell'allegato VII;

4) «emissioni totali», la somma delle emissioni diffuse e delle emissioni negli scarichi gassosi;

5) «miscela», una miscela come definita all'articolo 3, paragrafo 2, del regolamento (CE) n. 1907/2006 del Parlamento europeo e del Consiglio, del 18 dicembre 2006, concernente la registrazione, la valutazione, l'autorizzazione e la restrizione delle sostanze chimiche (REACH) e che istituisce un'agenzia europea per le sostanze chimiche [1];

6) «adesivo», qualsiasi miscela, compresi tutti i solventi organici o le miscele contenenti solventi organici necessari per una corretta applicazione, usata per far aderire parti separate di un prodotto;

7) «inchiostro», una miscela, compresi tutti i solventi organici o le miscele contenenti i solventi organici necessari per una corretta applicazione, usata in un'attività di stampa per stampare testi o immagini su una superficie;

8) «vernice», un rivestimento trasparente;

9) «consumo», l'input totale di solventi organici utilizzato in un'installazione per anno civile ovvero qualsiasi altro periodo di dodici mesi, detratto qualsiasi composto organico volatile recuperato per riutilizzo;

10) «input», la quantità di solventi organici e la loro quantità nelle miscele utilizzate nello svolgimento di un'attività, inclusi i solventi riciclati all'interno e all'esterno dell'installazione, che vengono registrati ogniqualvolta vengano utilizzati per svolgere l'attività;

11) «riutilizzo», l'uso di solventi organici recuperati da un'installazione per qualsiasi scopo tecnico o commerciale, ivi compreso l'uso come combustibile, ad esclusione dello smaltimento definitivo, come rifiuti, dei solventi organici recuperati;

12) «condizioni di confinamento», le condizioni nelle quali un'installazione è gestita in maniera tale che i componenti organici volatili scaricati dall'attività sono raccolti ed evacuati in modo controllato mediante un camino o un dispositivo di abbattimento e non sono quindi completamente diffusi;

13) «operazioni di avviamento e di arresto», le operazioni, ad esclusione delle fasi regolari di oscillazione di un'attività, di messa in servizio, messa fuori servizio, interruzione di un'attività, di un elemento dell'impianto o di un serbatoio.

Articolo 58

Sostituzione delle sostanze pericolose

Le sostanze o le miscele a cui sono assegnate o che devono recare le indicazioni di pericolo H340, H350, H350i, H360D o H360F, a causa del loro tenore di composti organici volatili classificati come cancerogeni, mutageni o tossici per la riproduzione ai sensi del regolamento (CE) n. 1272/2008, sono sostituite, quanto prima e nei limiti del possibile, con sostanze o miscele meno nocive.

Articolo 59

Controllo delle emissioni

1. Gli Stati membri adottano le misure necessarie per assicurare che ogni installazione osservi quanto segue:

a) le emissioni di composti organici volatili da parte delle installazioni non superano i valori limite di emissione negli scarichi gassosi e i valori limite di emissione diffusa, o i valori limite di emissione totale, e gli altri requisiti indicati all'allegato VII, parti 2 e 3, sono soddisfatti;

b) i requisiti del piano di riduzione di cui all'allegato VII, parte 5, a condizione che sia ottenuta una riduzione equivalente delle emissioni rispetto a quella conseguita attraverso l'applicazione dei valori limite di emissione di cui alla lettera a).

Gli Stati membri riferiscono alla Commissione in merito ai progressi realizzati nel conseguimento di una riduzione equivalente delle emissioni di cui alla lettera b), a norma dell'articolo 72, paragrafo 1.

2. In deroga al paragrafo 1, lettera a), nel caso in cui il gestore dimostri all'autorità competente che per una singola installazione il valore limite di emissione delle emissioni diffuse non è tecnicamente ed economicamente fattibile, l'autorità competente può permettere che le emissioni superino tale valore limite di emissione, a condizione che ciò non comporti rischi per la salute umana o per l'ambiente e che il gestore dimostri all'autorità competente che sono utilizzate le migliori tecniche disponibili.

[1] GU L 396 del 30.12.2006, pag. 1.

3. In deroga al paragrafo 1, per le attività di rivestimento di cui all'allegato VII, parte 2, voce 8 della tabella, che non possono essere effettuate in condizioni di confinamento, l'autorità competente può permettere che le emissioni dell'installazione non rispettino le prescrizioni fissate in quel paragrafo, se il gestore dimostra all'autorità competente che tale osservanza non è tecnicamente ed economicamente fattibile e che sono utilizzate le migliori tecniche disponibili.

4. Gli Stati membri riferiscono alla Commissione in merito alle deroghe di cui ai paragrafi 2 e 3 del presente articolo a norma dell'articolo 72, paragrafo 2.

5. Le emissioni di composti organici volatili ai quali sono assegnate o sui quali devono essere apposte le indicazioni di pericolo H340, H350, H350i, H360D o H360F, ovvero di composti organici volatili alogenati ai quali sono assegnate o sui quali devono essere apposte le indicazioni di pericolo H341 o H351 sono controllate in condizioni di confinamento nella misura in cui ciò sia tecnicamente ed economicamente fattibile al fine di tutelare la salute umana e l'ambiente e non superano i pertinenti valori limite di emissione di cui all'allegato VII, parte 4.

6. Le installazioni adibite a due o più attività che individualmente superano le soglie di cui all'allegato VII, parte 2:

a) per le sostanze specificate nel paragrafo 5 soddisfano i requisiti di tale paragrafo per ciascuna attività;

b) per tutte le altre sostanze:

   i) soddisfano i requisiti di cui al paragrafo 1 per ciascuna attività; or

   ii) hanno emissioni totali di composti organici volatili che non superino quelle che si sarebbero avute applicando il disposto del punto i).

7. Sono adottate tutte le precauzioni opportune per ridurre al minimo le emissioni di composti organici volatili durante le operazioni di avviamento e di arresto.

Articolo 60

Controllo delle emissioni

Gli Stati membri, precisando le condizioni di autorizzazione o emanando disposizioni generali vincolanti, provvedono affinché le misure delle emissioni siano effettuate conformemente all'allegato VII, parte 6.

Articolo 61

Conformità ai valori limite di emissione

I valori limite di emissione per l'atmosfera sono considerati rispettati se si osservano le condizioni di cui all'allegato VII, parte 8.

Articolo 62

Relazione sulla conformità

Il gestore fornisce all'autorità competente, su richiesta, dati che consentono a quest'ultima di verificare il rispetto di uno dei seguenti elementi:

a) i valori limite di emissione negli scarichi gassosi, i valori limite di emissione diffusa e i valori limite di emissione totale;

b) i requisiti del piano di riduzione di cui all'allegato VII, parte 5;

c) le deroghe concesse conformemente all'articolo 59, paragrafi 2 e 3.

Ciò può includere un piano di gestione dei solventi preparato conformemente all'allegato VII, parte 7.

Articolo 63

Modifiche sostanziali alle installazioni esistenti

1. Una modifica al massimo input di un'installazione esistente riferito alla massa di solventi organici, espresso in media giornaliera, laddove l'installazione funzioni con il rendimento previsto in condizioni di esercizio diverse dalle operazioni di avviamento e di arresto e di manutenzione delle attrezzature, è considerata sostanziale se comporta un aumento delle emissioni di composti organici volatili superiore:

a) al 25 % per un'installazione che svolge attività che rientrano nella fascia di soglia più bassa dei punti 1, 3, 4, 5, 8, 10, 13, 16 o 17 della tabella dell'allegato VII, parte 2, oppure attività che rientrano in uno degli altri punti dell'allegato VII, parte 2, e che hanno un consumo di solventi inferiore a 10 Mg all'anno;

b) al 10 % per tutte le altre installazioni.

2. Se un'installazione esistente è sottoposta a modifica sostanziale oppure rientra nell'ambito di applicazione della presente direttiva per la prima volta a seguito di una modifica sostanziale, la parte dell'installazione oggetto della modifica sostanziale è trattata come una nuova installazione oppure come un'installazione esistente, purché le emissioni totali dell'intera installazione non superino quelle che si sarebbero ottenute se la parte oggetto della modifica sostanziale fosse stata trattata come una nuova installazione.

3. Nel caso di una modifica sostanziale l'autorità competente verifica la conformità dell'installazione alle prescrizioni della presente direttiva.

Articolo 64

Scambio di informazioni sulla sostituzione di solventi organici

La Commissione organizza lo scambio di informazioni con gli Stati membri, le imprese interessate e le organizzazioni non governative che promuovono la protezione ambientale sull'uso di solventi organici e i loro sostituti potenziali e sulle tecniche aventi il minore impatto potenziale sull'aria, sull'acqua, sul suolo, sugli ecosistemi e sulla salute umana.

I temi elencati in seguito sono oggetto dello scambio di informazioni:

a) idoneità all'uso;

b) possibili effetti sulla salute umana in generale e in particolare quelli derivanti dall'esposizione per motivi professionali;

c) effetti potenziali sull'ambiente;

d) conseguenze economiche, in particolare i costi e i vantaggi delle soluzioni disponibili.

Articolo 65

Accesso all'informazione

1. La decisione dell'autorità competente, comprendente almeno una copia dell'autorizzazione e di qualsiasi suo successivo aggiornamento, è messa a disposizione del pubblico.

Le regole generali vincolanti applicabili alle installazioni e l'elenco delle installazioni soggette ad autorizzazione e registrazione sono messe a disposizione del pubblico.

2. I risultati delle operazioni di controllo delle emissioni di cui all'articolo 60 e in possesso dell'autorità competente sono messi a disposizione del pubblico.

3. I paragrafi 1 e 2 del presente articolo si applicano fatte salve le restrizioni di cui all'articolo 4, paragrafi 1 e 2, della direttiva 2003/4/CE.

CAPO VI

DISPOSIZIONI PARTICOLARI PER LE INSTALLAZIONI CHE PRODUCONO BIOSSIDO DI TITANIO

Articolo 66

Ambito di applicazione

Il presente capo si applica alle installazioni che producono biossido di titanio.

Articolo 67

Divieto di scarico dei rifiuti

Gli Stati membri vietano lo scarico dei seguenti rifiuti in qualsiasi corpo d'acqua, in mare o nell'oceano:

a) rifiuti solidi;

b) le acque madri provenienti dalla fase di filtrazione successiva all'idrolisi della soluzione di solfato di titanile da installazioni che utilizzano il procedimento al solfato; compresi i rifiuti acidi associati a tali acque madri, contenenti complessivamente più dello 0,5 % di acido solforico libero nonché vari metalli pesanti e comprese le acque madri che sono state diluite fino a contenere lo 0,5 % o meno di acido solforico libero;

c) i rifiuti provenienti da installazioni che utilizzano il procedimento con cloruro, contenenti più dello 0,5 % di acido cloridrico, nonché vari metalli pesanti, compresi i rifiuti acidi che sono stati diluiti fino a contenere lo 0,5 % o meno di acido cloridrico libero;

d) i sali di filtrazione, i fanghi ed i rifiuti liquidi ottenuti dal trattamento (concentrazione o neutralizzazione) dei rifiuti di cui alle lettere b) e c) e contenenti vari metalli pesanti, esclusi i rifiuti neutralizzati e filtrati o decantati che contengono metalli pesanti solo in tracce e che, prima di qualsiasi diluizione, hanno un valore di pH superiore a 5,5.

Articolo 68

Controllo delle emissioni nell'acqua

Le emissioni delle installazioni nell'acqua non superano i valori limite di emissione di cui all'allegato VIII, parte 1.

Articolo 69

Prevenzione e controllo delle emissioni nell'atmosfera

1. Si previene l'emissione di acidi vescicolari dalle installazioni.

2. Le emissioni delle installazioni nell'atmosfera non superano i valori limite di emissione di cui all'allegato VIII, parte 2.

Articolo 70

Controllo delle emissioni

1. Gli Stati membri assicurano il controllo delle emissioni nell'acqua per permettere all'autorità competente di verificare il rispetto delle condizioni di autorizzazione e del disposto dell'articolo 68.

2. Gli Stati membri assicurano il controllo delle emissioni nell'atmosfera per permettere all'autorità competente di verificare il rispetto delle condizioni di autorizzazione e del disposto dell'articolo 69. Tale controllo comprende almeno il controllo delle emissioni di cui all'allegato VIII, parte 3.

3. Il controllo è effettuato conformemente alle norme CEN oppure, se non sono disponibili norme CEN, conformemente a norme ISO, nazionali o internazionali che assicurino dati equivalenti sotto il profilo della qualità scientifica.

CAPO VII

COMITATO, DISPOSIZIONI TRANSITORIE E FINALI

Articolo 71

Autorità competenti

Gli Stati membri designano le autorità competenti incaricate dell'adempimento dei compiti derivanti dalla presente direttiva.

Articolo 72

Relazioni presentate dagli Stati membri

1. Gli Stati membri provvedono affinché siano messe a disposizione della Commissione informazioni sull'attuazione della presente direttiva, sui dati rappresentativi circa le emissioni e altre forme di inquinamento, sui valori limite di emissione, sull'applicazione delle migliori tecniche disponibili conformemente agli articoli 14 e 15, in particolare sulla concessione di deroghe in conformità dell'articolo 15, paragrafo 4, e sui progressi compiuti nello sviluppo ed applicazione di tecniche emergenti ai sensi dell'articolo 27. Gli Stati membri rendono disponibili le informazioni in formato elettronico.

2. Il tipo, il formato e la frequenza delle informazioni che devono essere messe a disposizione a norma del paragrafo 1 sono stabiliti secondo la procedura di regolamentazione di cui all'articolo 75, paragrafo 2. Ciò comprende la determinazione delle attività e degli inquinanti specifici per i quali sono messi a disposizione i dati di cui al paragrafo 1.

3. Per tutti gli impianti di combustione contemplati dal capo III della presente direttiva gli Stati membri stabiliscono, a partire dal 1° gennaio 2016, un inventario annuale delle emissioni di ossido di zolfo, ossido di azoto e polveri e dell'apporto di energia.

Tenendo conto delle norme sul cumulo delle emissioni di cui all'articolo 29, l'autorità competente riceve i seguenti dati per ogni impianto di combustione:

a) la potenza termica nominale totale (in MW) dell'impianto di combustione;

b) il tipo di impianto di combustione: caldaia, turbina a gas, motore a gas, motore diesel, altro (specificandone il tipo);

c) la data di inizio del funzionamento dell'impianto di combustione;

d) le emissioni annue totali (in Mg l'anno) di ossido di zolfo, ossido di azoto e polveri (come totale di particelle in sospensione);

e) il numero di ore operative dell'impianto di combustione;

f) la quantità annua totale di apporto di energia, con riferimento al potere calorifico netto (in TJ l'anno), suddiviso nelle seguenti categorie di combustibile: carbone, lignite, biomassa, torba, altri combustibili solidi (specificandone il tipo), combustibili liquidi, gas naturale, altri gas (specificandone il tipo).

I dati annuali, impianto per l'impianto, contenuti in detti inventari sono messi a disposizione della Commissione su richiesta di quest'ultima.

Un sommario degli inventari è messo a disposizione della Commissione ogni tre anni, entro dodici mesi dalla fine del triennio considerato. Tale sommario mostra separatamente i dati relativi agli impianti di combustione interni a raffinerie.

La Commissione mette a disposizione degli Stati membri e del pubblico, conformemente alla direttiva 2003/4/CE, un sommario del raffronto e della valutazione di tali inventari entro ventiquattro mesi dalla fine del triennio considerato.

4. A partire dal 1° gennaio 2016, gli Stati membri comunicano annualmente alla Commissione i seguenti dati:

a) per gli impianti di combustione cui si applica l'articolo 31, il tenore di zolfo del combustibile solido indigeno usato e il grado di desolforazione raggiunto in media mensile. Per il primo anno di applicazione dell'articolo 31, viene comunicata anche la motivazione tecnica dell'impossibilità di rispettare i valori limite di emissione di cui all'articolo 30, paragrafi 2 e 3; e

b) per gli impianti di combustione che non sono in funzione per più di 1 500 ore operative annue calcolate in media mobile su un periodo di cinque anni, il numero di ore operative annue.

Articolo 73

Riesame

1. Entro il 7 gennaio 2016, e in seguito ogni tre anni, la Commissione presenta al Parlamento europeo e al Consiglio una relazione di riesame dell'attuazione della presente direttiva, redatta sulla base delle informazioni di cui all'articolo 72 corredandola di proposte legislative.

La relazione include una valutazione della necessità dell'intervento dell'Unione mediante la definizione o l'aggiornamento di requisiti minimi a livello di Unione per i valori limite di emissione e per le norme in materia di monitoraggio e conformità per le attività nell'ambito delle conclusioni sulle BAT adottate nel corso del triennio precedente, sulla base dei seguenti criteri:

a) l'impatto delle attività in questione sull'ambiente nel suo complesso; e

b) lo stato di applicazione delle migliori tecniche disponibili per le attività in questione.

Tale valutazione prende in considerazione il parere del forum di cui all'articolo 13, paragrafo 4.

Nel caso di grandi impianti di combustione il capo III e l'allegato V della presente direttiva sono considerati rappresentativi delle prescrizioni minime a livello di Unione.

La relazione è eventualmente corredata da una proposta legislativa. Ove la valutazione di cui al secondo comma individui una siffatta necessità, la proposta legislativa contiene disposizioni che definiscono o aggiornano requisiti minimi a livello di Unione per i valori limite di emissione e le norme in materia di monitoraggio e verifica della conformità per le attività in questione.

2. Entro il 31 dicembre 2012, la Commissione riesamina la necessità di controllare le emissioni derivanti:

a) dalla combustione dei carburanti nelle installazioni con una potenza termica nominale totale inferiore a 50 MW;

b) dall'allevamento intensivo di bovini; e

c) dallo spargimento di effluenti.

La Commissione riferisce i risultati di tale riesame al Parlamento europeo e al Consiglio corredandoli, se del caso, di una proposta legislativa.

3. Entro il 31 dicembre 2011 la Commissione riferisce al Parlamento europeo e al Consiglio in merito alla definizione nell'allegato I di:

a) valori soglia di capacità differenziati per l'allevamento di diverse specie di pollame, tra cui il caso specifico delle quaglie;

b) valori soglia di capacità per il simultaneo allevamento di diversi tipi di animali nella stessa installazione.

La Commissione riferisce i risultati di tale riesame al Parlamento europeo e al Consiglio corredandoli, se del caso, con una proposta legislativa.

Articolo 74

Modifiche degli allegati

Al fine di consentire l'adeguamento delle disposizioni della presente direttiva al progresso tecnico e scientifico sulla base delle migliori tecniche disponibili, la Commissione adotta atti delegati in conformità dell'articolo 76 e fatte salve le condizioni stabilite dagli articoli 77 e 78 per quanto riguarda l'adeguamento dell'allegato V, parti 3 e 4, dell'allegato VI, parti 2, 6, 7 e 8 e dell'allegato VII, parti 5, 6, 7 e 8, a tale progresso tecnico e scientifico.

Articolo 75

Procedura di comitato

1. La Commissione è assistita da un comitato.

2. Nei casi in cui è fatto riferimento al presente paragrafo, si applicano gli articoli 5 e 7 della decisione 1999/468/CE, tenendo conto delle disposizioni dell'articolo 8 della stessa.

Il termine stabilito dall'articolo 5, paragrafo 6, della decisione 1999/468/CE è fissato a tre mesi.

Articolo 76

Esercizio della delega

1. Il potere di adottare gli atti delegati di cui all'articolo 48, paragrafo 5, e all'articolo 74 è conferito alla Commissione per un periodo di cinque anni a decorrere dal 6 gennaio 2011. La Commissione redige una relazione sui poteri delegati al più tardi sei mesi prima della scadenza del periodo di cinque anni. La delega di potere è automaticamente prorogata per periodi di identica durata, tranne in caso di revoca da parte del Parlamento europeo o del Consiglio ai sensi dell'articolo 77.

2. Non appena adotta un atto delegato, la Commissione lo notifica simultaneamente al Parlamento europeo e al Consiglio.

3. Il potere conferito alla Commissione di adottare atti delegati è soggetto alle condizioni stabilite agli articoli 77 e 78.

Articolo 77

Revoca della delega

1. La delega all'articolo 48, paragrafo 5, e all'articolo 74 può essere revocata in qualsiasi momento dal Parlamento europeo o dal Consiglio.

2. L'istituzione che ha avviato una procedura interna per decidere l'eventuale revoca di una delega si adopera a informare l'altra istituzione e la Commissione entro un termine ragionevole prima di adottare una decisione definitiva, specificando il potere delegato che potrebbe essere oggetto di revoca e gli eventuali motivi della revoca.

3. La decisione di revoca pone fine alla delega del potere specificato nella decisione medesima. Gli effetti della decisione decorrono immediatamente o a una data successiva ivi precisata. La decisione di revoca non incide sulla validità degli atti delegati già in vigore. Essa è pubblicata nella *Gazzetta ufficiale dell'Unione europea*.

Articolo 78

Obiezioni agli atti delegati

1. Il Parlamento europeo e il Consiglio possono sollevare obiezioni a un atto delegato entro due mesi dalla data di notifica.

Su iniziativa del Parlamento europeo o del Consiglio, tale periodo è prorogato di due mesi.

2. Se allo scadere del periodo di cui al paragrafo 1 né il Parlamento europeo né il Consiglio hanno sollevato obiezioni all'atto delegato, quest'ultimo è pubblicato nella *Gazzetta ufficiale dell'Unione europea* ed entra in vigore alla data ivi fissata.

L'atto delegato può essere pubblicato nella *Gazzetta ufficiale dell'Unione europea* ed entrare in vigore prima della scadenza di tale termine se il Parlamento europeo e il Consiglio hanno entrambi informato la Commissione della loro intenzione di non sollevare obiezioni.

3. Se il Parlamento europeo o il Consiglio sollevano obiezioni all'atto delegato entro il termine di cui al paragrafo 1, l'atto delegato non entra in vigore. L'istituzione che solleva obiezioni all'atto delegato ne illustra le ragioni.

Articolo 79

Sanzioni

Gli Stati membri stabiliscono le sanzioni da irrogare in caso di violazione delle disposizioni nazionali adottate ai sensi della presente direttiva. Le sanzioni previste sono effettive, proporzionate e dissuasive. Gli Stati membri notificano tali disposizioni alla Commissione entro il 7 gennaio 2013 e la informano senza indugio di eventuali modifiche successive.

Articolo 80

Recepimento

1. Gli Stati membri adottano le disposizioni legislative, regolamentari ed amministrative necessarie per conformarsi all'articolo 2, all'articolo 3, punto 8, punti da 11 a 15, da 18 a 23, da 26 a 30, da 34 a 38 e punto 41, all'articolo 4, paragrafi 2 e 3, all'articolo 7, agli articoli 8 e 10, all'articolo 11, lettere e) e h), all'articolo 12, paragrafo 1, lettere e) e h), all'articolo 13, paragrafo 7, all'articolo 14, paragrafo 1, lettera c), punto ii), all'articolo 14, paragrafo 1, lettere d), e), f) e h), all'articolo 14, paragrafi 2 e 7, all'articolo 15, paragrafi da 2 a 5, agli articoli 16, 17 e 19, all'articolo 21, paragrafi da 2 a 5, agli articoli 22, 23, 24, 27, 28 e 29, all'articolo 30, paragrafi 1, 2, 3, 4, 7 e 8, agli articoli 31, 32, 33, 34, 35 e 36, 38 e 39, all'articolo 40, paragrafi 2 e 3, agli articoli 42 e 43, all'articolo 45, paragrafo 1, all'articolo 58, all'articolo 59, paragrafo 5, all'articolo 63, all'articolo 65, paragrafo 3, agli articoli 69, 70, 71, 72 e 79, e all'allegato I, primo comma, punti 1.1, 1.4, 2.5, lettera b), 3.1, 4, 5, 6.1, lettera c), 6.4, lettera b), 6.10 e 6.11, all'allegato II, all'allegato III, punto 12, all'allegato V, parte 1, lettera b), punti 2.2, 2.4, 3.1 e parte 4, punto 3.2, parte 6, punti 2.5 e 2.6 e all'allegato VI, parte 8, punto 1.1, lettera d), all'allegato VII, parte 4, punto 2, parte 5, punto 1, parte 7, punto 3, all'allegato VIII, parte 1, punti 1 e 2, lettera c), parte 2, punti 2 e 3, parte 3, entro il 7 gennaio 2013.

Essi applicano tali disposizioni a decorrere dalla medesima data.

Quando gli Stati membri adottano tali disposizioni, queste contengono un riferimento alla presente direttiva o sono corredate di un siffatto riferimento all'atto della pubblicazione ufficiale. Le modalità del riferimento sono decise dagli Stati membri.

2. Gli Stati membri comunicano alla Commissione il testo delle disposizioni essenziali di diritto interno che essi adottano nel settore disciplinato dalla presente direttiva.

Articolo 81

Abrogazione

1. Le direttive 78/176/CEE, 82/883/CEE, 92/112/CEE, 1999/13/CE, 2000/76/CE e 2008/1/CE, come modificate dagli atti elencati nell'allegato IX, parte A, sono abrogate con effetto dal 7 gennaio 2014, salvi gli obblighi degli Stati membri per quanto riguarda i termini di attuazione nel diritto nazionale e applicazione delle direttive figuranti nell'allegato IX, parte B.

2. La direttiva 2001/80/CE, come modificata dagli atti elencati nell'allegato IX, parte A, è abrogata con effetto dal 1° gennaio 2016, salvi gli obblighi degli Stati membri per quanto riguarda i termini di attuazione nel diritto nazionale e applicazione delle direttive di cui all'allegato IX, parte B.

3. I riferimenti alle direttive abrogate si intendono fatti alla presente direttiva e si leggono secondo la tavola di concordanza di cui all'allegato X.

Articolo 82

Disposizioni transitorie

1. Per quanto riguarda le installazioni che svolgono attività di cui all'allegato I, punto 1.1 per attività con potenza termica nominale totale superiore a 50 MW, punti 1.2 e 1.3, punto 1.4, lettera a), punti da 2.1 a 2.6, punti da 3.1 a 3.5, punti da 4.1 a 4.6 per attività relative a produzione mediante trasformazione chimica, punti 5.1 e 5.2 per attività contemplate dalla direttiva 2008/1/CE, punto 5.3, lettera a), punti i) e ii), punto 5.4, punto 6.1, lettere a) e b), punti 6.2 e 6.3, punto 6.4, lettera a), punto 6.4, lettera b) per attività contemplate dalla direttiva 2008/1/CE, punto 6.4, lettera c), e punti da 6.5 a 6.9 che sono in funzione o detengono un'autorizzazione prima del 7 gennaio 2013 oppure i cui gestori hanno presentato una domanda completa di autorizzazione prima di tale data, a condizione che tali installazioni siano messe in funzione entro un anno a decorrere dal 7 gennaio 2014, gli Stati membri applicano le disposizioni legislative, regolamentari e amministrative adottate conformemente all'articolo 80, paragrafo 1, a decorrere dal 7 gennaio 2014, fatta eccezione per il capo III e per l'allegato V.

2. Per quanto riguarda le installazioni che svolgono attività di cui all'allegato I, punto 1.1 per attività con potenza termica nominale totale di 50 MW, punto 1.4, lettera b), punti da 4.1 a 4.6 per attività relative a produzione mediante trasformazione biologica, punti 5.1 e 5.2 per attività non contemplate dalla direttiva 2008/1/CE, punto 5.3, lettera a), punti da iii) a v), punto 5.3, lettera b), punti 5.5 e 5.6, punto 6.1, lettera c), punto 6.4, lettera b), per attività non contemplate dalla direttiva 2008/1/CE e punti 6.10 e 6.11 che sono in funzione prima del 7 gennaio 2013 gli Stati membri applicano le disposizioni legislative, regolamentari e amministrative adottate conformemente alla presente direttiva a decorrere dal 7 luglio 2015, ad eccezione dei capi III e IV e degli allegati V e VI.

3. Per quanto riguarda gli impianti di combustione di cui all'articolo 30, paragrafo 2, a partire dal 1° gennaio 2016 gli Stati membri applicano le disposizioni legislative, regolamentari e amministrative adottate conformemente all'articolo 80, paragrafo 1, per ottemperare al capo III e all'allegato V.

4. Per quanto riguarda gli impianti di combustione di cui all'articolo 30, paragrafo 3, gli Stati membri cessano di applicare la direttiva 2001/80/CE a decorrere dal 7 gennaio 2013.

5. Per quanto riguarda gli impianti di combustione per il coincenerimento dei rifiuti, l'allegato VI, parte 4, punto 3.1, si applica fino al:

a) 31 dicembre 2015, per gli impianti di combustione di cui all'articolo 30, paragrafo 2;

b) 7 gennaio 2013, per gli impianti di combustione di cui all'articolo 30, paragrafo 3.

6. L'allegato VI, parte 4, punto 3.2, si applica agli impianti di combustione per il coincenerimento dei rifiuti a decorrere dal:

a) 1° gennaio 2016, per gli impianti di combustione di cui all'articolo 30, paragrafo 2;

b) 7 gennaio 2013, per gli impianti di combustione di cui all'articolo 30, paragrafo 3.

7. L'articolo 58 si applica a decorrere dal 1° giugno 2015. Fino a tale data le sostanze o le miscele alle quali sono assegnate o sulle quali devono essere apposte le indicazioni di pericolo H340, H350, H350i, H360D o H360F oppure le frasi di rischio R45, R46, R49, R60 o R61 a causa del loro tenore di composti organici volatili classificati come cancerogeni, mutageni o tossici per la riproduzione ai sensi del regolamento (CE) n. 1272/2008 sono sostituite, quanto prima e nei limite del possibile, con sostanze o miscele meno nocive.

8. L'articolo 59, paragrafo 5, si applica a decorrere dal 1° giugno 2015. Fino a tale data le emissioni di composti organici volatili ai quali sono assegnate o sui quali devono essere apposte le indicazioni di pericolo H340, H350, H350i, H360D o H360F oppure le frasi di rischio R45, R46, R49, R60 o R61 ovvero di composti organici volatili alogenati ai quali sono assegnate o sui quali devono essere apposte le indicazioni di pericolo H341 o H351 oppure le frasi di rischio R40 o R68 sono controllate in condizioni di confinamento nella misura in cui ciò sia tecnicamente ed economicamente fattibile al fine di tutelare la salute umana e l'ambiente e non superano i pertinenti valori limite di emissione di cui all'allegato VII, parte 4.

9. L'allegato VII, parte 4, punto 2, si applica a decorrere dal 1° giugno 2015. Fino a tale data per le emissioni dei composti organici volatili alogenati ai quali cui sono assegnate o sui quali devono essere apposte le indicazioni di pericolo H341 o H351 oppure le frasi di rischio R40 o R68, vale a dire emissioni in cui il flusso di massa della somma dei composti che comportano le indicazioni di pericolo H341 o H351 o l'etichettatura R40 o R68 è uguale o superiore a 100 g/h, è rispettato un valore limite di emissione di 20 mg/Nm^3. Il valore limite di emissione si riferisce alla somma di massa dei singoli composti.

Articolo 83

Entrata in vigore

La presente direttiva entra in vigore il ventesimo giorno successivo alla pubblicazione nella *Gazzetta ufficiale dell'Unione europea*.

Articolo 84

Destinatari

Gli Stati membri sono destinatari della presente direttiva.

Fatto a Strasburgo, il 24 novembre 2010.

Per il Parlamento europeo	*Per il Consiglio*
Il presidente	*Il presidente*
J. BUZEK	O. CHASTEL

ALLEGATO I

Categorie di attività di cui all'articolo 10

I valori soglia di seguito riportati si riferiscono generalmente alla capacità di produzione o alla resa. Qualora varie attività elencate nella medesima descrizione delle attività contenente una soglia siano gestite in una stessa installazione, si sommano le capacità di tali attività. Per le attività di gestione dei rifiuti, tale calcolo si applica al livello delle attività 5.1 e 5.3, lettere a) e b).

La Commissione stabilisce linee guida riguardanti:

a) il rapporto tra le attività di gestione dei rifiuti descritte nel presente allegato e quelle descritte negli allegati I e II della direttiva 2008/98/CE; e

b) l'interpretazione del termine «scala industriale» in riferimento alle attività dell'industria chimica descritte nel presente allegato.

1. Attività energetiche

1.1. Combustione di combustibili in installazione con una potenza termica nominale totale pari o superiore a 50 MW

1.2. Raffinazione di petrolio e di gas

1.3. produzione di coke

1.4. Gassificazione o liquefazione di:

a) carbone;

b) altri combustibili in installazioni con una potenza termica nominale totale pari o superiore a 20 MW.

2. Produzione e trasformazione dei metalli

2.1. Arrostimento o sinterizzazione di minerali metallici compresi i minerali solforati

2.2. Produzione di ghisa o acciaio (fusione primaria o secondaria), compresa la relativa colata continua di capacità superiore a 2,5 Mg all'ora

2.3. Trasformazione di metalli ferrosi mediante:

a) attività di laminazione a caldo con una capacità superiore a 20 Mg di acciaio grezzo all'ora;

b) attività di forgiatura con magli la cui energia di impatto supera 50 kJ per maglio e allorché la potenza calorifica è superiore a 20 MW;

c) applicazione di strati protettivi di metallo fuso con una capacità di trattamento superiore a 2 Mg di acciaio grezzo all'ora.

2.4. Funzionamento di fonderie di metalli ferrosi con una capacità di produzione superiore a 20 Mg al giorno.

2.5. Lavorazione di metalli non ferrosi:

a) produzione di metalli grezzi non ferrosi da minerali, nonché concentrati o materie prime secondarie attraverso procedimenti metallurgici, chimici o elettrolitici;

b) fusione e lega di metalli non ferrosi, compresi i prodotti di recupero e funzionamento di fonderie di metalli non ferrosi, con una capacità di fusione superiore a 4 Mg al giorno per il piombo e il cadmio o a 20 Mg al giorno per tutti gli altri metalli;

2.6. Trattamento di superficie di metalli o materie plastiche mediante processi elettrolitici o chimici qualora le vasche destinate al trattamento utilizzate abbiano un volume superiore a 30 m^3.

3. Industria dei prodotti minerali

3.1. Produzione di cemento, calce viva e ossido di magnesio

a) Produzione di clinker (cemento) in forni rotativi la cui capacità di produzione supera 500 Mg al giorno oppure altri forni aventi una capacità di produzione di oltre 50 Mg al giorno;

b) produzione di calce viva in forni aventi una capacità di produzione di oltre 50 Mg al giorno;

c) produzione di ossido di magnesio in forni aventi una capacità di produzione di oltre 50 Mg al giorno.

3.2. Produzione di amianto o alla fabbricazione di prodotti dell'amianto

3.3. Fabbricazione del vetro compresi quelli destinati alla produzione di fibre di vetro, con capacità di fusione di oltre 20 Mg al giorno

3.4. Fusione di sostanze minerali compresi quelli destinati alla produzione di fibre minerali, con una capacità di fusione di oltre 20 Mg al giorno

3.5. Fabbricazione di prodotti ceramici mediante cottura, in particolare tegole, mattoni, mattoni refrattari, piastrelle, gres o porcellane con una capacità di produzione di oltre 75 Mg al giorno e/o con una capacità di forno superiore a 4 m^3 e con una densità di carica per forno superiore a 300 kg/m^3.

4. Industria chimica

nell'ambito delle categorie di attività di cui alla presente sezione, si intende per produzione la produzione su scala industriale mediante trasformazione chimica o biologica delle sostanze o dei gruppi di sostanze di cui ai punti da 4.1 a 4.6.

4.1. Fabbricazione di prodotti chimici organici, e in particolare:

a) idrocarburi semplici (lineari o anulari, saturi o insaturi, alifatici o aromatici);

b) idrocarburi ossigenati, segnatamente alcoli, aldeidi, chetoni, acidi carbossilici, esteri e miscele di esteri, acetati, eteri, perossidi e resine epossidiche;

c) idrocarburi solforati;

d) idrocarburi azotati, segnatamente amine, amidi, composti nitrosi, nitrati o nitrici, nitrili, cianati, isocianati;

e) idrocarburi fosforosi;

f) idrocarburi alogenati;

g) composti organometallici;

h) materie plastiche (polimeri, fibre sintetiche, fibre a base di cellulosa);

i) gomme sintetiche;

j) sostanze coloranti e pigmenti;

k) tensioattivi e agenti di superficie.

4.2. Fabbricazione di prodotti chimici inorganici, e in particolare:

a) gas, quali ammoniaca, cloro o cloruro di idrogeno, fluoro e fluoruro di idrogeno, ossidi di carbonio, composti di zolfo, ossidi di azoto, idrogeno, biossido di zolfo, bicloruro di carbonile;

b) acidi, quali acido cromico, acido fluoridrico, acido fosforico, acido nitrico, acido cloridrico, acido solforico, oleum e acidi solforati;

c) basi, quali idrossido d'ammonio, idrossido di potassio, idrossido di sodio;

d) sali, quali cloruro d'ammonio, clorato di potassio, carbonato di potassio, carbonato di sodio, perborato, nitrato d'argento;

e) metalloidi, ossidi metallici o altri composti inorganici, quali carburo di calcio, silicio, carburo di silicio.

4.3. Fabbricazione di fertilizzanti a base di fosforo, azoto o potassio (fertilizzanti semplici o composti)

4.4. Fabbricazione di prodotti fitosanitari o di biocidi

4.5. Fabbricazione di prodotti farmaceutici compresi i prodotti intermedi

4.6. Fabbricazione di esplosivi

5. Gestione dei rifiuti

5.1. Lo smaltimento o il recupero di rifiuti pericolosi, con capacità di oltre 10 Mg al giorno, che comportano il ricorso ad una o più delle seguenti attività:

a) trattamento biologico;

b) trattamento fisico-chimico;

c) dosaggio o miscelatura prima di una delle altre attività di cui ai punti 5.1 e 5.2;

d) ricondizionamento prima di una delle altre attività di cui ai punti 5.1 e 5.2;

e) rigenerazione/recupero dei solventi;

f) rigenerazione/recupero di sostanze inorganiche diverse dai metalli o dai composti metallici;

g) rigenerazione degli acidi o delle basi;

h) recupero dei prodotti che servono a captare le sostanze inquinanti;

i) recupero dei prodotti provenienti dai catalizzatori;

j) rigenerazione o altri reimpieghi degli oli;

k) lagunaggio.

5.2. Smaltimento o recupero dei rifiuti in impianti di incenerimento dei rifiuti o in impianti di coincenerimento dei rifiuti:

a) per i rifiuti non pericolosi con una capacità superiore a 3 Mg all'ora;

b) per i rifiuti pericolosi con una capacità superiore a 10 Mg al giorno.

5.3. a) Lo smaltimento dei rifiuti non pericolosi, con capacità superiore a 50 Mg al giorno, che comporta il ricorso ad una o più delle seguenti attività ed escluse le attività contemplate dalla direttiva 91/271/CEE del Consiglio, del 21 maggio 1991, concernente il trattamento delle acque reflue urbane [1]:

i) trattamento biologico;

ii) trattamento fisico-chimico;

iii) pretrattamento dei rifiuti destinati all'incenerimento o al coincenerimento;

iv) trattamento di scorie e ceneri;

v) trattamento nelle trinciatrici di rifiuti metallici, compresi i rifiuti di apparecchiature elettriche ed elettroniche e i veicoli fuori uso e relativi componenti.

[1] GU L 135 del 30.5.1991, pag. 40.

b) Il recupero, o una combinazione di recupero e smaltimento, di rifiuti non pericolosi, con una capacità superiore a 75 Mg al giorno, che comportano il ricorso ad una o più delle seguenti attività ed escluse le attività contemplate dalla direttiva 91/271/CEE:

i) trattamento biologico;

ii) pretrattamento dei rifiuti destinati all'incenerimento o al coincenerimento;

iii) trattamento di scorie e ceneri;

iv) trattamento nelle trinciatrici di rifiuti metallici, compresi i rifiuti di apparecchiature elettriche ed elettroniche e i veicoli fuori uso e relativi componenti.

Qualora l'attività di trattamento dei rifiuti consista unicamente nella digestione anaerobica, la soglia di capacità di siffatta attività è fissata a 100 Mg al giorno.

5.4. Discariche, quali definite all'articolo 2, lettera g), della direttiva 1999/31/CE del Consiglio, del 26 aprile 1999, relativa alle discariche di rifiuti [1], che ricevono più di 10 Mg di rifiuti al giorno o con una capacità totale di oltre 25 000 Mg, ad esclusione delle discariche per i rifiuti inerti.

5.5. Deposito temporaneo di rifiuti pericolosi non contemplati al punto 5.4 prima di una delle attività elencate ai punti 5.1, 5.2, 5.4 e 5.6 con una capacità totale superiore a 50 Mg, eccetto il deposito temporaneo, prima della raccolta, nel luogo in cui sono generati i rifiuti.

5.6. Deposito sotterraneo di rifiuti pericolosi con una capacità totale superiore a 50 Mg.

6. Altre attività

6.1. Fabbricazione in installazioni industriali di:

a) pasta per carta a partire dal legno o da altre materie fibrose;

b) carta o cartoni con capacità di produzione superiore a 20 Mg al giorno;

c) uno o più dei seguenti pannelli a base di legno: pannelli a fibre orientate (pannelli OSB), pannelli truciolari o pannelli di fibre, con una capacità di produzione superiore a 600 m^3 al giorno.

6.2. Pretrattamento (operazioni di lavaggio, imbianchimento, mercerizzazione) o tintura di fibre tessili o di tessili la cui capacità di trattamento supera le 10 Mg al giorno

6.3. Concia delle pelli qualora la capacità di trattamento superi le 12 Mg al giorno di prodotto finito

6.4. a) Funzionamento di macelli aventi una capacità di produzione di carcasse di oltre 50 Mg al giorno;

b) Trattamento e trasformazione, diversi dal semplice imballo, delle seguenti materie prime, sia trasformate in precedenza sia non trasformate destinate alla fabbricazione di prodotti alimentari o mangimi da:

i) solo materie prime animali (diverse dal semplice latte) con una capacità di produzione di prodotti finiti di oltre 75 Mg al giorno;

ii) solo materie prime vegetali con una capacità di produzione di prodotti finiti di oltre 300 Mg al giorno o 600 Mg al giorno se l'installazione è in funzione per un periodo non superiore a 90 giorni consecutivi all'anno;

iii) materie prime animali e vegetali, sia in prodotti combinati che separati, con una capacità di produzione di prodotti finiti in Mg al giorno superiore a;

— 75 se A è pari o superiore a 10; oppure

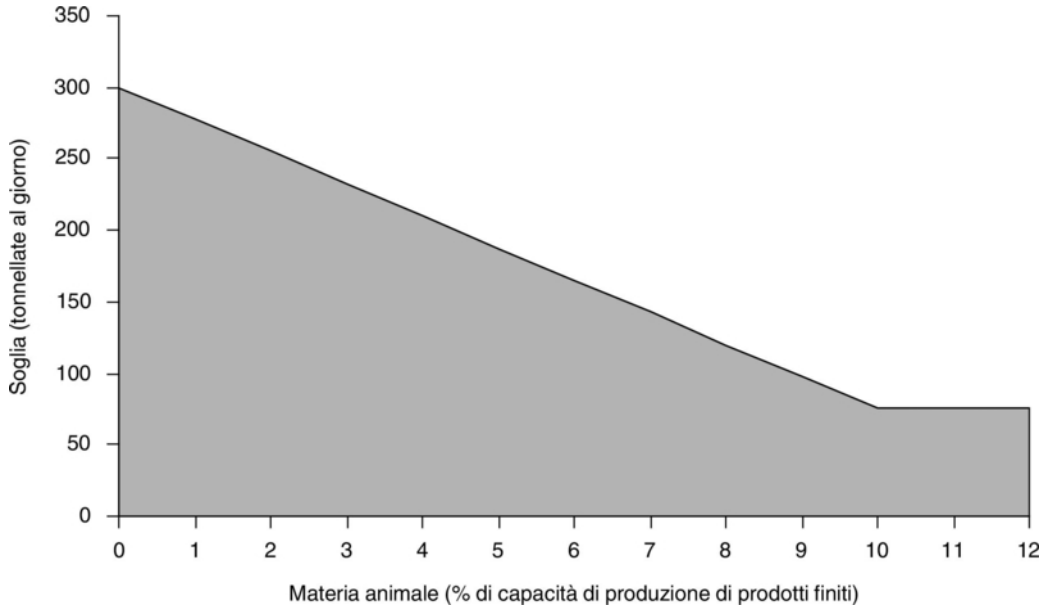
— [300 - (22,5 × A)] in tutti gli altri casi

dove «A» è la percentuale (%) in peso di materia animale della capacità di produzione di prodotti finiti.

L'imballaggio non è compreso nel peso finale del prodotto.

[1] GU L 182 del 16.7.1999, pag. 1.

La presente sottosezione non si applica nel caso in cui la materia prima sia esclusivamente il latte.



c) Trattamento e trasformazione esclusivamente del latte, con un quantitativo di latte ricevuto di oltre 200 Mg al giorno (valore medio su base annua)

6.5. Lo smaltimento o il riciclaggio di carcasse o di residui di animali con una capacità di trattamento di oltre 10 Mg al giorno.

6.6. Allevamento intensivo di pollame o di suini:

a) con più di 40 000 posti pollame;

b) con più di 2 000 posti suini da produzione (di oltre 30 kg); o

c) con più di 750 posti scrofe.

6.7. Trattamento di superficie di materie, oggetti o prodotti utilizzando solventi organici, in particolare per apprettare, stampare, spalmare, sgrassare, impermeabilizzare, incollare, verniciare, pulire o impregnare, con una capacità di consumo di solventi organici superiore a 150 kg all'ora o a 200 Mg all'anno.

6.8. Fabbricazione di carbonio (carbone duro) o grafite per uso elettrico mediante combustione o grafitizzazione.

6.9. Cattura di flussi di CO_2 provenienti da installazioni che rientrano nella presente direttiva ai fini dello stoccaggio geologico in conformità alla direttiva 2009/31/CE.

6.10. Conservazione del legno e dei prodotti in legno con prodotti chimici con una capacità di produzione superiore a 75 m^3 al giorno eccetto il trattamento esclusivamente contro l'azzurratura.

6.11. Trattamento a gestione indipendente di acque reflue non coperto dalla direttiva 91/271/CEE ed evacuate da un'installazione di cui al capo II.

ALLEGATO II

Elenco delle sostanze inquinanti

ARIA

1. Ossidi di zolfo e altri composti dello zolfo
2. Ossidi di azoto e altri composti dell'azoto
3. Monossido di carbonio
4. Composti organici volatili
5. Metalli e relativi composti
6. Polveri comprese le particelle sottili
7. Amianto (particelle in sospensione e fibre)
8. Cloro e suoi composti
9. Fluoro e suoi composti
10. Arsenico e suoi composti
11. Cianuri
12. Sostanze e miscele di cui sono comprovate proprietà cancerogene, mutagene o tali da poter influire sulla riproduzione quando sono immessi nell'atmosfera
13. Poli-cloro-dibenzo-diossina (PCDD) e poli-cloro-dibenzo-furani (PCDF)

ACQUA

1. Composti organoalogenati e sostanze che possono dar loro origine nell'ambiente idrico
2. Composti organofosforici
3. Composti organici dello stagno
4. Sostanze e miscele di cui sono comprovate proprietà cancerogene, mutagene o tali da poter influire sulla riproduzione in ambiente idrico o con il concorso dello stesso
5. Idrocarburi persistenti e sostanze organiche tossiche persistenti e bioaccumulabili
6. Cianuri
7. Metalli e loro composti
8. Arsenico e suoi composti
9. Biocidi e prodotti fitosanitari
10. Materie in sospensione
11. Sostanze che contribuiscono all'eutrofizzazione (nitrati e fosfati, in particolare)
12. Sostanze che esercitano un'influenza sfavorevole sul bilancio di ossigeno (misurabili con parametri quali DBO, DCO)
13. Sostanze di cui all'allegato X della direttiva 2000/60/CE.

ALLEGATO III

Criteri per la determinazione delle migliori tecniche disponibili

1. Impiego di tecniche a scarsa produzione di rifiuti;
2. impiego di sostanze meno pericolose;
3. sviluppo di tecniche per il ricupero e il riciclo delle sostanze emesse e usate nel processo, e, ove opportuno, dei rifiuti;
4. processi, sistemi o metodi operativi comparabili, sperimentati con successo su scala industriale;
5. progressi in campo tecnico e evoluzione delle conoscenze in campo scientifico;
6. natura, effetti e volume delle emissioni in questione;
7. date di messa in funzione delle installazioni nuove o esistenti;
8. tempo necessario per utilizzare una migliore tecnica disponibile;
9. consumo e natura delle materie prime, ivi compresa l'acqua, usate nel processo e efficienza energetica;
10. necessità di prevenire o di ridurre al minimo l'impatto globale sull'ambiente delle emissioni e dei rischi;
11. necessità di prevenire gli incidenti e di ridurne le conseguenze per l'ambiente;
12. informazioni pubblicate da organizzazioni internazionali pubbliche.

ALLEGATO IV

Partecipazione del pubblico alle decisioni

1. Il pubblico è informato (attraverso pubblici avvisi oppure in altra forma adeguata quali mezzi di comunicazione elettronici, se disponibili) in una fase precoce della procedura di adozione di una decisione o, al più tardi, non appena sia ragionevolmente possibile fornire le informazioni, sui seguenti aspetti:

   a) la domanda di autorizzazione o, secondo il caso, la proposta di aggiornamento di un'autorizzazione o delle condizioni di autorizzazione ai sensi dell'articolo 21, compresa la descrizione degli elementi di cui all'articolo 12, paragrafo 1;

   b) eventualmente, il fatto che la decisione sia soggetta ad una procedura di valutazione dell'impatto ambientale nazionale o transfrontaliera o alle consultazioni tra Stati membri ai sensi dell'articolo 26;

   c) informazioni sulle autorità competenti responsabili dell'adozione della decisione, quelle da cui possono essere ottenute informazioni in oggetto, quelle cui possono essere presentati osservazioni o quesiti, nonché indicazioni sui termini per la trasmissione di osservazioni o quesiti;

   d) la natura delle possibili decisioni o l'eventuale progetto di decisione;

   e) le eventuali informazioni riguardanti una proposta di aggiornamento di un'autorizzazione o delle condizioni di autorizzazione;

   f) l'indicazione dei tempi e dei luoghi in cui possono essere ottenute le informazioni e le modalità alle quali esse sono rese disponibili;

   g) le modalità precise della partecipazione e della consultazione del pubblico ai sensi del paragrafo 5.

2. Gli Stati membri provvedono affinché, entro scadenze ragionevoli, il pubblico interessato abbia accesso:

   a) conformemente alla normativa nazionale, ai principali rapporti e consulenze pervenuti alla o alle autorità competenti nel momento in cui il pubblico interessato è informato conformemente al paragrafo 1;

   b) conformemente alla direttiva 2003/4/CE, alle informazioni diverse da quelle previste al paragrafo 1 che sono pertinenti ai fini della decisione di cui all'articolo 5 della presente direttiva e che sono disponibili soltanto dopo che il pubblico interessato è stato informato conformemente al paragrafo 1.

3. Il pubblico interessato ha il diritto di presentare osservazioni e di esprimere pareri all'autorità competente prima che sia adottata una decisione.

4. I risultati delle consultazioni condotte ai sensi del presente allegato devono essere presi adeguatamente in considerazione al momento della decisione.

5. Gli Stati membri stabiliscono le modalità precise di informazione del pubblico (ad esempio mediante affissione entro una certa area o mediante pubblicazione nei giornali locali) e di consultazione del pubblico interessato (ad esempio per iscritto o tramite indagine pubblica). Sono fissate scadenze adeguate per le varie fasi, che concedano un tempo sufficiente per informare il pubblico nonché per consentire al pubblico interessato di prepararsi e di partecipare efficacemente al processo decisionale in materia ambientale ai sensi del presente allegato.

ALLEGATO V

Disposizioni tecniche per gli impianti di combustione

PARTE 1

Valori limite per gli impianti di combustione di cui all'articolo 30, paragrafo 2

1. Tutti i valori limite di emissione sono calcolati a una temperatura di 273,15 K, a una pressione di 101,3 kPa e previa detrazione del tenore di vapore acqueo degli scarichi gassosi e a un tenore standard di O_2 pari al 6 % per i combustibili solidi, al 3 % per gli impianti di combustione, diversi dalle turbine a gas e dai motori a gas, che utilizzano combustibili liquidi e gassosi e al 15 % per le turbine a gas e per i motori a gas.

2. Valori limite di emissione (mg/Nm^3) per SO_2 per gli impianti di combustione alimentati a combustibile solido o liquido ad eccezione delle turbine a gas e dei motori a gas

Potenza termica nominale totale (MWth)	Carbone e lignite e altri combustibili solidi	Biomassa	Torba	Combustibili liquidi
50-100	400	200	300	350
100-300	250	200	300	250
> 300	200	200	200	200

Gli impianti di combustione alimentati a combustibile solido che hanno ottenuto un'autorizzazione anteriormente al 27 novembre 2002, o i cui gestori hanno presentato una domanda completa di autorizzazione prima di tale data, a condizione che l'impianto sia stato messo in funzione entro il 27 novembre 2003, e che non sono in funzione per più di 1 500 ore operative annue, calcolate in media mobile su un periodo di cinque anni, sono soggetti a un valore limite di emissione di anidride solforosa pari a 800 mg/Nm^3.

Gli impianti di combustione alimentati a combustibile liquido che hanno ottenuto un'autorizzazione anteriormente al 27 novembre 2002, o i cui gestori hanno presentato una domanda completa di autorizzazione prima di tale data, a condizione che l'impianto sia stato messo in funzione entro il 27 novembre 2003, e che non sono in funzione per più di 1 500 ore operative annue calcolate in media mobile su un periodo di cinque anni, sono soggetti a un valore limite di emissione di SO_2 pari a 850 mg/Nm^3 nel caso degli impianti con potenza termica nominale totale non superiore a 300 MWth e pari a 400 mg/Nm^3 nel caso degli impianti con potenza termica nominale totale superiore a 300 MWth.

Una parte di un impianto di combustione che disperde il suo scarico gassoso attraverso una o più canne di scarico separate in un camino comune e che non è in funzione per più di 1 500 ore operative annue calcolate in media mobile su un periodo di cinque anni, può essere soggetta ai valori limite di emissione di cui ai due paragrafi precedenti in funzione della potenza termica nominale totale dell'intero impianto di combustione. In tali casi, le emissioni attraverso ciascuna di tali canne di scarico sono controllate separatamente.

3. Valori limite di emissione (in mg/Nm^3) di SO_2 per gli impianti di combustione alimentati a combustibile gassoso ad eccezione delle turbine a gas e dei motori a gas.

In generale	35
Gas liquido	5
Gas a basso potere calorifico originati da forni a coke	400
Gas a basso potere calorifico originati da altiforni	200

Gli impianti di combustione alimentati con gas a basso potere calorifico originati dalla gassificazione dei residui delle raffinerie che hanno ottenuto un'autorizzazione anteriormente al 27 novembre 2002 o per i quali i gestori hanno presentato una domanda completa di autorizzazione prima di tale data, a condizione che l'impianto sia stato messo in funzione entro il 27 novembre 2003, sono soggetti a un valore limite di emissione di SO_2 pari a 800 mg/Nm^3.

4. Valori limite di emissione di NO_x espressi in mg/Nm^3 per gli impianti di combustione alimentati con combustibili solidi o liquidi ad eccezione delle turbine a gas e dei motori a gas

Potenza termica nominale totale (MWth)	Carbone e lignite e altri combustibili solidi	Biomassa e torba	Combustibili liquidi
50-100	300 450 in caso di combustione di lignite polverizzata	300	450
100-300	200	250	200 (1)
> 300	200	200	150 (1)

Nota:

(1) Il valore limite di emissione è pari a 450 mg/Nm^3 per la combustione di residui di distillazione e di conversione della raffinazione del petrolio greggio per il loro proprio consumo negli impianti di combustione con una potenza termica nominale totale non superiore a 500 MWth e che hanno ottenuto un'autorizzazione anteriormente al 27 novembre 2002 o per i quali i gestori hanno presentato una domanda completa di autorizzazione prima di tale data, a condizione che l'impianto sia stato messo in funzione entro il 27 novembre 2003.

Gli impianti di combustione all'interno di installazioni chimiche alimentate con residui liquidi di produzione quale combustibile non commerciale per il loro proprio consumo, con una potenza termica nominale totale non superiore a 500 MWth e che hanno ottenuto un'autorizzazione anteriormente al 27 novembre 2002, o per i quali i gestori hanno presentato una domanda completa di autorizzazione prima di tale data, a condizione che l'impianto sia stato messo in funzione entro il 27 novembre 2003, sono soggetti a un valore limite di emissione di NO_x pari a 450 mg/Nm^3.

Gli impianti di combustione alimentati a combustibile solido o liquido con potenza termica nominale totale non superiore a 500 MW th che hanno ottenuto un'autorizzazione anteriormente al 27 novembre 2002, o i cui gestori hanno presentato una domanda completa di autorizzazione prima di tale data, a condizione che l'impianto sia stato messo in funzione entro il 27 novembre 2003, e che non sono in funzione per più di 1 500 ore operative all'anno, calcolate in media mobile su un periodo di cinque anni, sono soggetti a un valore limite di emissione di NO_x pari a 450 mg/Nm^3.

Gli impianti di combustione con potenza termica nominale totale superiore a 500 MW th alimentati a combustibile solido che hanno ottenuto un'autorizzazione prima del 1° luglio 1987 e che non sono in funzione per più di 1 500 ore operative all'anno, calcolate in media mobile su un periodo di cinque anni, sono soggetti a un valore limite di emissione di NO_x pari a 450 mg/Nm^3.

Gli impianti di combustione alimentati a combustibile liquido con potenza termica nominale totale superiore a 500 MWth che hanno ottenuto un'autorizzazione anteriormente al 27 novembre 2002, o i cui gestori hanno presentato una domanda completa di autorizzazione prima di tale data, a condizione che l'impianto sia stato messo in funzione entro il 27 novembre 2003, e che non sono in funzione per più di 1 500 ore operative annue calcolate in media mobile su un periodo di cinque anni sono soggetti a un valore limite di emissione di NO_x pari a 400 mg/Nm^3.

Una parte di un impianto di combustione che disperde il suo scarico gassoso attraverso una o più canne di scarico separate in un camino comune e che non è in funzione per più di 1 500 ore operative annue calcolate in media mobile su un periodo di cinque anni, può essere soggetta ai valori limite di emissione di cui ai tre paragrafi precedenti in funzione della potenza termica nominale totale dell'intero impianto di combustione. In tali casi, le emissioni attraverso ciascuna di tali canne di scarico sono controllate separatamente.

5. Le turbine a gas (comprese le turbine a gas a ciclo combinato — CCGT) che utilizzano distillati leggeri e medi come combustibili liquidi sono soggette ad un valore limite di emissione di NO_x pari a 90 mg/Nm^3 e di CO pari a 100 mg/Nm^3.

Le turbine a gas per casi di emergenza che sono in funzione meno di 500 ore operative annue non sono coperte dai valori limite di emissione di cui al presente punto. Il gestore di questi impianti registra le ore operative utilizzate.

6. Valori limite di emissione (mg/Nm^3) di NO_x e CO per gli impianti di combustione a gas

	NO_x	CO
Impianti di combustione alimentate con gas naturale, ad eccezione delle turbine a gas e dei motori a gas	100	100
Impianti di combustione alimentati con gas di altoforno, gas da forno a coke o gas a basso potere calorifico originati dalla gassificazione dei residui delle raffinerie, ad eccezione delle turbine a gas e dei motori a gas	200 (4)	—
Impianti di combustione alimentati con gas, ad eccezione delle turbine a gas e dei motori a gas	200 (4)	—
Turbine a gas (comprese le CCGT) che utilizzano il gas naturale (1)come combustibile	50 (2) (3)	100
Turbine a gas (comprese le CCGT) che utilizzano altri gas come combustibile	120	—
Motori a gas	100	100

Note:

(1) Il gas naturale è il metano presente in natura con non più del 20 % (in volume) di inerti ed altri costituenti.

(2) 75 mg/Nm^3 nei casi seguenti, in cui l'efficienza della turbina a gas è determinata alle condizioni ISO di carico di base:

i) turbine a gas usate in un sistema di produzione combinata di calore e di elettricità che hanno un grado di rendimento globale superiore al 75 %;

ii) turbine a gas usate in impianti a ciclo combinato che hanno un grado di rendimento elettrico globale medio annuo superiore al 55 %;

iii) turbine a gas per trasmissioni meccaniche.

(3) Per le turbine a gas che non rientrano in una delle categorie di cui alla nota 2), ma che hanno un grado di efficienza superiore al 35 %, determinato alle condizioni ISO di carico base, il valore limite di emissione di NO_x sarà pari a 50xη/35 dove η è l'efficienza della turbina a gas alle condizioni ISO di carico base espressa in percentuale.

(4) 300 mg/Nm^3 per gli impianti di combustione con potenza termica nominale totale non superiore a 500 MWth che hanno ottenuto un'autorizzazione anteriormente al 27 novembre 2002 o i cui gestori hanno presentato una domanda completa di autorizzazione prima di tale data, a condizione che l'impianto sia stato messo in funzione entro il 27 novembre 2003.

Per le turbine a gas (comprese le CCGT), i valori limite di emissione di NO_x e CO fissati nella tabella di cui al presente punto si applicano soltanto con un carico superiore al 70 %.

Per le turbine a gas (comprese le CCGT) che hanno ottenuto un'autorizzazione anteriormente al 27 novembre 2002 o i cui gestori hanno presentato una domanda completa di autorizzazione prima di tale data, a condizione che l'impianto sia stato messo in funzione entro il 27 novembre 2003, e che non sono in funzione per più di 1 500 ore operative annue calcolate in media mobile su un periodo di cinque anni, il valore limite di emissione di NO_x è pari a 150 mg/Nm^3 se sono alimentate a gas naturale e a 200 mg/Nm^3 se sono alimentate con altri gas o combustibili liquidi.

Una parte di un impianto di combustione che disperde il suo scarico gassoso attraverso una o più canne di scarico separate in un camino comune e che non è in funzione per più di 1 500 ore operative annue calcolate in media mobile su un periodo di cinque anni, può essere soggetta ai valori limite di emissione di cui al paragrafo precedente in funzione della potenza termica nominale totale dell'intero impianto di combustione. In tali casi, le emissioni attraverso ciascuna di tali canne di scarico sono controllate separatamente.

Le turbine a gas e i motori a gas per casi di emergenza che funzionano meno di 500 ore operative all'anno non sono coperte dai valori limite di emissione di cui al presente punto. Il gestore di questi impianti registra le ore operative utilizzate.

7. Valori limite di emissione di polveri, espressi in mg/Nm^3, per gli impianti di combustione che utilizzano combustibili solidi o liquidi ad eccezione delle turbine a gas e dei motori a gas

Potenza termica nominale totale (MWth)	Carbone e lignite ed altri combustibili solidi	Biomassa e torba	Combustibili liquidi (1)
50-100	30	30	30
100-300	25	20	25
> 300	20	20	20

Nota:

(1) Il valore limite di emissione è pari a 50 mg/Nm^3 per la combustione di residui di distillazione e di conversione della raffinazione del petrolio greggio, per il loro proprio consumo, negli impianti di combustione che hanno ottenuto un'autorizzazione anteriormente al 27 novembre 2002 o i cui gestori hanno presentato una domanda completa di autorizzazione prima di tale data, a condizione che l'impianto sia stato messo in funzione entro il 27 novembre 2003.

8. Valori limite di emissione di polveri, espressi in mg/Nm^3, per impianti di combustione che utilizzano combustibili gassosi ad eccezione delle turbine a gas e dei motori a gas

In generale	5
Gas di altiforni	10
Gas prodotti dall'industria siderurgica che possono essere usati altrove	30

PARTE 2

Valori limite di emissione per gli impianti di combustione di cui all'articolo 30, paragrafo 3

1. Tutti i valori limite di emissione sono calcolati a una temperatura di 273,15 K, a una pressione di 101,3 kPa e previa detrazione del tenore di vapore acqueo degli scarichi gassosi e a un tenore standard di O_2 pari al 6 % per i combustibili solidi, al 3 % per gli impianti di combustione diversi dalle turbine a gas e dai motori a gas che utilizzano combustibili liquidi e gassosi e al 15 % per le turbine a gas e per i motori a gas.

   Nel caso delle turbine a gas usate in impianti a ciclo combinato dotate di un bruciatore supplementare, il tenore di O_2 standard può essere definito dall'autorità competente, in funzione delle caratteristiche dell'installazione interessata.

2. Valori limite di emissione (mg/Nm^3) per SO_2 per gli impianti di combustione alimentati a combustibile solido o liquido ad eccezione delle turbine a gas e dei motori a gas.

Potenza termica nominale totale (MWth)	Carbone e lignite ed altri combustibili solidi	Biomassa	Torba	Combustibili liquidi
50-100	400	200	300	350
100-300	200	200	300 250 in caso di combustione a letto fluido	200
> 300	150 200 in caso di combustione a letto fluido circolante o sotto pressione	150	150 200 in caso di combustione a letto fluido	150

3. Valori limite di emissione di SO_2 espressi in mg/Nm^3 per gli impianti di combustione che utilizzano combustibili gassosi ad eccezione delle turbine a gas e dei motori a gas

In generale	35
Gas liquido	5
Gas a basso potere calorifico da forno a coke	400
Gas a basso potere calorifico d'altoforno	200

4. Valori limite di emissione di NO_x espressi in mg/Nm^3 per gli impianti di combustione che utilizzano combustibili solidi o liquidi ad eccezione delle turbine e dei motori a gas

Potenza termica nominale totale (MWth)	Carbone e lignite ed altri combustibili solidi	Biomassa e torba	Combustibili liquidi
50-100	300 400 in caso di combustione di lignite polverizzata	250	300
100-300	200	200	150
> 300	150 200 in caso di combustione di lignite polverizzata	150	100

5. Le turbine a gas (comprese le CCGT) che utilizzano distillati leggeri e medi come combustibili liquidi sono soggette ad un valore limite di emissione di NO_x pari a 50 mg/Nm^3 e di CO pari a 100 mg/Nm^3.

Le turbine a gas per casi di emergenza che sono in funzione meno di 500 ore operative annue non sono coperte dai valori limite di emissione di cui al presente punto. Il gestore di questi impianti registra le ore operative utilizzate.

6. Valori limite di emissione di NO_x e CO espressi in mg/Nm^3 per impianti di combustione alimentati a gas

	NO_x	CO
Impianti di combustione diversi dalle turbine a gas e dai motori a gas	100	100
Turbine a gas (comprese le CCGT)	50 (1)	100
Motori a gas	75	100

Nota:

(1) Per le turbine a gas che hanno un grado di efficienza superiore al 35 % — determinato alle condizioni ISO di carico di base — il valore limite di emissione di NO_x sarà pari a 50xη/35 dove η è l'efficienza della turbina a gas alle condizioni ISO di carico base espressa in percentuale.

Per le turbine a gas (comprese le CCGT), i valori limite di emissione di NO_x e CO di cui al presente punto si applicano soltanto con un carico superiore al 70 %.

Le turbine a gas e i motori a gas per casi di emergenza che funzionano meno di 500 ore operative all'anno non sono coperte dai valori limite di emissione di cui al presente punto. Il gestore di questi impianti registra le ore operative utilizzate.

7. Valori limite di emissione di polveri espressi in mg/Nm^3 per gli impianti di combustione che utilizzano combustibili solidi o liquidi ad eccezione delle turbine a gas e dei motori a gas.

Potenza termica nominale totale (MWth)	
50-300	20
> 300	10 20 per la biomassa e la torba

8. Valori limite di emissione di polveri espressi in mg/Nm^3 per gli impianti di combustione che utilizzano combustibili gassosi ad eccezione delle turbine a gas e dei motori a gas.

In generale	5
Gas di altiforni	10
Gas prodotti dall'industria siderurgica che possono essere usati altrove.	30

PARTE 3

Controllo delle emissioni

1. Le concentrazioni di SO_2, NO_x e polveri negli scarichi gassosi di ciascun impianto di combustione con una potenza termica nominale totale pari o superiore a 100 MW sono misurate in continuo.

La concentrazione di CO negli scarichi gassosi di ogni impianto di combustione alimentati con combustibili gassosi e con una potenza termica nominale totale pari o superiore a 100 MW è misurata in continuo.

2. L'autorità competente può decidere di non rendere obbligatorie le misurazioni in continuo di cui al punto 1 nei casi seguenti:

a) per gli impianti di combustione con un ciclo di vita inferiore a 10 000 ore di funzionamento;

b) per SO_2e per le polveri degli impianti di combustione alimentati con gas naturale;

c) per SO_2degli impianti di combustione alimentati a gasolio con tenore di zolfo noto, in assenza di apparecchiature di desolforazione degli scarichi gassosi;

d) per SO_2degli impianti di combustione alimentati con biomassa se il gestore può provare che le emissioni di SO_2 non possono in nessun caso superare i valori limite di emissione previsti.

3. Nei casi in cui non sono richieste misurazioni in continuo, sono necessarie come minimo misurazioni di SO_2, NO_x, polveri e, per gli impianti alimentati a gas, anche di CO una volta ogni sei mesi.

4. Per gli impianti di combustione alimentati a carbone o lignite, le emissioni di mercurio totale saranno misurate almeno una volta all'anno.

5. In alternativa alle misurazioni di SO_2e NO_x di cui al punto 3, si possono usare altre procedure, verificate ed approvate dall'autorità competente, per determinare le emissioni di SO_2 e di NO_x. Queste procedure applicano le pertinenti norme CEN oppure, se non sono disponibili norme CEN, le norme ISO, le norme nazionali o altre norme internazionali che assicurino dati equivalenti sotto il profilo della qualità scientifica.

6. In caso di significative modifiche in merito al combustibile utilizzato o al modo di conduzione degli impianti, l'autorità competente ne è informata. L'autorità competente decide se le disposizioni in materia di controllo di cui ai punti da 1 a 4 sono appropriate o se richiedono un adeguamento.

7. Le misurazioni in continuo effettuate conformemente al punto 1 comprendono le misurazioni del tenore di ossigeno, della temperatura, della pressione e del tenore di vapore acqueo degli scarichi gassosi. La misurazione in continuo del tenore di vapore acqueo degli scarichi gassosi non è necessaria, a condizione che lo scarico gassoso prelevato sia essiccato prima dell'analisi delle emissioni.

8. Il campionamento e l'analisi delle sostanze inquinanti pertinenti e le misurazioni dei parametri di processo, nonché l'assicurazione di qualità dei sistemi automatici di misurazione e i metodi di misurazione di riferimento per calibrare tali sistemi, sono effettuati conformemente alle norme CEN. Se non sono disponibili norme CEN si applicano norme ISO, norme nazionali o altre norme internazionali che assicurino dati equivalenti sotto il profilo della qualità scientifica.

   I sistemi di misurazione automatici sono soggetti a controllo mediante misurazioni parallele secondo i metodi di riferimento, almeno una volta all'anno.

   I gestori informano l'autorità competente dei risultati della verifica dei sistemi di misurazione automatici.

9. A livello dei valori limite di emissione, i valori degli intervalli di fiducia al 95 % di un singolo risultato di misurazione non superano le seguenti percentuali dei valori limite di emissione:

Monossido di carbonio	10 %
Anidride solforosa	20 %
Ossidi di azoto	20 %
Polveri	30 %

10. I valori medi orari e giornalieri convalidati sono determinati in base ai valori medi orari validi misurati dopo detrazione del valore dell'intervallo di fiducia di cui al punto 9.

    Qualsiasi giorno nel quale più di 3 valori medi orari non sono validi a causa di malfunzionamento o manutenzione del sistema automatico di misure non è considerato valido. Se in un anno più di dieci giorni non sono considerati validi per tali ragioni, l'autorità competente chiede al gestore di prendere adeguati provvedimenti per migliorare l'affidabilità del sistema automatico di misure.

11. Nel caso di impianti che devono rispondere ai gradi di desolforazione di cui all'articolo 31, viene controllato regolarmente anche il tenore di zolfo del combustibile bruciato nell'impianto di combustione. Le autorità competenti sono informate delle modifiche sostanziali del tipo di combustibile utilizzato.

PARTE 4

Valutazione del rispetto dei valori limite di emissione

1. Nel caso di misurazioni in continuo si considerano rispettati i valori limite di emissione indicate nelle parti 1 e 2, se la valutazione dei risultati delle misurazioni rivela che, nelle ore di funzionamento nel corso di un anno civile, sono state rispettate tutte le condizioni che seguono:

   a) nessun valore medio mensile convalidato supera i valori limite di emissione pertinenti indicati nelle parti 1 e 2;

   b) nessun valore medio giornaliero convalidato supera il 110 % dei valori limite di emissione pertinenti indicati nelle parti 1 e 2;

   c) nei casi di impianti di combustione composti esclusivamente da caldaie alimentate a carbone con una potenza termica nominale totale inferiore a 50 MW, nessun valore medio giornaliero convalidato supera il 150 % dei valori limite di emissione pertinenti indicate nelle parti 1 e 2,

   d) il 95 % di tutti i valori medio orari convalidati nel corso dell'anno non supera il 200 % dei valori limite di emissione pertinenti indicati nelle parti 1 e 2.

   I valori medi convalidati sono determinati conformemente a quanto disposto alla parte 3, punto 10.

   Ai fini del calcolo dei valori medi di emissione, non si tiene conto dei valori misurati durante i periodi di cui all'articolo 30, paragrafi 5 e 6 e all'articolo 37, né di quelli misurati durante i periodi di avvio e di arresto.

2. Qualora non siano richieste misurazioni in continuo, i valori limite di emissione indicate nelle parti 1 e 2 sono considerati rispettati se i risultati di ogni serie di misurazioni o delle altre procedure, definiti e determinati secondo le modalità stabilite dalle competenti autorità, non superano i valori limite di emissione.

PARTE 5

Grado minimo di desolforazione

1. Grado minimo di desolforazione per gli impianti di combustione di cui all'articolo 30, paragrafo 2

Potenza termica nominale totale (MW)	Grado minimo di desolforazione	
	Impianti che hanno ottenuto un'autorizzazione anteriormente al 27 novembre 2002 o i cui gestori hanno presentato una domanda completa di autorizzazione prima di tale data, a condizione che l'impianto sia stato messo in funzione entro il 27 novembre 2003	Altri impianti
50-100	80 %	92 %
100-300	90 %	92 %
> 300	96 % (1)	96 %

Nota
(1) Per impianti di combustione alimentati a scisti bituminosi il grado minimo di desolforazione è 95 %.

2. Grado minimo di desolforazione per gli impianti di combustione di cui all'articolo 30, paragrafo 3

Potenza termica nominale totale (MW)	Grado minimo di desolforazione
50-100	93 %
100-300	93 %
> 300	97 %

PARTE 6

Rispetto del grado di desolforazione

I gradi minimi di desolforazione di cui alla parte 5 del presente allegato si applicano come valore limite medio mensile.

PARTE 7

Valori limite medi di emissione per gli impianti di combustione multicombustibile all'interno di una raffineria

I valori limite medi di emissione (mg/Nm^3) di SO_2 per gli impianti di combustione multicombustibile all'interno di una raffineria, ad eccezione delle turbine a gas e dei motori a gas, alimentati con i residui di distillazione e di conversione della raffinazione del petrolio greggio, da soli o con altri combustibili, per il loro proprio consumo, sono i seguenti:

a) per gli impianti di combustione che hanno ottenuto un'autorizzazione anteriormente al 27 novembre 2002 o i cui gestori hanno presentato una domanda completa di autorizzazione prima di tale data, a condizione che l'impianto sia stato messo in funzione entro il 27 novembre 2003: 1 000 mg/Nm^3;

b) per gli altri impianti di combustione: 600 mg/Nm^3.

Tali valori limite di emissione sono calcolati ad una temperatura di 273,15 K, a una pressione di 101,3 kPa e previa detrazione del tenore di vapore acqueo degli scarichi gassosi e a un tenore standard di O_2 pari al 6 % per i combustibili solidi e al 3 % per i combustibili liquidi e gassosi.

ALLEGATO VI

Disposizioni tecniche relative agli impianti di incenerimento dei rifiuti e agli impianti di coincenerimento dei rifiuti

PARTE 1

Definizioni

Ai fini del presente allegato si intende per:

a) «impianto di incenerimento dei rifiuti esistente» un impianto di incenerimento dei rifiuti:

   i) che era in esercizio e era autorizzato conformemente alla normativa dell'Unione applicabile prima del 28 dicembre 2002;

   ii) che era autorizzato o registrato per l'incenerimento dei rifiuti e la cui autorizzazione era stata concessa prima del 28 dicembre 2002, conformemente alla normativa dell'Unione applicabile, purché l'impianto sia stato messo in funzione entro il 28 dicembre 2003;

   iii) che era stato oggetto, a parere dell'autorità competente, di una richiesta completa di autorizzazione prima del 28 dicembre 2002, purché l'impianto sia stato messo in funzione entro il 28 dicembre 2004;

b) «nuovo impianto di incenerimento dei rifiuti», ogni impianto di incenerimento dei rifiuti che non rientra nella lettera a).

PARTE 2

Fattori di equivalenza per le dibenzo-p-diossine e i dibenzofurani

Per la determinazione della concentrazione totale delle diossine e dei furani, le concentrazioni di massa delle seguenti dibenzo-p-diossine e dibenzofurani devono essere moltiplicate per i seguenti fattori di equivalenza, prima di eseguire la somma:

	Fattore di equivalenza tossico
2,3,7,8 – Tetraclorodibenzodiossina (TCDD)	1
1,2,3,7,8 – Pentaclorodibenzodiossina (PeCDD)	0,5
1,2,3,4,7,8 – Esaclorodibenzodiossina (HxCDD)	0,1
1,2,3,6,7,8 – Esaclorodibenzodiossina (HxCDD)	0,1
1,2,3,7,8,9 – Esaclorodibenzodiossina (HxCDD)	0,1
1,2,3,4,6,7,8 – Heptaclorodibenzodiossina (HpCDD)	0,01
Octaclorodibenzodiossina (OCDD)	0,001
2,3,7,8 – Tetraclorodibenzofurano (TCDF)	0,1
2,3,4,7,8 – Pentaclorodibenzofurano (PeCDF)	0,5
1,2,3,7,8 – Pentaclorodibenzofurano (PeCDF)	0,05
1,2,3,4,7,8 – Esaclorodibenzofurano (HxCDF)	0,1
1,2,3,6,7,8 – Esaclorodibenzofurano (HxCDF)	0,1
1,2,3,7,8,9 – Esaclorodibenzofurano (HxCDF)	0,1
2,3,4,6,7,8 – Esaclorodibenzofurano (HxCDF)	0,1
1,2,3,4,6,7,8 – Heptaclorodibenzofurano (HpCDF)	0,01
1,2,3,4,7,8,9 – Heptaclorodibenzofurano (HpCDF)	0,01
Octaclorodibenzofurano (OCDF)	0,001

PARTE 3

Valori limite per le emissioni nell'atmosfera da parte degli impianti di incenerimento dei rifiuti

1. Tutti i valori limite di emissione saranno calcolati a una temperatura di 273,15 K, a una pressione di 101,3 kPa e dopo la correzione del tenore di vapore acqueo degli scarichi gassosi.

I valori limite di emissione sono normalizzati all'11 % di ossigeno negli scarichi gassosi, tranne che nel caso di incenerimento di oli minerali usati, come definiti all'articolo 3, paragrafo 3, della direttiva 2008/98/CE, quando sono normalizzati al 3 % di ossigeno, e nei casi di cui alla parte 6, punto 2.7.

1.1. Valori medi giornalieri dei limiti di emissione per le seguenti sostanze inquinanti, espressi in mg/Nm^3

Polvere totale	10
Sostanze organiche sotto forma di gas e vapori espresse come carbonio organico totale (TOC)	10
Cloruro di idrogeno (HCl)	10
Fluoruro di idrogeno (HF)	1
Biossido di zolfo (SO_2)	50
Monossido di azoto (NO) e biossido di azoto (NO_2), espressi come NO_2 per gli impianti di incenerimento dei rifiuti esistenti dotati di una capacità nominale superiore a 6 t/ora e per i nuovi impianti di incenerimento dei rifiuti	200
Monossido di azoto (NO) e biossido di azoto (NO_2), espressi come NO_2 per gli impianti di incenerimento dei rifiuti esistenti con una capacità nominale pari o inferiore a 6 t/ora	400

1.2. Valori limite di emissione su 30 minuti per le seguenti sostanze inquinanti espressi in mg/Nm^3

	(100 %) A	(97 %) B
Polvere totale	30	10
Sostanze organiche sotto forma di gas e vapori espresse come carbonio organico totale (TOC)	20	10
Cloruro di idrogeno (HCl)	60	10
Fluoruro di idrogeno (HF)	4	2
Biossido di zolfo (SO_2)	200	50
Monossido di azoto (NO) e biossido di azoto (NO_2), espressi come NO_2 per gli impianti di incenerimento dei rifiuti esistenti dotati di una capacità nominale superiore a 6 t/ora e per i nuovi impianti di incenerimento dei rifiuti	400	200

1.3. Valori limite di emissione medi espressi in mg/Nm^3 per i metalli pesanti elencati di seguito in un periodo di campionamento minimo di 30 minuti e massimo di 8 ore.

Cadmio e suoi composti, espressi come cadmio (Cd)	0,05 in totale
Tallio e suoi composti espressi come tallio (Tl)	
Mercurio e suoi composti espressi come mercurio (Hg)	0,05
Antimonio e suoi composti espressi come antimonio (Sb)	0,5 in totale
Arsenico e suoi composti espressi come arsenico (As)	
Piombo e suoi composti espressi come piombo (Pb)	
Cromo e suoi composti espressi come cromo (Cr)	
Cobalto e suoi composti espressi come cobalto (Co)	
Rame e suoi composti espressi come rame (Cu)	
Manganese e suoi composti espressi come manganese (Mn)	
Nickel e suoi composti espressi come nickel (Ni)	
Vanadio e suoi composti espressi come vanadio (V)	

Tali valori medi comprendono anche le emissioni sotto forma di gas e vapori dei metalli pesanti in questione dei relativi composti.

1.4. Valori limite di emissione medi espressi in ng/Nm^3 per diossine e furani in un periodo di campionamento minimo di 6 ore e massimo di 8 ore. I valori limite di emissione si riferiscono alla concentrazione totale di diossine e furani calcolata in conformità della parte 2.

Diossine e furani	0,1

1.5. Valori limite di emissione espressi in mg/Nm^3 per il monossido di carbonio (CO) negli scarichi gassosi:

a) 50 come valore medio giornaliero;

b) 100 come valore medio su 30 minuti;

c) 150 come valore medio su 10 minuti.

L'autorità competente può concedere deroghe ai valori limite di emissione di cui al presente punto per gli impianti di incenerimento dei rifiuti che utilizzano la tecnologia del letto fluido, purché l'autorizzazione fissi un valore limite di emissione per il monossido di carbonio (CO) inferiore o pari a 100 mg/Nm^3 come valore medio orario.

2. Valori limite di emissione applicabile nelle circostanze descritte nell'articolo 46, paragrafo 6, e nell'articolo 47.

La concentrazione di polvere nelle emissioni nell'atmosfera di un impianto di incenerimento dei rifiuti non può superare in nessun caso i 150 mg/Nm^3 espressi come media su 30 minuti. Non possono essere superati i valori limite relativi alle emissioni nell'atmosfera di TOC e CO di cui ai punti 1.2 e 1.5, lettera b).

3. Gli Stati membri possono stabilire norme volte a disciplinare le deroghe previste nella presente parte.

PARTE 4

Determinazione dei valori limite per le emissioni nell'atmosfera provenienti dal coincenerimento dei rifiuti

1. La seguente formula (formula di miscelazione) sarà applicata ogniqualvolta non sia stato fissato uno specifico valore limite totale di emissione «C» in una tabella della presente parte.

Il valore limite di emissione per ciascuna sostanza inquinante e il CO presenti negli scarichi gassosi provenienti dal coincenerimento dei rifiuti è calcolato come segue:

$$\frac{V_{rifiuti} \times C_{rifiuti} + V_{processo} \times C_{processo}}{V_{rifiuti} + C_{processo}} = C$$

$V_{rifiuti}$: volume degli scarichi gassosi provenienti dall'incenerimento dei soli rifiuti, determinato in base ai rifiuti che hanno il più basso potere calorifico specificato nell'autorizzazione e normalizzato alle condizioni stabilite nella presente direttiva.

Qualora il calore liberato dall'incenerimento di rifiuti pericolosi sia inferiore al 10 % del calore totale liberato nell'impianto, $V_{rifiuti}$ deve essere calcolato in base ad un quantitativo (nozionale) di rifiuti che, se incenerito, libererebbe un calore pari al 10 % del calore totale liberato in questione.

$C_{rifiuti}$: valore limite di emissione per gli impianti di incenerimento dei rifiuti di cui alla parte 3

$V_{processo}$: volume degli scarichi gassosi provenienti dal processo dell'impianto, inclusa la combustione dei combustibili autorizzati normalmente utilizzati nell'impianto (esclusi i rifiuti), determinato sulla base dei tenori di ossigeno stabiliti nella normativa dell'Unione o nazionale ai fini della normalizzazione delle emissioni. In assenza di normativa per questo tipo di impianti, si deve utilizzare il tenore reale di ossigeno degli scarichi gassosi non diluiti con aggiunta di aria non indispensabile per il processo.

$C_{processo}$: valori limite di emissione fissati nella presente parte per talune attività industriali o, in caso di assenza di tali valori, valori limite di emissione degli impianti conformi alle disposizioni nazionali legislative, regolamentari e amministrative vigenti per tali impianti, quando vengono bruciati i combustibili normalmente utilizzati (rifiuti esclusi). In mancanza di tali disposizioni si applicano i valori limite di emissione fissati nell'autorizzazione. Se in questa non sono menzionati tali valori, si ricorre alle concentrazioni reali di massa.

C: valori limite totali di emissione ad un determinato tenore di ossigeno fissati nella presente parte per talune attività industriali e per talune sostanze inquinanti o, in caso di assenza di tali valori, valori limite totali di emissione che sostituiscono i valori limite di emissione fissati nei pertinenti allegati della presente direttiva. Il tenore totale di ossigeno che sostituisce il tenore di ossigeno ai fini della normalizzazione è calcolato sulla base del suddetto tenore, rispettando i volumi parziali.

Tutti i valori limite si emissione sono calcolati a una temperatura di 273,15 K, a una pressione di 101,3 kPa e dopo la correzione del tenore di vapore acqueo degli scarichi gassosi.

Gli Stati membri possono stabilire misure volte a disciplinare le esenzioni previste nella presente parte.

2. Disposizioni speciali relative ai forni per cemento che coinceneriscono rifiuti

2.1. I valori limite di emissione di cui ai punti 2.2 e 2.3 si applicano come valori medi giornalieri di polveri totali, HC1, HF, NO_x, SO_2 e TOC (per misurazioni in continuo), come valori medi in un periodo di campionamento minimo di 30 minuti e massimo di 8 ore per i metalli pesanti e come valori medi in un periodi di campionamento minimo di 6 ore e massimo di 8 ore per diossine e furani.

Tutti i valori sono normalizzati a ossigeno 10 %.

I valori medi su 30 minuti sono necessari solo ai fini del calcolo dei valori medi giornalieri.

2.2. C – Valori limite totali di emissione (espressi in mg/Nm^3 tranne che per diossine e furani) per le seguenti sostanze inquinanti

Sostanza inquinante	C
Polveri totali	30
HCl	10
HF	1
NO_x	500 (1)
Cd + Tl	0,05
Hg	0,05
Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V	0,5
Diossine e furani (ng/Nm^3)	0,1

(1) Fino al 1° gennaio 2016 l'autorità competente può autorizzare esenzioni dal valore limite per i NO_x per i forni Lepol e per i forni rotativi lunghi purché l'autorizzazione stabilisca un valore limite di emissione complessivo per i NO_x inferiore o pari a 800 mg/Nm^3.

2.3. C – Valori limite totali di emissione (espressi in mg/Nm^3) per SO_2 e TOC

Inquinanti	C
SO_2	50
TOC	10

L'autorità competente può concedere deroghe rispetto ai valori limite di emissione di cui al presente punto nei casi in cui il coincenerimento di rifiuti non dia luogo a TOC e SO_2.

2.4. C — Valori limite di emissione complessivi per il CO

L'autorità competente può stabilire valori limite di emissione per il CO

3. Disposizioni speciali per impianti di combustione che coinceneriscono rifiuti

3.1. $C_{processo}$ espresso come valori medi giornalieri (in mg/Nm^3) valido fino alla data di cui all'articolo 82, paragrafo 5

Per determinare la potenza termica nominale totale degli impianti di combustione si applicano le norme sul cumulo delle emissioni di cui all'articolo 29.I valori medi su 30 minuti sono necessari solo ai fini del calcolo dei valori medi giornalieri.

$C_{processo}$ per combustibili solidi esclusa la biomassa (tenore di O_2 6 %):

Sostanza inquinante	< 50 MWth	da 50 a 100 MWth	da 100 a 300 MWth	> 300 MWth
SO_2	—	850	200	200
NO_x	—	400	200	200
Polvere	50	50	30	30

$C_{processo}$ per la biomassa (tenore di O_2 6 %):

Sostanza inquinante	< 50 MWth	da 50 a 100 MWth	da 100 a 300 MWth	> 300 MWth
SO_2	—	200	200	200
NO_x	—	350	300	200
Polvere	50	50	30	30

$C_{processo}$ per i combustibili liquidi (tenore di O_2 3 %):

Sostanza inquinante	< 50 MWth	da 50 a 100 MWth	da 100 a 300 MWth	> 300 MWth
SO_2	—	850	400 a da 200 (decremento lineare da 100 a 300 MWth)	200
NO_x	—	400	200	200
Polvere	50	50	30	30

3.2. $C_{processo}$ espresso in valori medi giornalieri (in mg/Nm^3) valido dalla data di cui all'articolo 82, paragrafo 6

Per determinare la potenza termica nominale totale degli impianti di combustione si applicano le norme sul cumulo delle emissioni di cui all'articolo 29. I valori medi su 30 minuti sono necessari solo ai fini del calcolo dei valori medi giornalieri.

3.2.1. $C_{processo}$ per gli impianti di combustione di cui all'articolo 30, paragrafo 2, ad eccezione delle turbine a gas e dei motori a gas

$C_{processo}$ per i combustibili solidi ad eccezione della biomassa (tenore di O_2 6 %):

Sostanza inquinante	< 50 MWth	da 50 a 100 MWth	da 100 a 300 MWth	> 300 MWth
SO_2	—	400 per la torba: 300	200	200
NO_x	—	300 per la polverizzata: 400	200	200
Polvere	50	30	25 per la torba: 20	20

$C_{processo}$ per la biomassa (tenore di O_2 6 %):

Sostanza inquinante	< 50 MWth	da 50 a 100 MWth	da 100 a 300 MWth	> 300 MWth
SO_2	—	200	200	200
NO_x	—	300	250	200
Polvere	50	30	20	20

$C_{processo}$ per i combustibili liquidi (tenore di O_2 3 %):

Sostanza inquinante	< 50 MWth	da 50 a 100 MWth	da 100 a 300 MWth	> 300 MWth
SO_2	—	350	250	200
NO_x	—	400	200	150
Polvere	50	30	25	20

3.2.2. $C_{processo}$ per gli impianti di combustione di cui all'articolo 30, paragrafo 3, ad eccezione delle turbine a gas e dei motori a gas

$C_{processo}$ per i combustibili solidi ad eccezione della biomassa (tenore di O_2 6 %):

Sostanza inquinante	< 50 MWth	da 50 a 100 MWth	da 100 a 300 MWth	> 300 MWth
SO_2	—	400 per la torba: 300	200 per la torba: 300, tranne nel caso di combustione a letto fluido: 250	150 per combustione a letto fluido circolante o a letto fluido oppure, nel caso di combustione di torba, per tutti i tipi di combustione a letto fluido: 200
NO_x	—	300 per la torba: 250	200	150 per la combustione di lignite polverizzata: 200
Polvere	50	20	20	10 per la torba: 20

$C_{processo}$ per la biomassa (tenore di O_2 6 %):

Sostanza inquinante	< 50 MWth	da 50 a 100 MWth	da 100 a 300 MWth	> 300 MWth
SO_2	—	200	200	150
NO_x	—	250	200	150
Polvere	50	20	20	20

$C_{processo}$ per i combustibili liquidi (tenore di O_2 3 %):

Sostanza inquinante	< 50 MWth	da 50 a 100 MWth	da 100 a 300 MWth	> 300 MWth
SO_2	—	350	200	150
NO_x	—	300	150	100
Polvere	50	20	20	10

3.3. C – Valori limite totali di emissione per metalli pesanti (in mg/Nm^3) espresso come valori medi in un periodo di campionamento minimo di 30 minuti e massimo di 8 ore (tenore di O_2 6 % per i combustibili solidi e 3 % per i combustibili liquidi).

Sostanze inquinanti	C
Cd + Tl	0,05
Hg	0,05
Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V	0,5

3.4. C – valori limite totali di emissione (in ng/Nm^3) per diossine e furani espresso come valore medio misurato in un periodo di campionamento minimo di 6 ore e massimo di 8 ore (tenore di O_2 6 % per i combustibili solidi e 3 % per i combustibili liquidi).

Sostanza inquinante	C
Diossine e furani	0,1

4. Disposizioni speciali per gli impianti di coincenerimento di rifiuti nei settori industriali non contemplati nei punti 2 e 3 della presente parte

4.1. C – valore limite totale di emissione (in ng/Nm^3) per diossine e furani espresso come valore medio misurato in un periodo di campionamento minimo di 6 ore e massimo di 8 ore:

Sostanza inquinante	C
Diossine e furani	0,1

4.2. C – valori limite totali di emissione (in mg/Nm^3) per i metalli pesanti espresso come valori medi misurati in un periodo di campionamento minimo di 30 minuti e massimo di 8 ore:

Sostanze inquinanti	C
Cd + Tl	0,05
Hg	0,05

PARTE 5

Valori limite di emissione relativi agli scarichi di acque reflue derivanti dalla depurazione degli scarichi gassosi

Inquinanti	Valori limite di emissione per campioni non filtrati (mg/l tranne che per diossine e furani)	
1. Solidi sospesi totali definiti nell'allegato I della direttiva 91/271/CEE	(95 %)	(100 %)
	30	45
2. Mercurio e suoi composti, espressi come mercurio (Hg)	0,03	
3. Cadmio e suoi composti, espressi come cadmio (Cd)	0,05	
4. Tallio e suoi composti, espressi come tallio (Tl)	0,05	
5. Arsenico e suoi composti, espressi come arsenico (As)	0,15	
6. Piombo e suoi composti, espressi come piombo (Pb)	0,2	
7. Cromo e suoi composti, espressi come cromo (Cr)	0,5	
8. Rame e suoi composti, espressi come rame (Cu)	0,5	
9. Nichel e suoi composti, espressi come nichel (Ni)	0,5	
10. Zinco e suoi composti, espressi come zinco (Zn)	1,5	
11. Diossine e furani	0,3 ng/l	

PARTE 6

Controllo delle emissioni

1. Tecniche di misurazione

1.1. Le misurazioni relative alla determinazione delle concentrazioni di inquinanti nell'atmosfera e nell'acqua sono eseguite in modo rappresentativo.

1.2. Il campionamento e l'analisi di tutte le sostanze inquinanti, ivi compresi le diossine e i furani, nonché l'assicurazione di qualità dei sistemi automatici di misurazione e la loro taratura in base ai metodi di misurazione di riferimento devono essere eseguiti in conformità delle norme CEN. Qualora non siano disponibili norme CEN, si applicano norme ISO, norme nazionali o altre norme internazionali che assicurino la disponibilità di dati di qualità scientifica equivalente. I sistemi automatici di misurazione sono sottoposti a controllo per mezzo di misurazioni parallele in base ai metodi di misurazione di riferimento almeno una volta l'anno.

1.3. I valori degli intervalli di confidenza al 95 % di un singolo risultato di misurazione determinati ai valori limite giornalieri di emissione non devono superare le seguenti percentuali dei valori limite di emissione:

Monossido di carbonio:	10 %
Biossido di zolfo:	20 %
Biossido di azoto:	20 %
Polvere totale:	30 %
Carbonio organico totale:	30 %
Cloruro di idrogeno:	40 %
Fluoruro di idrogeno:	40 %.

Le misurazioni periodiche delle emissioni nell'atmosfera e nell'acqua sono effettuate in conformità dei punti 1.1 e 1.2.

2. Misurazioni relative agli inquinanti atmosferici

2.1. Sono eseguite le seguenti misurazioni relative agli inquinanti atmosferici:

a) misurazioni in continuo delle seguenti sostanze: NO_x, purché siano fissati i valori limite di emissione, CO, polveri totali, TOC, HCl, HF, SO_2;

b) misurazioni in continuo dei seguenti parametri di processo: temperatura vicino alla parete interna o in un altro punto rappresentativo della camera di combustione, secondo quanto autorizzato dall'autorità competente, concentrazione di ossigeno, pressione, temperatura e tenore di vapore acqueo degli scarichi gassosi;

c) almeno due misurazioni all'anno per i metalli pesanti, le diossine e i furani; per i primi dodici mesi di funzionamento è tuttavia effettuata una misurazione almeno ogni tre mesi.

2.2. Il tempo di permanenza, la temperatura minima e il tenore di ossigeno degli scarichi gassosi sono adeguatamente verificati almeno una volta quando l'impianto di incenerimento dei rifiuti o l'impianto di coincenerimento dei rifiuti è messo in funzione e nelle condizioni di funzionamento più sfavorevoli.

2.3. La misurazione in continuo dell'HF può essere omessa se vengono utilizzate fasi di trattamento per l'HCl che garantiscano che il valore limite di emissione relativo a tale sostanza non è superato. In tal caso le emissioni di HF sono sottoposte alle misurazioni periodiche di cui al in punto 2.1, lettera c).

2.4. La misurazione in continuo del tenore di vapore acqueo non è richiesta qualora gli scarichi gassosi i campionati siano essiccati prima dell'analisi delle emissioni.

2.5. L'autorità competente può decidere di non imporre misurazioni in continuo per HC1, HF e SO_2 negli impianti di incenerimento dei rifiuti o negli impianti di coincenerimento dei rifiuti e può prescrivere le misurazioni periodiche stabilite nel punto 2.1, lettera c), oppure può decidere di non imporre alcuna misurazione se il gestore può dimostrare che le emissioni di tali inquinanti non possono in nessun caso essere superiori ai valori limite di emissione stabiliti.

L'autorità competente può decidere di non imporre misurazioni in continuo per NO_x e può prescrivere le misurazioni periodiche stabilite nel punto 2.1, lettera c), negli impianti esistenti di incenerimento dei rifiuti aventi una capacità nominale inferiore a 6 t/ora oppure negli impianti esistenti di coincenerimento dei rifiuti aventi una capacità nominale inferiore a 6 t/ora se il gestore può dimostrare, sulla base di informazioni relative alla qualità dei rifiuti in questione, delle tecnologie utilizzate e dei risultati del monitoraggio delle emissioni, che in nessuna circostanza le emissioni di NO_x possono essere superiori al valore limite di emissione prescritto.

2.6. L'autorità competente può decidere di imporre una misurazione ogni due anni per i metalli pesanti e una misurazione all'anno per le diossine e i furani nei seguenti casi:

a) le emissioni derivanti dal coincenerimento o dall'incenerimento dei rifiuti siano in tutte le circostanze inferiori al 50 % dei valori limite di emissione;

b) i rifiuti da coincenerire o da incenerire consistano esclusivamente in determinate frazioni combustibili selezionate di rifiuti non pericolosi non adatti ad essere riciclati, dotati di determinate caratteristiche e ulteriormente specificati in base alla valutazione di cui alla lettera c);

c) il gestore possa provare sulla base di informazioni relative alla qualità dei rifiuti in questione e del monitoraggio delle emissioni che le emissioni sono in tutte le circostanze significativamente al di sotto dei valori limite di emissione per i metalli pesanti, le diossine e i furani;

2.7. I risultati delle misurazioni sono normalizzati utilizzando le concentrazioni di ossigeno standard di cui alla parte 3 o calcolate conformemente alla parte 4 e applicando la formula di cui alla parte 7.

Se i rifiuti sono inceneriti o coinceneriti in un'atmosfera arricchita di ossigeno, i risultati delle misurazioni possono essere normalizzati a un tenore di ossigeno stabilito dall'autorità competente che rifletta le circostanze specifiche del singolo caso.

Se le emissioni di sostanze inquinanti sono ridotte mediante trattamento degli scarichi gassosi in un impianto di incenerimento dei rifiuti o in un impianto di coincenerimento dei rifiuti destinato al trattamento di rifiuti pericolosi, la normalizzazione in base ai tenori di ossigeno di cui al primo comma è applicata soltanto se il tenore di ossigeno misurato per lo stesso periodo per la sostanza inquinante in questione supera il pertinente tenore di ossigeno normalizzato.

3. Misurazioni relative alle sostanze inquinanti dell'acqua

3.1. Al punto di scarico delle acque reflue sono effettuate le seguenti misurazioni:

a) misurazioni in continuo di pH, temperatura e flusso;

b) misurazioni giornaliere del totale dei solidi sospesi effettuate su campioni per sondaggio oppure misurazioni di un campione rappresentativo proporzionale al flusso su un periodo di 24 ore;

c) misurazioni almeno mensili di un campione rappresentativo proporzionale al flusso dello scarico, su un periodo di 24 ore di Hg, Cd, Tl, As, Pb, Cr, Ni e Zn;

d) misurazioni almeno semestrali delle diossine e dei furani; tuttavia nei primi dodici mesi di funzionamento è effettuata una misurazione almeno ogni tre mesi.

3.2. Qualora le acque reflue provenienti dalla depurazione degli scarichi gassosi siano trattate in loco congiuntamente ad acque reflue provenienti da altre fonti del sito, il gestore effettua le misurazioni:

a) sul flusso di acque reflue provenienti dai processi di depurazione degli scarichi gassosi prima dell'immissione nell'impianto di trattamento collettivo delle acque reflue;

b) sugli altri flussi di acque reflue prima dell'immissione nell'impianto di trattamento collettivo delle acque reflue;

c) al punto di scarico finale, dopo il trattamento, delle acque reflue provenienti dall'impianto di incenerimento dei rifiuti o dall'impianto di coincenerimento dei rifiuti.

PARTE 7

Formula per il calcolo delle concentrazioni di emissioni calcolata alla concentrazione percentuale di ossigeno normalizzata

$$E_S = \frac{21 - O_S}{21 - O_M} \times E_M$$

E_S = concentrazione di emissione calcolata alla concentrazione percentuale di ossigeno normalizzata

E_M = concentrazione di emissione misurata

O_S = concentrazione di ossigeno normalizzata

O_M = concentrazione di ossigeno misurata

PARTE 8

Valutazione dell'osservanza dei valori limite di emissione

1. Valori limite di emissione nell'atmosfera

1.1. I valori limite di emissione per l'atmosfera si considerano rispettati se:

a) nessuno dei valori medi giornalieri supera uno qualsiasi dei valori limite di emissione di cui al punto 1.1 della parte 3 o nella parte 4 oppure calcolati conformemente alla parte 4;

b) nessuno dei valori medi su 30 minuti supera uno qualsiasi dei valori limite di emissione di cui alla colonna A, della tabella al punto 1.2 della parte 3 oppure, ove applicabile, il 97 % dei valori medi su 30 minuti nel corso dell'anno non supera uno qualsiasi dei valori limite di emissione di cui alla colonna B, della tabella al punto 1.2 della parte 3;

c) nessuno dei valori medi stabiliti per i metalli pesanti, le diossine e i furani durante il periodo di campionamento supera i valori limite di emissione di cui ai punti 1.3 e 1.4 della parte 3 o nella parte 4 oppure calcolati conformemente alla parte 4;

d) per il monossido di carbonio (CO):

i) nel caso di impianti di incenerimento dei rifiuti:

— almeno il 97 % dei valori medi giornalieri nel corso dell'anno non supera il valore limite di emissione stabiliti nel punto 1.5, lettera a), della parte 3; e

— almeno il 95 % di tutti i valori medi su 10 minuti in un qualsiasi periodo di 24 ore oppure tutti i valori medi su 30 minuti nello stesso periodo non superano i valori limite di emissione di cui al punto 1.5, lettere b) e c) della parte 3; nel caso di impianti di incenerimento dei rifiuti incui i gas prodotti dal processo di incenerimento sono portati ad una temperatura di almeno 1 100 °C per almeno 2 secondi, gli Stati membri possono applicare un periodo di valutazione di 7 giorni per i valori medi su 10 minuti.

ii) nel caso di impianti di coincenerimento dei rifiuti: sono rispettate le disposizioni della parte 4.

1.2. I valori medi su 30 minuti e i valori medi su 10 minuti sono determinati durante il periodo di effettivo funzionamento (esclusi i periodi di avvio e di arresto se non vengono inceneriti rifiuti) in base ai valori misurati, previa sottrazione del valore rilevato nell'intervallo di confidenza specificato al punto 1.3 della parte 6. I valori medi giornalieri sono determinati in base ai valori medi convalidati.

Per ottenere un valore medio giornaliero valido non possono essere scartati più di 5 valori medi su 30 minuti in un giorno qualsiasi a causa di disfunzioni o per ragioni di manutenzione del sistema di misurazione in continuo. Non più di 10 valori medi giornalieri all'anno possono essere scartati a causa di disfunzioni o per ragioni di manutenzione del sistema di misurazione in continuo.

1.3. I valori medi durante il periodo di campionamento e i valori medi in caso di misurazioni periodiche di HF, HCl e SO_2 sono determinati come previsto agli articoli 45, paragrafo 1, lettera e), e 48, paragrafo 3, e al punto 1 della parte 6.

2. Valori limite di emissione nell'acqua.

I valori limite di emissione per l'acqua si considerano rispettati se:

a) per il totale dei solidi sospesi il 95 % e il 100 % dei valori misurati non superano i rispettivi valori limite di emissione di cui alla parte 5;

b) per i metalli pesanti (Hg, Cd, TI, As, Pb, Cr, Cu, Ni e Zn) non più di una misurazione all'anno supera i valori limite di emissione di cui alla parte 5; ovvero, ove lo Stato membro effettui più di venti campionamenti l'anno, se non oltre il 5 % di tali campioni supera i valori limite di emissione di cui alla parte 5;

c) per le diossine e i furani, i risultati delle misurazioni non superano i valori limite di emissione di cui alla parte 5.

ALLEGATO VII

Disposizioni tecniche relative ad installazioni ed attività che utilizzano solventi organici

PARTE 1

Attività

1. In ciascuno dei punti che seguono l'attività comprende la pulizia dell'apparecchiatura ma non quella dei prodotti, salvo indicazione contraria.

2. Rivestimento adesivo

Qualsiasi attività in cui un adesivo è applicato ad una superficie, ad eccezione dei rivestimenti e laminati adesivi nelle attività di stampa.

3. Attività di rivestimento

Qualsiasi attività in cui un film continuo di un rivestimento è applicato in una sola volta o in più volte su:

a) uno qualsiasi dei seguenti veicoli:

i) autovetture nuove, definite come veicoli della categoria M1 nella direttiva 2007/46/CE del Parlamento europeo e del Consiglio, del 5 settembre 2007, che istituisce un quadro per l'omologazione dei veicoli a motore e dei loro rimorchi, nonché dei sistemi, componenti ed entità tecniche destinati a tali veicoli ([1]), e di categoria N1 nella misura in cui esse sono trattate nella stessa installazione dei veicoli M1;

ii) cabine di autocarri, definite come la cabina per il guidatore e tutto l'alloggiamento integrato per l'apparecchiatura tecnica dei veicoli delle categorie N2 e N3 nella direttiva 2007/46/CE;

iii) furgoni e autocarri, definiti come veicoli delle categorie N1, N2 e N3 nella direttiva 2007/46/CE, ma escluse le cabine di autocarri;

iv) autobus, definiti come veicoli delle categorie M2 e M3 nella direttiva 2007/46/CE;

v) rimorchi, definiti nelle categorie O1, O2, O3 e O4 nella direttiva 2007/46/CE;

b) superfici metalliche e di plastica, comprese le superfici di aeroplani, navi, treni, ecc.;

c) superfici di legno;

d) superfici tessili, di tessuto, di film e di carta;

e) cuoio.

Le attività di rivestimento non comprendono il rivestimento metallico di substrati mediante tecniche di elettroforesi e spruzzatura chimica. Se l'attività di rivestimento comprende una fase durante la quale è stampato lo stesso articolo, indipendentemente dalla tecnica utilizzata, questa fase di stampa è considerata parte dell'attività di rivestimento. Non sono però incluse le attività di stampa a sé stanti, ma possono essere contemplate dal capo V della presente direttiva se l'attività di stampa rientra nell'ambito di applicazione della stessa.

4. Verniciatura in continuo di metalli (coil coating)

Qualsiasi attività per rivestire acciaio in bobine, acciaio inossidabile, acciaio rivestito, leghe di rame o nastro di alluminio con rivestimento filmogeno o rivestimento con lamine in un processo in continuo.

([1]) GU L 263 del 9.10.2007, pag. 1.

5. Pulitura a secco

Qualsiasi attività industriale o commerciale che utilizza composti organici volatili in un'installazione di pulitura di indumenti, elementi di arredamento e prodotti di consumo analoghi, ad eccezione della rimozione manuale di macchie e chiazze nell'industria tessile e dell'abbigliamento.

6. Fabbricazione di calzature

Qualsiasi attività di produzione di calzature, o di parti di esse.

7. Fabbricazione di miscele per rivestimenti, vernici, inchiostri e adesivi

La fabbricazione dei prodotti finali sopra indicati e di quelli intermedi se effettuata nello stesso sito mediante miscela di pigmenti, resine e materiali adesivi con solventi organici o altre basi, comprese attività di dispersione e di dispersione preliminare, correzioni di viscosità e tinta, nonché operazioni di riempimento del contenitore con il prodotto finale.

8. Fabbricazione di prodotti farmaceutici

Sintesi chimica, fermentazione, estrazione, formulazione e finitura di prodotti farmaceutici e, se effettuata nello stesso sito, la fabbricazione di prodotti intermedi.

9. Stampa

Qualsiasi attività di riproduzione di testi e/o immagini nella quale, mediante un supporto dell'immagine, l'inchiostro è trasferito su qualsiasi tipo di superficie. Sono comprese le tecniche correlate di verniciatura, rivestimento e laminazione. Tuttavia, nell'ambito di applicazione del capo V rientrano soltanto i sottoprocessi seguenti:

a) flessografia — un'attività di stampa rilievografica, con un supporto dell'immagine di gomma o fotopolimeri elastici, in cui la zona stampante si trova al di sopra della zona non stampante, che impiega inchiostri a bassa viscosità che seccano mediante evaporazione;

b) offset — un'attività di stampa con sistema a bobina con un supporto dell'immagine in cui la zona stampante e quella non stampante sono sullo stesso piano: per «sistema a bobina» si intende che il materiale da stampare è immesso nella macchina da una bobina e non in lamine separate. La zona non stampante è trattata in modo da attirare acqua e quindi respingere inchiostro. La zona stampante è trattata per assorbire e trasmettere inchiostro sulla superficie da stampare. L'evaporazione avviene in un forno dove si utilizza aria calda per riscaldare il materiale stampato;

c) laminazione associata all'attività di stampa — si fanno aderire insieme due o più materiali flessibili per produrre laminati;

d) fabbricazione di carta per rotocalco — rotocalcografia per stampare carta destinata a riviste, opuscoli, cataloghi o prodotti simili, usando inchiostri a base di toluene;

e) rotocalcografia — un'attività di stampa incavografica nella quale il supporto dell'immagine è un cilindro in cui la zona stampante si trova al di sotto della zona non stampante e vengono usati inchiostri liquidi che asciugano mediante evaporazione. Le cellette sono riempite con inchiostro e l'eccesso è rimosso dalla zona non stampante prima che la zona stampante venga a contatto del cilindro e assorba l'inchiostro dalle cellette;

f) offset dal rotolo — un'attività di stampa con sistema a bobina, nella quale l'inchiostro è trasferito sulla superficie da stampare facendolo passare attraverso un supporto dell'immagine poroso in cui la zona stampante è aperta e quella non stampante è isolata ermeticamente, usando inchiostri liquidi che seccano soltanto mediante evaporazione. Per «sistema a bobina» si intende che il materiale da stampare è immesso nella macchina da una bobina e non in lamine separate;

g) laccatura — un'attività di applicazione ad un materiale flessibile di una vernice o di un rivestimento adesivo in vista della successiva sigillatura del materiale di imballaggio.

10. Conversione di gomma

Qualsiasi attività di miscela, macinazione, dosaggio, calandratura, estrusione e vulcanizzazione di gomma naturale o sintetica e ogni operazione ausiliaria per trasformare gomma naturale o sintetica in un prodotto finito.

11. Pulizia di superficie

Qualsiasi attività, a parte la pulitura a secco, che utilizza solventi organici per eliminare la contaminazione dalla superficie di materiali, compresa la sgrassatura. Un'attività di pulizia comprendente più di una fase prima o dopo qualsiasi altra fase di lavorazione viene considerata attività di pulizia di superficie. Questa attività non riguarda la pulizia dell'attrezzatura, bensì la pulizia della superficie dei prodotti.

12. Estrazione di olio vegetale e grasso animale e attività di raffinazione di olio vegetale

Qualsiasi attività di estrazione di olio vegetale da semi e altre sostanze vegetali, la lavorazione di residui secchi per la produzione di mangimi, la depurazione di grassi e oli vegetali ricavati da semi, sostanze vegetali e/o sostanze animali.

13. Finitura di veicoli

Qualsiasi attività industriale o commerciale di rivestimento nonché attività associata di sgrassatura riguardante:

a) il rivestimento originale dei veicoli stradali come definiti nella direttiva 2007/46/CE, o parti di essi, con materiali del tipo di finitura se il trattamento è eseguito al di fuori della linea originale di produzione;

b) il rivestimento di rimorchi (compresi i semirimorchi) (categoria O nella direttiva 2007/46/CE).

14. Rivestimento di filo per avvolgimento

Qualsiasi attività di rivestimento di conduttori metallici usati per avvolgimenti di trasformatori, motori, ecc.

15. Impregnazione del legno

Qualsiasi attività di applicazione al legno di antisettici.

16. Stratificazione di legno e plastica

Qualsiasi attività in cui si fanno aderire insieme legno e/o plastica per produrre laminati.

PARTE 2

Soglie e valori limite di emissione

I valori limite di emissione negli scarichi gassosi sono calcolati a una temperatura di 273,15 K e a una pressione di 101,3 kPa.

	Attività (soglia di consumo di solvente in Mg/anno)	Soglia (soglie di consumo di solvente in Mg/anno)	Valori limite di emissione negli scarichi gassosi (mg C/Nm^3)	Valori limite di emissione diffusa (percentuale di input di solvente)		Valori limite di emissione totale		Disposizioni speciali
				Installazioni nuove	Installazioni esistenti	Installazioni nuove	Installazioni esistenti	
1	Stampa offset (> 15)	15 – 25 > 25	100 20		30 (1) 30 (1)			(1) Il residuo di solvente nel prodotto finito non va considerato parte delle emissioni diffuse.
2	Carta per rotocalco (> 25)		75	10	15			
3	Altri tipi di rotocalcografia, flessografia, offset dal rotolo, unità di laminazione o laccatura (> 15), offset dal rotolo su tessili/cartone (> 30)	15 – 25 > 25 > 30 (1)	100 100 100		25 20 20			(1) Soglia per offset dal rotolo su tessili e cartone.
4	Pulizia di superficie usando composti specificati all'articolo 59, paragrafo 5. (> 1)	1 – 5 > 5	20 (1) 20 (1)		15 10			(1) Il valore limite si riferisce alla massa di composti in mg/Nm^3 e non al carbonio totale.
5	Altri tipi di pulizia di superficie (> 2)	2 – 10 > 10	75 (1) 75 (1)		20 (1) 15 (1)			(1) Le installazioni che dimostrano all'autorità competente che il tenore medio di solvente organico di tutti i materiali da pulizia usati non supera il 30 % in peso sono esonerate dall'applicare questi valori.
6	Rivestimento di veicoli (< 15) e finitura di veicoli	> 0,5	50 (1)		25			(1) L'ottemperanza al disposto del punto 2 della parte 8 è dimostrata in base a misurazioni della durata media di 15 minuti.
7	Verniciatura in continuo (coil coating) (> 25)		50 (1)	5	10			(1) Per le installazioni che usano tecniche che consentono di riutilizzare i solventi recuperati, il valore limite di emissione è 150.

	Attività (soglia di consumo di solvente in Mg/anno)	Soglia (soglie di consumo di solvente in Mg/anno)	Valori limite di emissione negli scarichi gassosi (mg C/Nm^3)	Valori limite di emissione diffusa (percentuale di input di solvente)		Valori limite di emissione totale		Disposizioni speciali
				Installazioni nuove	Installazioni esistenti	Installazioni nuove	Installazioni esistenti	
8	Altri rivestimenti, compreso il rivestimento di metalli, plastica, tessili ([5]), tessuti, film e carta (> 5)	5 – 15 > 15	100 ([1]) ([4]) 50/75 ([2]) ([3]) ([4])		25 ([4]) 20 ([4])			([1]) Il valore limite di emissione concerne l'applicazione del rivestimento e i processi di essiccazione in condizioni di confinamento. ([2]) Il primo valore limite di emissione concerne i processi di essiccazione, il secondo i processi di applicazione del rivestimento. ([3]) Per le installazioni di rivestimento di tessili che applicano tecniche che consentono di riutilizzare i solventi recuperati, il valore limite di emissione applicato ai processi di applicazione del rivestimento e di essiccazione considerati insieme è di 150. ([4]) Le attività di rivestimento che non possono essere svolte in condizioni di confinamento (come la costruzione di navi o la verniciatura di aerei) possono essere esonerate da questi valori, a norma dell'articolo 59, paragrafo 3. ([5]) L'offset dal rotolo su tessili è coperta dall'attività n. 3.
9	Rivestimento di filo per avvolgimento (> 5)					10 g/kg ([1]) 5 g/kg ([2])		([1]) Si applica alle installazioni dove il diametro medio del filo è ≤ 0,1 mm. ([2]) Si applica a tutte le altre installazioni.
10	Rivestimento delle superfici di legno (> 15)	15 – 25 > 25	100 ([1]) 50/75 ([2])		25 20			([1]) Il valore limite di emissione si applica ai processi di applicazione del rivestimento ed essiccazione in condizioni di confinamento. ([2]) Il primo valore concerne i processi di essiccazione e il secondo quelli di applicazione del rivestimento.
11	Pulitura a secco					20 g/kg ([1]) ([2])		([1]) Espressa in massa di solvente emesso per chilogrammo di prodotto pulito e asciugato. ([2]) Il valore limite di emissione di cui al punto 2 della parte 4 non si applica a questa attività.

	Attività (soglia di consumo di solvente in Mg/anno)	Soglia (soglie di consumo di solvente in Mg/anno)	Valori limite di emissione negli scarichi gassosi (mg C/Nm^3)	Valori limite di emissione diffusa (percentuale di input di solvente)		Valori limite di emissione totale		Disposizioni speciali
				Installazioni nuove	Installazioni esistenti	Installazioni nuove	Installazioni esistenti	
12	Impregnazione del legno (> 25)		100 (1)	45		11 kg/m^3		(1) Il valore limite di emissione non si applica all'impregnazione con creosoto.
13	Rivestimento di cuoio (> 10)	10 – 25 > 25 > 10 (1)				85 g/m^2 75 g/m^2 150 g/m^2		I valori limite di emissione sono espressi in grammi di solvente emesso per m^2 di prodotto fabbricato. (1) Per le attività di rivestimento di cuoio nell'arredamento e nella pelletteria particolare utilizzata come piccoli articoli per i consumatori (per esempio borse, cinture, portafogli, ecc.).
14	Fabbricazione di calzature (> 5)					25 g per paio		Il valore limite di emissione è espresso in grammi di solvente emesso per paio completo di calzature prodotto.
15	Stratificazione di legno e plastica (> 5)					30 g/m^2		
16	Rivestimenti adesivi (> 5)	5 – 15 > 15	50 (1) 50 (1)	25 20				(1) Se sono applicate tecniche che consentono il riuso del solvente recuperato, il valore limite di emissione negli scarichi gassosi è 150.
17	Fabbricazione di miscele per rivestimenti, vernici, inchiostri e adesivi (> 100)	100 – 1 000 > 1 000	150 150	5 3		5 % di input di solvente 3 % di input di solvente		Il valore limite di emissioni diffuse non comprende il solvente venduto come parte di una miscela per rivestimenti in un contenitore sigillato.
18	Conversione della gomma (> 15)		20 (1)	25 (2)		25 % di input di solvente		(1) Se si applicano tecniche che consentono il riuso del solvente recuperato, il valore limite di emissione negli scarichi gassosi è 150. (2) Il valore limite di emissione diffusa non comprende il solvente venduto come parti di prodotti o miscele in un contenitore sigillato.

	Attività (soglia di consumo di solvente in Mg/anno)	Soglia (soglie di consumo di solvente in Mg/anno)	Valori limite di emissione negli scarichi gassosi (mg C/Nm^3)	Valori limite di emissione diffusa (percentuale di input di solvente)		Valori limite di emissione totale		Disposizioni speciali
				Installazioni nuove	Installazioni esistenti	Installazioni nuove	Installazioni esistenti	
19	Estrazione di olio vegetale e grasso animale e attività di raffinazione di olio vegetale (> 10)					Grasso animale: 1,5 kg/Mg ricino 3 kg/Mg colza: 1 kg/Mg semi di girasole: 1 kg/Mg semi di soia (frantumazione normale): 0,8 kg/Mg semi di soia (fiocchi bianchi): 1,2 kg/Mg altri semi e altre sostanze vegetali: 3 kg/Mg (1) 1,5 kg/Mg (2) 4 kg/Mg (3)		(1) I valori limite di emissione totale per le installazioni che lavorano partite individuali di semi e altre sostanze vegetali dovrebbero essere fissati dalle autorità competenti caso per caso, applicando le migliori tecniche disponibili. (2) Si applica a tutti i processi di frazionamento, ad esclusione della demucillaginazione (eliminazione delle materie gommose dall'olio). (3) Si applica alla demucillaginazione.
20	Fabbricazione di prodotti farmaceutici (> 50)		20 (1)	5 (2)	15 (2)	5 % di input di solvente	15 % di input di solvente	(1) Se si applicano tecniche che consentono il riuso del solvente recuperato, il valore limite di emissione negli scarichi gassosi è 150. (2) Il valore limite di emissione diffusa non comprende il solvente venduto come parte di prodotti o miscele in un contenitore sigillato.

PARTE 3

Valori limite di emissione per le installazioni dell'industria del rivestimento di veicoli

1. I valori limite di emissione totale sono espressi in grammi di solvente organico emesso per metro quadrato di superficie del prodotto e in chilogrammi di solvente organico emesso in rapporto con la carrozzeria del veicolo.

2. La superficie dei prodotti di cui alla tabella al punto 3 è definita come la superficie calcolata sulla base del rivestimento per elettroforesi totale e la superficie di tutte le parti eventualmente aggiunte nelle fasi successive del processo di rivestimento, rivestite con gli stessi rivestimenti usati per il prodotto in questione, o la superficie totale del prodotto rivestito nell'installazione.

   La superficie del rivestimento per elettroforesi è calcolata con la seguente formula:

$$\frac{2 \times \text{peso totale della scocca}}{\text{Spessore medio della lamiera} \times \text{densità della lamiera}}$$

   Questo metodo si applica anche per altre parti di lamiera rivestite.

   La progettazione assistita da calcolatore o altri metodi equivalenti sono usati per calcolare la superficie delle altre parti aggiunte oppure la superficie totale rivestita nell'installazione.

3. Nella tabella seguente, i valori limite di emissione totale si riferiscono a tutte le tappe del processo che si svolgono nella stessa installazione, dal rivestimento mediante elettroforesi o altro processo, sino alle operazioni di lucidatura finale comprese, nonché al solvente utilizzato per pulire l'attrezzatura, comprese le cabine di verniciatura a spruzzo e altre attrezzature fisse sia durante il tempo di produzione che al di fuori di esso.

Attività (soglia di consumo di solvente in Mg/anno)	Soglia di produzione (produzione annuale del prodotto rivestito)	Valore limite di emissione totale	
		Installazioni nuove	Installazioni esistenti
Rivestimento di autovetture nuove (> 15)	> 5 000	45 g/m^2 o 1,3 kg/carrozzeria + 33 g/m^2	60 g/m^2 o 1,9 kg/carrozzeria + 41 g/m^2
	≤ 5 000 monoscocca o > 3 500 telaio	90 g/m^2 o 1,5 kg/carrozzeria + 70 g/m^2	90 g/m^2 o 1,5 kg/carrozzeria + 70 g/m^2
		Valore limite di emissione totale (g/m^2)	
Rivestimento di cabine di autocarri nuovi (> 15)	≤ 5 000	65	85
	> 5 000	55	75
Rivestimento di furgoni e autocarri nuovi (> 15)	≤ 2 500	90	120
	> 2 500	70	90
Rivestimento di autobus nuovi (> 15)	≤ 2 000	210	290
	> 2 000	150	225

4. Le installazioni di rivestimento di veicoli con soglie di consumo di solvente inferiori ai valori riportati nella tabella al punto 3 devono rispettare i requisiti per il settore finitura di veicoli di cui alla parte 2.

PARTE 4

Valori limite di emissione relativi ai composti organici volatili aventi frasi di rischio specifiche

1. Per le emissioni dei composti organici volatili di cui all'articolo 58 vale a dire emissioni in cui il flusso di massa della somma dei composti che comportano l'etichettatura di cui al detto articolo è uguale o superiore a 10 g/h, deve essere rispettato un valore limite di emissione di 2 mg/Nm^3. Il valore limite di emissione si riferisce alla somma di massa dei singoli composti.

2. Per le emissioni dei composti organici volatili alogenati cui sono assegnate, o sulle quali devono essere apposte, le indicazioni di pericolo H341 o H351, vale a dire emissioni in cui il flusso di massa della somma dei composti che comportano le indicazioni di pericolo H341 o H351 è uguale o superiore a 100 g/h, è rispettato un valore limite di emissione di 20 mg/Nm^3. Il valore limite di emissione si riferisce alla somma di massa dei singoli composti.

PARTE 5

Programma di riduzione

1. Il gestore può utilizzare qualsiasi programma di riduzione appositamente elaborato per la sua installazione.

2. In caso di applicazione di rivestimenti, vernici, adesivi o inchiostri può essere utilizzato il programma seguente. Qualora il metodo seguente sia inadeguato, l'autorità competente può autorizzare il gestore ad applicare qualsiasi programma alternativo che permetta di conseguire riduzioni delle emissioni equivalenti a quelli conseguiti se fossero applicati i valori limite di emissione di cui alle parti 2 e 3. Il programma è impostato in modo da tener conto degli elementi seguenti:

   a) se i prodotti di sostituzione a tenore di solvente zero o ridotto sono ancora in fase di sviluppo, il gestore dispone di un periodo di proroga per attuare i suoi piani di riduzione di emissione;

   b) il punto di riferimento per le riduzioni di emissione dovrebbe corrispondere il più fedelmente possibile alle emissioni che ci sarebbero state in assenza di un intervento di riduzione.

3. Il programma seguente si applica alle installazioni per le quali un tenore costante in materia solida del prodotto può essere ipotizzato:

   a) L'emissione annua di riferimento è calcolata come segue:

      i) La massa totale di materia solida nella quantità di rivestimento e/o inchiostro, vernice o adesivo consumata in un anno è determinata. Per materia solida si intendono tutte le sostanze contenute nelle vernici, negli inchiostri e negli adesivi che diventano solide dopo l'evaporazione dell'acqua o dei composti organici volatili.

      ii) Le emissioni annue di riferimento sono calcolate moltiplicando la massa determinata di cui al punto i) per l'opportuno fattore elencato nella tabella seguente. Le autorità competenti possono modificare questi fattori per singole installazioni onde riflettere il provato aumento di efficienza nell'uso di materia solida.

Attività	Fattore di moltiplicazione da usare per la lettera a), punto ii)
Rotocalcografia, flessografia; laminazione associata all'attività di stampa; laccatura associata all'attività di stampa; rivestimento del legno; rivestimento di tessili, tessuti o carta; rivestimento adesivo	4
Verniciatura in continuo (coil coating), finitura di veicoli	3
Rivestimento a contatto di prodotti alimentari, rivestimenti aerospaziali	2,33
Altri rivestimenti e offset dal rotolo	1,5

   b) L'emissione bersaglio è uguale all'emissione annua di riferimento moltiplicata per una percentuale pari:

      i) (al valore limite di emissione diffusa + 15), per le installazioni che rientrano nel punto 6 e nella fascia di soglia inferiore dei punti 8 e 10 della parte 2;

      ii) (al valore limite di emissione diffusa + 5) per tutti le altre installazioni.

   c) La conformità è realizzata se l'emissione effettiva di solvente determinata in base al piano di gestione dei solventi è inferiore o uguale all'emissione bersaglio.

PARTE 6

Controllo delle emissioni

1. I canali muniti di dispositivi di abbattimento e con più di 10 kg/h di carbonio organico totale al punto finale di scarico, sono oggetto di un monitoraggio in continuo delle emissioni onde verificarne la conformità.

2. Negli altri casi gli Stati membri provvedono affinché vengano eseguite misurazioni in continuo o periodiche. Per le misurazioni periodiche si devono ottenere almeno tre valori di misurazione durante ogni misurazione.

3. Non sono richieste misurazioni quando il dispositivo di abbattimento di fine ciclo non è tenuto a conformarsi alla presente direttiva.

PARTE 7

Piano di gestione dei solventi

1. Principi

Il piano di gestione dei solventi serve a:

a) verificare la conformità come specificato all'articolo 62;

b) individuare le future opzioni di riduzione;

c) consentire di mettere a disposizione del pubblico informazioni in materia di consumo di solvente, emissioni di solvente e conformità alle prescrizioni del capo V.

2. Definizioni

Le seguenti definizioni forniscono un quadro di riferimento per elaborare il bilancio di massa.

Input di solventi organici (I):

I1 La quantità di solventi organici, o la loro quantità nelle miscele acquistate che sono usate come input nel processo nell'arco di tempo in cui viene calcolato il bilancio di massa.

I2 La quantità di solventi organici, o la loro quantità nelle miscele, recuperati e reimmessi come solventi nel processo. Il solvente riciclato è registrato ogniqualvolta sia usato per svolgere l'attività.

Output di solventi organici (O):

O1 Emissioni negli scarichi gassosi.

O2 Solventi organici dispersi nell'acqua, tenendo conto del trattamento delle acque reflue nel calcolare O5.

O3 La quantità di solventi organici che rimane come contaminante o residuo nei prodotti all'uscita del processo.

O4 Emissioni non catturate di solventi organici nell'aria. Ciò comprende la ventilazione generale dei locali, nei quali l'aria è scaricata all'esterno attraverso finestre, porte, sfiati e aperture simili.

O5 Solventi organici e/o composti organici persi a causa di reazioni chimiche o fisiche (inclusi quelli distrutti mediante incenerimento o altri trattamenti di scarichi gassosi o acque reflue, o catturati, mediante assorbimento, se non sono registrati ai punti O6, O7 o O8).

O6 Solventi organici contenuti nei rifiuti di raccolta.

O7 Solventi organici o solventi organici contenuti in miscele che sono o saranno venduti come prodotto a validità commerciale.

O8 Solventi organici contenuti in miscele recuperati per riuso, ma non per immissione nel processo, se non sono registrati al punto O7.

O9 Solventi organici scaricati in altro modo.

3. Uso del piano di gestione dei solventi per la verifica di conformità.

L'uso del piano di gestione dei solventi è determinato in base al requisito particolare da verificare, come segue:

a) verifica della conformità rispetto al sistema di riduzione stabilito nella parte 5, con un valore limite di emissione totale espresso in emissioni di solvente per unità di prodotto, ove non altrimenti specificato nelle parti 2 e 3.

i) per tutte le attività che utilizzano il sistema di riduzione stabilito nella parte 5, il piano di gestione dei solventi è elaborato ogni anno per determinare il consumo (C). Il consumo è calcolato secondo la formula seguente:

$$C = I1 - O8$$

In parallelo si determinano anche le materie solide usate nel rivestimento per calcolare l'emissione di riferimento annua e l'emissione bersaglio ogni anno.

ii) per valutare la conformità ad un valore limite di emissione totale espresso in emissioni di solvente per unità di prodotto, ove non altrimenti specificato nelle parti 2 e 3, il piano di gestione dei solventi è elaborato ogni anno per determinare le emissioni (E). Le emissioni sono calcolate con la formula seguente:

$$E = F + O1$$

Dove F è l'emissione diffusa quale definita alla lettera b, punto i). Il valore di emissione è poi diviso per il pertinente parametro di prodotto.

iii) per valutare la conformità ai requisiti dell'articolo 59, paragrafo 6, lettera b), punto ii), il piano di gestione dei solventi è ogni anno per determinare le emissioni totali di tutte le attività interessate; questa cifra è poi comparata con le emissioni totali che si sarebbero avute se fossero stati rispettati per ogni singola attività i requisiti delle parti 2, 3 e 5.

b) Determinazione delle emissioni diffuse per raffronto con i valori limite di emissione diffusa della parte 2:

i) L'emissione diffusa è calcolata secondo una delle seguenti formule;

$$F = I1 - O1 - O5 - O6 - O7 - O8$$

oppure

$$F = O2 + O3 + O4 + O9$$

F è determinata sia mediante misurazioni dirette delle quantità sia mediante un metodo o un calcolo equivalente, ad esempio utilizzando l'efficienza di cattura del processo.

Il valore limite di emissione diffusa è espresso in percentuale dell'input, che è calcolato con la seguente formula:

$$I = I1 + I2$$

ii) La determinazione delle emissioni diffuse è effettuata mediante una serie breve ma completa di misurazioni e non deve ripetuta sino all'eventuale modifica dell'impianto.

PARTE 8

Valutazione della conformità ai valori limite di emissione negli scarichi gassosi

1. In caso di misurazioni in continuo la conformità ai valori limite di emissione è considerata raggiunta se:

   a) nessuna delle medie aritmetiche di tutte le letture valide prese durante un qualsiasi periodo di 24 ore di esercizio di un'installazione o di un'attività, ad eccezione delle operazioni di avviamento, arresto e manutenzione delle attrezzature supera i valori limite di emissione,

   b) nessuna delle medie orarie supera i valori limite di emissione stabiliti di un fattore superiore a 1,5.

2. Per le misurazioni periodiche la conformità ai valori limite di emissione è considerata raggiunta se nel corso di un controllo:

   a) la media di tutti i valori di misurazione non supera i valori limite di emissione;

   b) nessuna delle medie orarie supera il valore limite di emissione stabilito di un fattore superiore a 1,5.

3. La conformità alla parte 4 è verificata sulla base della somma delle concentrazioni di massa dei singoli COV interessati. In tutti gli altri casi si prende come riferimento la massa totale di carbonio organico emesso, ove non altrimenti specificato nella parte 2.

4. Nel determinare la concentrazione di massa dell'inquinante nello scarico gassoso non vengono presi in considerazione i volumi di gas che possono essere aggiunti, ove tecnicamente giustificato, agli scarichi gassosi per scopi di raffreddamento o diluizione.

ALLEGATO VIII

Disposizioni tecniche relative alle installazioni che producono biossido di titanio

PARTE 1

Valori limite di emissione per le emissioni nell'acqua

1. Nel caso di installazioni che utilizzano il procedimento al solfato (come media annuale):

   550 kg di solfato per Mg di biossido di titano prodotto;

2. Nel caso di installazioni che utilizzano il procedimento con cloruro (come media annuale):

   a) 130 kg di cloruro per Mg di biossido di titanio prodotto se si utilizza rutilio naturale;

   b) 228 kg di cloruro per Mg di biossido di titanio prodotto se si utilizza rutilio sintetico;

   c) 330 kg di cloruro per Mg di biossido di titanio prodotto se si utilizza «slag». Le installazioni che scaricano in acque salate (estuariali, costiere, d'altura) possono essere soggetti ad un valore limite di emissione di 450 kg di cloruro per Mg di biossido di titanio prodotto se si utilizza «slag».

3. Per installazioni che utilizzano il processo con cloruro e che utilizzano più di un tipo di minerale, i valori limite di emissione di cui al punto 2 si applicano in proporzione ai quantitativi di ciascun minerale utilizzato.

PARTE 2

Valori limite di emissione nell'atmosfera

1. I valori limite di emissione espressi come in concentrazioni di massa per metro cubo (Nm^3) sono calcolati a una temperatura di 273,15 K ad una pressione di 101,3 kPa.

2. Per le polveri: 50 mg/Nm^3 come media oraria dalle fonti più importanti e 150 mg/Nm^3 come media oraria dalle altre fonti.

3. Per l'anidride solforosa e solforica gassosa scaricate dalla digestione e dalla calcinazione, compresi gli acidi vescicolari calcolati come SO_2 equivalente a:

   a) 6 kg per Mg di biossido di titanio prodotto come media annuale;

   b) 500 mg/Nm^3 come media oraria per gli impianti per la concentrazione dei rifiuti acidi.

4. Per il cloro nel caso di installazioni che utilizzano il procedimento con cloruro:

   a) 5 mg/Nm^3 come media giornaliera;

   b) 40 mg/Nm^3 in ogni momento.

PARTE 3

Controllo delle emissioni

Il controllo delle emissioni nell'atmosfera comprende almeno il monitoraggio in continuo:

a) dell'anidride solforosa o solforica gassosa scaricate dalla digestione e dalla calcinazione da impianti per la concentrazione dei rifiuti acidi in installazioni che utilizzano il procedimento al solfato;

b) il cloro proveniente dalle fonti principali all'interno di installazioni che utilizzano il procedimento con cloruro;

c) polvere provenienti dalle fonti principali.

ALLEGATO IX

PARTE A

Direttive abrogate e loro successive modifiche

(previste all'articolo 81)

Direttiva 78/176/CEE del Consiglio (GU L 54 del 25.2.1978, pag. 19).	
Direttiva 83/29/CEE del Consiglio (GU L 32 del 3.2.1983, pag. 28).	
Direttiva 91/692/CEE del Consiglio (GU L 377 del 31.12.1991, pag. 48).	esclusivamente l'allegato I, lettera b)
Direttiva 82/883/CEE del Consiglio (GU L 378 del 31.12.1982, pag. 1).	
Atto di adesione del 1985	esclusivamente l'allegato I, punto X.1, lettera o)
Atto di adesione del 1994	esclusivamente l'allegato I, punto VIII.A.6
Regolamento (CE) n. 807/2003 del Consiglio (GU L 122 del 16.5.2003, pag. 36).	esclusivamente l'allegato III, punto 34
Regolamento (CE) n. 219/2009 del Parlamento europeo e del Consiglio (GU L 87 del 31.3.2009, pag. 109).	esclusivamente l'allegato, punto 3.1
Direttiva 92/112/CEE del Consiglio (GU L 409 del 31.12.1992, pag. 11).	
Direttiva 1999/13/CE del Consiglio (GU L 85 del 29.3.1999, pag. 1).	
Regolamento (CE) n. 1882/2003 del Parlamento europeo e del Consiglio (GU L 284 del 31.10.2003, pag. 1).	esclusivamente l'allegato I, punto 17
Direttiva 2004/42/CE del Parlamento europeo e del Consiglio (GU L 143 del 30.4.2004, pag. 87).	esclusivamente l'articolo 13, paragrafo 1
Direttiva 2008/112/CE del Parlamento europeo e del Consiglio (GU L 345 del 23.12.2008, pag. 68).	esclusivamente l'articolo 3
Direttiva 2000/76/CE del Parlamento europeo e del Consiglio (GU L 332 del 28.12.2000, pag. 91).	
Regolamento (CE) n. 1137/2008 del Parlamento europeo e del Consiglio (GU L 311 del 21.11.2008, pag. 1).	esclusivamente l'allegato, punto 4.8
Direttiva 2001/80/CE del Parlamento europeo e del Consiglio (GU L 309 del 27.11.2001, pag. 1).	
Direttiva 2006/105/CE del Consiglio (GU L 363 del 20.12.2006, pag. 368).	esclusivamente l'allegato, parte B, punto 2
Direttiva 2009/31/CE del Parlamento europeo e del Consiglio (GU L 140 del 5.6.2009, pag. 114).	esclusivamente l'articolo 33
Direttiva 2008/1/CE del Parlamento europeo e del Consiglio GU L 24 del 29.1.2008, pag. 8).	
Direttiva 2009/31/CE del Parlamento europeo e del Consiglio (GU L 140 del 5.6.2009, pag. 114).	esclusivamente l'articolo 37

PARTE B

Termini di attuazione nel diritto nazionale e di applicazione

(previsti all'articolo 81)

Direttiva	Termine per l'attuazione	Termini di applicazione
78/176/CEE	25 febbraio 1979	
82/883/CEE	31 dicembre 1984	
92/112/CEE	15 giugno 1993	
1999/13/CE	1° aprile 2001	
2000/76/CE	28 dicembre 2000	28 dicembre 2002
		28 dicembre 2005
2001/80/CE	27 novembre 2002	27 novembre 2004
2003/35/CE	25 giugno 2005	
2003/87/CE	31 dicembre 2003	
2008/1/CE	30 ottobre 1999 (1)	30 ottobre 1999
		30 ottobre 2007

(1) La direttiva 2008/1/CE è una versione codificata della direttiva 96/61/CE del Consiglio, del 24 settembre 1996, sulla prevenzione e la riduzione integrate dell'inquinamento (GU L 257 del 10.10.1996, pag. 26) e i termini per l'attuazione e l'applicazione restano in vigore.

ALLEGATO X

Tavola di concordanza

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
Articolo 1, paragrafo 1	Articolo 1	Articolo 1					Articolo 66
—	—	—	—	—	—	—	Articolo 2
Articolo 1, paragrafo 2, lettera a)			Articolo 2, paragrafo 2				Articolo 3, paragrafo 2
Articolo 1, paragrafo 2, lettera b)					Articolo 3, paragrafo 1		Articolo 3, paragrafo 37
Articolo 1, paragrafo 2, lettere c), d) ed e)							—
—	—	—	—	—	—	—	Articolo 66
Articolo 2							Articolo 67
Articolo 3							Articolo 11, lettere d) ed e)
Articolo 4			Articolo 4	Articolo 3, frase introduttiva e paragrafo 1	Articolo 4, paragrafo 1		Articolo 4, paragrafo 1, primo comma
Articolo 5							Articolo 11, lettere d) ed e)
Articolo 6							Articolo 11, lettere d) ed e)
Articolo 7, paragrafo 1		Articolo 10					Articoli 70, paragrafo 1, e 70, paragrafo 2, prima frase
Articolo 7, paragrafi 2 e 3							—
—	—	—	—	—	—	—	Articolo 70, paragrafo 2, seconda frase e articolo 70, paragrafo 3
Articolo 8, paragrafo 1							—
Articolo 8, paragrafo 2							Articolo 26, paragrafo 1, secondo comma
Articolo 9							—
Articolo 10							—
Articolo 11							Articolo 12
Articolo 12							—

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
Articolo 13, paragrafo 1			Articolo 17, paragrafo 1, primo comma e articolo 17, primo comma, prima frase	Articolo 11, paragrafo 1, prima frase e articolo 11, paragrafo 2			Articolo 72, paragrafo 1, prima frase
—	—	—	—	—	—	—	Articolo 72, paragrafo 1, seconda frase
Articolo 13, paragrafi 2, 3 e 4							—
Articolo 14							—
Articolo 15	Articolo 14	Articolo 12	Articolo 21	Articolo 15	Articolo 21	Articolo 18, paragrafi 1 e 3	Articolo 80
Articolo 16	Articolo 15	Articolo 13	Articolo 23	Articolo 17	Articolo 23	Articolo 20	Articolo 84
Allegato I							—
Allegato II, sezione A, frase introduttiva e punto 1							—
Allegato II, sezione A, punto 2							—
Allegato II, sezione B							—
	Articolo 2						—
	Articolo 3						—
	Articolo 4, paragrafo 1 e articolo 4, paragrafo 2, primo comma						—
	Articolo 4, paragrafo 2, secondo comma						—
	Articolo 4, paragrafi 3 e 4						—
	Articolo 5						—
	Articolo 6						—
	Articolo 7						—
	Articolo 8						—
	Articolo 9						—
	Articolo 10						—

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
	Articolo 11, paragrafo 1			Articolo 13, paragrafo 1	Articolo 17, paragrafo 1		Articolo 75, paragrafo 1
—	—	—	—	—	—	—	Articolo 75, paragrafo 2
	Articolo 11, paragrafo 2				Articolo 17, paragrafo 2		—
	Articolo 11, paragrafo 3						—
	Articolo 12						—
	Articolo 13						—
	Allegato I						—
	Allegato II						—
	Allegato III						—
	Allegato IV						—
	Allegato V						—
		Articolo 2, paragrafo 1, frase introduttiva					—
		Articolo 2, paragrafo 1, lettera a), frase introduttiva					—
		Articolo 2, paragrafo 1, lettera a), primo trattino					Articolo 67, lettera a)
		Articolo 2, paragrafo 1, lettera a), secondo trattino					Articolo 67, lettera b)
		Articolo 2, paragrafo 1, lettera a), terzo trattino e articolo 2, paragrafo 1, lettera b), terzo trattino					Articolo 67, lettera d)
		Articolo 2, paragrafo 1, lettera a), quarto, quinto, sesto e settimo trattino					—

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
		Articolo 2, paragrafo 1, lettera b), frase introduttiva e primo, quarto, quinto, sesto e settimo trattino					—
		Articolo 2, paragrafo 1, lettera b), secondo trattino					Articolo 67, lettera c)
		Articolo 2, paragrafo 1, lettera c),					—
		Articolo 2, paragrafo 2					—
		Articolo 3					Articolo 67
		Articolo 4					Articolo 67
		Articolo 5					—
		Articolo 6, primo paragrafo, frase introduttiva					Articolo 68, paragrafo 1
		Articolo 6, primo paragrafo, lettera a)					Allegato VIII, parte 1, punto 1
		Articolo 6, primo paragrafo, lettera b)					Allegato VIII, parte 1, punto 2
		Articolo 6, secondo paragrafo					Allegato VIII, parte 1, punto 3
		Articolo 7					—
		Articolo 8					—
		Articolo 9, paragrafo 1, frase introduttiva					Articolo 69, paragrafo 2
		Articolo 9, paragrafo 1, lettera a), frase introduttiva					—
		Articolo 9, paragrafo 1, lettera a, punto i)					Allegato VIII, parte 2, punto 2
		Articolo 9, paragrafo 1, lettera a), punto ii)					Allegato VIII, parte 2, punto 3, frase introduttiva, e punto 3), lettera a)

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
		Articolo 9, paragrafo 1, lettera a), punto iii)					Articolo 69, paragrafo 1
		Articolo 9, paragrafo 1, lettera a), punto iv)					Allegato VIII, parte 2, punto 3, lettera b)
		Articolo 9, paragrafo 1, lettera a), punto v)					—
		Articolo 9, paragrafo 1, lettera b)					Allegato VIII, parte 2, punto 4
		Articolo 9, paragrafi 2 e 3					—
		Articolo 11					Articolo 11, lettere d) ed e)
		Allegato					—
			Articolo 1				Articolo 1
			Articolo 2, frase introduttiva				Articolo 3, frase introduttiva
			Articolo 2, paragrafo 1	Articolo 2, paragrafo 14			Articolo 3, paragrafo 1
			Articolo 2, paragrafo 3	Articolo 2, paragrafo 1			Articolo 3, paragrafo 3
			Articolo 2, paragrafo 4				—
			Articolo 2, paragrafo 5	Articolo 2, paragrafo 9	Articolo 3, paragrafo 8	Articolo 2, paragrafo 1	Articolo 3, paragrafo 4
			Articolo 2, paragrafo 6, prima frase	Articolo 2, paragrafo 13	Articolo 3, paragrafo 9	Articolo 2, paragrafo 3, prima parte	Articolo 3, paragrafo 5
			Articolo 2, paragrafo 6, seconda frase				Articolo 15, paragrafo 1
			Articolo 2, paragrafo 7				Articolo 3, paragrafo 6
			Articolo 2, paragrafo 8	Articolo 2, paragrafo 5			Articolo 71
			Articolo 2, paragrafo 9, prima frase	Articolo 2, paragrafo 7	Articolo 3, paragrafo 12		Articolo 3, paragrafo 7
			Articolo 2, paragrafo 9, seconda frase				Articolo 4, paragrafo 2, primo comma
—	—	—	—	—	—	—	Articolo 4, paragrafo 2, secondo comma
—	—	—	—	—	—	—	Articolo 4, paragrafo 3

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
			Articolo 2, paragrafo 10				—
—	—	—	—	—	—	—	Articolo 3, paragrafo 8
			Articolo 2, paragrafo 11, prima frase				Articolo 3, paragrafo 9
			Articolo 2, paragrafo 11, seconda frase				Articolo 20, paragrafo 3
			Articolo 2, paragrafo 12, primo comma e allegato IV, frase introduttiva				Articolo 3, paragrafo 10
			Articolo 2, paragrafo 12, secondo comma				Articoli 14, paragrafo 5, lettera a), e articolo 14, paragrafo 6,
			Articolo 2, paragrafo 13	Articolo 2, paragrafo 6	Articolo 3, paragrafo 11	Articolo 2, paragrafo 5	Articolo 3, paragrafo 15
			Articolo 2, paragrafo 14				Articolo 3, paragrafo 16
			Articolo 2, paragrafo 15				Articolo 3, paragrafo 17
—	—	—	—	—	—	—	Articolo 3, paragrafi da 11 a 14, da 18 a 23, da 26 a 30 e da 34 a 36
			Articolo 3, paragrafo 1, frase introduttiva				Articolo 11, frase introduttiva
			Articolo 3, paragrafo 1, lettera a)				Articolo 11, lettere a) e b)
			Articolo 3, paragrafo 1, lettera b)				Articolo 11, lettera c)
			Articolo 3, paragrafo 1, lettera c)				Articolo 11, lettere d) ed e)
			Articolo 3, paragrafo 1, lettera d)				Articolo 11, lettera f)
			Articolo 3, paragrafo 1, lettera e)				Articolo 11, lettera g)
			Articolo 3, paragrafo 1, lettera f)				Articolo 11, lettera h)
			Articolo 3, paragrafo 2				—
			Articolo 5, paragrafo 1				—

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
			Articolo 5, paragrafo 2				Articolo 80, paragrafo 1, secondo comma
			Articolo 6, paragrafo 1, frase introduttiva				Articolo 12, paragrafo 1, primo comma, frase introduttiva
			Articolo 6, paragrafo 1, primo comma, lettere da a) a d)				Articolo 12, paragrafo 1, primo comma, lettere da a) a d)
—	—	—	—	—	—	—	Articolo 12, paragrafo 1, primo comma, lettera e)
			Articolo 6, paragrafo 1, primo comma, lettera e)				Articolo 12, paragrafo 1, primo comma, lettera f)
			Articolo 6, paragrafo 1, primo comma, lettera f)				Articolo 12, paragrafo 1, primo comma, lettera g)
			Articolo 6, paragrafo 1, primo comma, lettera g)				Articolo 12, paragrafo 1, primo comma, lettera h)
			Articolo 6, paragrafo 1, primo comma, lettera h)				Articolo 12, paragrafo 1, primo comma, lettera i)
			Articolo 6, paragrafo 1, primo comma, lettera i)				Articolo 12, paragrafo 1, primo comma, lettera j)
			Articolo 6, paragrafo 1, primo comma, lettera j)				Articolo 12, paragrafo 1, primo comma, lettera k)
			Articolo 6, paragrafo 1, secondo comma				Articolo 12, paragrafo 1, secondo comma
			Articolo 6, paragrafo 2				Articolo 12, paragrafo 2
			Articolo 7				Articolo 5, paragrafo 2
			Articolo 8, primo paragrafo		Articolo 4, paragrafo 3		Articolo 5, paragrafo 1
			Articolo 8, secondo paragrafo				—
			Articolo 9, paragrafo 1, prima parte della frase				Articolo 14, paragrafo 1, primo comma

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
			Articolo 9, paragrafo 1, seconda parte della frase				—
			Articolo 9, paragrafo 2				Articolo 5, paragrafo 3
			Articolo 9, paragrafo 3, primo comma, prima e seconda frase				Articolo 14, paragrafo 1, secondo comma, frase introduttiva e lettere a) e b)
			Articolo 9, paragrafo 3, primo comma, terza frase				Articolo 14, paragrafo 2
—	—	—	—	—	—	—	Articolo 14, paragrafi 3, 4 e 7
—	—	—	—	—	—	—	Articolo 14, paragrafo 5, frase introduttiva e lettera b) del primo comma e articolo 14, paragrafo 5, secondo comma
			Articolo 9, paragrafo 3, secondo comma				—
			Articolo 9, paragrafo 3, terzo comma				Articolo 9, paragrafo 1
			Articolo 9, paragrafo 3, quarto comma				Articolo 9, paragrafo 2
			Articolo 9, paragrafo 3, quinto comma				Articolo 9, paragrafo 3
			Articolo 9, paragrafo 3, sesto comma				Articolo 9, paragrafo 4
—	—	—	—	—	—	—	Articolo 10
			Articolo 9, paragrafo 4, prima parte della prima frase				Articolo 15, paragrafo 2
			Articolo 9, paragrafo 4, seconda parte della prima frase				Articolo 15, paragrafo 4, primo comma
—	—	—	—	—	—	—	Articolo 15, paragrafo 4, commi dal secondo al quinto, e articolo 15, paragrafo 5

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
			Articolo 9, paragrafo 4, seconda frase				Articolo 14, paragrafo 1, secondo comma, lettera g)
—	—	—	—	—	—	—	Articolo 14, paragrafo 1, secondo comma, lettera h)
—	—	—	—	—	—	—	Articolo 15, paragrafo 3
—	—	—	—	—	—	—	Articolo 16
			Articolo 9, paragrafo 5, primo comma				Articolo 14, paragrafo 1, secondo comma, lettera c), punto i)
—	—	—	—	—	—	—	Articolo 14, paragrafo 1, secondo comma, lettera c), punto ii)
—	—	—	—	—	—	—	Articolo 14, paragrafo 1, secondo comma, lettera d)
			Articolo 9, paragrafo 5, secondo comma				—
—	—	—	—	—	—	—	Articolo 14, paragrafo 1, secondo comma, lettera e)
			Articolo 9, paragrafo 6, primo comma				Articolo 14, paragrafo 1, secondo comma, lettera f)
			Articolo 9, paragrafo 6, secondo comma				—
			Articolo 9, paragrafo 7				—
			Articolo 9, paragrafo 8				Articolo 6 e articolo 17, paragrafo 1
—	—	—	—	—	—	—	Articolo 17, paragrafi 2, 3 e 4
			Articolo 10				Articolo 18
			Articolo 11				Articolo 19
			Articolo 12, paragrafo 1				Articolo 20, paragrafo 1
			Articolo 12, paragrafo 2, prima frase				Articolo 20, paragrafo 2, primo comma
			Articolo 12, paragrafo 2, seconda frase				Articolo 20, paragrafo 2, secondo comma
			Articolo 12, paragrafo 2, terza frase				—

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
			Articolo 13, paragrafo 1				Articolo 21, paragrafo 1
—	—	—	—	—	—	—	Articolo 21, paragrafi 2, 3 e 4
			Articolo 13, paragrafo 2, frase introduttiva				Articolo 21, paragrafo 5, frase introduttiva
			Articolo 13, paragrafo 2, lettera a)				Articolo 21, paragrafo 5, lettera a)
			Articolo 13, paragrafo 2, lettera b)				—
			Articolo 13, paragrafo 2, lettera c)				Articolo 21, paragrafo 5, lettera b)
			Articolo 13, paragrafo 2, lettera d)				—
—	—	—	—	—	—	—	Articolo 21, paragrafo 5, lettera c)
—	—	—	—	—	—	—	Articolo 22
—	—	—	—	—	—	—	Articolo 23, paragrafo 1, primo comma
			Articolo 14, frase introduttiva e lettera a)				Articolo 8, paragrafo 1
			Articolo 14, lettera b)				Articolo 7, lettera a) e articolo 14, paragrafo 1, lettera d), punto i)
—	—	—	—	—	—	—	Articolo 7, frase introduttiva e lettere b) e c)
—	—	—	—	—	—	—	Articolo 14, paragrafo 1, lettera d), punto ii)
			Articolo 14, lettera c)				Articolo 23, paragrafo 1, secondo comma
—	—	—	—	—	—	—	Articolo 23, paragrafi da 2 a 6
			Articolo 15, paragrafo 1, primo comma, frase introduttiva e lettere a) e b)	Articolo 12, paragrafo 1, primo comma			Articolo 24, paragrafo 1, primo comma, frase introduttiva e lettere a) e b)
			Articolo 15, paragrafo 1, primo comma, lettera c)				Articolo 24, paragrafo 1, primo comma, lettera c)

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
			Articolo 15, paragrafo 1, secondo comma				Articolo 24, paragrafo 1, secondo comma
			Articolo 15, paragrafo 2				Articolo 24, paragrafo 3, lettera h)
			Articolo 15, paragrafo 3				Articolo 24, paragrafo 4
			Articolo 15, paragrafo 4				Articolo 24, paragrafo 2, frase introduttiva e lettere a) e b)
—	—	—	—	—	—	—	Articolo 24, paragrafo 2, lettere da c) a f), e paragrafo 3 frase introduttiva e lettera a)
			Articolo 16				Articolo 25
			Articolo 17, paragrafo 1, secondo comma				—
			Articolo 17, paragrafo 2, primo comma				Articolo 13, paragrafo 1
—	—	—	—	—	—	—	Articolo 13, paragrafi da 2 a 7
			Articolo 17, paragrafo 2, secondo comma				—
			Articolo 17, paragrafo 3, primo comma, seconda e terza frase	Articolo 11, paragrafo 1, seconda frase			Articolo 72, paragrafo 2
			Articolo 17, paragrafo 3, primo comma, quarta frase				—
—	—	—	—	—	—	—	Articolo 72, paragrafi 3 e 4
			Articolo 17, paragrafo 3, secondo comma				—
			Articolo 17, paragrafo 3, terzo comma	Articolo 11, paragrafo 3			Articolo 73, paragrafo 1
—	—	—	—	—	—	—	Articolo 73, paragrafo 2
			Articolo 17, paragrafo 4				—
—	—	—	—	—	—	—	Articolo 74
—	—	—	—	—	—	—	Articolo 27
			Articolo 18			Articolo 11	Articolo 26
			Articolo 19				—

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
			Articolo 20				—
			Articolo 21				Articolo 80, paragrafo 2
			Articolo 22		Articolo 18	Articolo 17	Articolo 81
—	—	—	—	—	—	—	Articolo 82
			Articolo 23	Articolo 16	Articolo 22	Articolo 19	Articolo 83
—	—	—	—	—	—	—	Articolo 2, paragrafo 1
			Allegato I, paragrafo 1 della frase introduttiva				Articolo 2, paragrafo 2
			Allegato I, paragrafo 2 della frase introduttiva				Allegato I, primo comma della frase introduttiva, prima frase
—	—	—	—	—	—	—	Allegato I, primo comma della frase introduttiva, seconda frase
—	—	—	—	—	—	—	Allegato I, secondo comma della frase introduttiva
			Allegato I, punti da 1.1 a 1.3				Allegato I, punti da 1.1. a 1.3
			Allegato I, punto 1.4.				Allegato I, punto 1.4, lettera a)
—	—	—	—	—	—	—	Allegato I, punto 1.4, lettera b)
			Allegato I, punto 2				Allegato I, punto 2
			Allegato I, punto 3.1				Allegato I, punto 3.1, lettere a) e b)
—	—	—	—	—	—	—	Allegato I, punto 3.1, lettera c)
			Allegato I, punti da 3.2 a 3.5				Allegato I, punti da 3.2 a 3.5
			Allegato I, punto 4				Allegato I, punto 4
			Allegato I, punto 5, frase introduttiva				—
			Allegato I, punti 5.1				Allegato I, punti 5.1, lettere b), f), g), i) e j) e 5.2
—	—	—	—	—	—	—	Allegato I, punto 5.1, lettere a), c), d), e), h), k)

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
			Allegato I, punto 5.2				Allegato I, punto 5.2, lettera a)
			Allegato, punto 5.3				Allegato I, punto 5.3., lettera a), punti i) e ii)
—	—	—	—	—	—	—	Allegato I, punto 5.3., lettera a), punti iii), iv) e v) e 5.3, lettera b)
			Allegato I, punto 5.4				Allegato I, punto 5.4.
—	—	—	—	—	—	—	Allegato I, Punti 5.5 e 5.6
			Allegato I, punto 6.1, lettere a) e b)				Allegato I, punto 6.1, lettere a) e b)
—	—	—	—	—	—	—	Allegato I, punto 6.1, lettera c)
			Allegato I, punti 6.2 – 6.4, lettera b)				Allegato I, punti 6.2 – 6.4, lettera b), punto ii)
—	—	—	—	—	—	—	Allegato I, punto 6.4, lettera b), punto iii)
			Allegato I, punti 6.4, lettera c) – 6.9				Allegato I, punti 6.4, lettera c) – 6.9
—	—	—	—	—	—	—	Allegato I, punti 6.10 e 6.11
			Allegato II				—
			Allegato III				Allegato II, «Aria», e «Acqua», punti da 1 a 12
—	—	—	—	—	—	—	Allegato II, «Acqua», punto 13
			Allegato IV				Allegato III
			Allegato V				Allegato IV
				Articolo 1			Articolo 56
				Articolo 2, paragrafo 2			Articolo 57, paragrafo 1

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
				Articolo 2, paragrafo 3			—
				Articolo 2, paragrafo 4			Articolo 63, paragrafo 1
				Articolo 2, paragrafo 8			Articolo 4, paragrafo 1, terzo comma
				Articolo 2, paragrafo 10			Articolo 57, paragrafo 3
				Articolo 2, paragrafo 11			Articolo 57, paragrafo 2
				Articolo 2, paragrafo 12			Articolo 57, paragrafo 4
				Articolo 2, paragrafo 15			Articolo 57, paragrafo 5
				Articolo 2, paragrafo 16			Articolo 3, paragrafo 44
				Articolo 2, paragrafo 17			Articolo 3, paragrafo 45
				Articolo 2, paragrafo 18			Articolo 3, paragrafo 46
				Articolo 2, paragrafo 19			—
				Articolo 2, paragrafo 20			Articolo 3, paragrafo 47
				Articolo 2, paragrafo 21			Articolo 57, paragrafo 6
				Articolo 2, paragrafo 22			Articolo 57, paragrafo 7
				Articolo 2, paragrafo 23			Articolo 57, paragrafo 8
				Articolo 2, paragrafo 24			Articolo 57, paragrafo 9
				Articolo 2, paragrafo 25			Articolo 57, paragrafo 10
				Articolo 2, paragrafo 26			Articolo 57, paragrafo 11
				Articolo 2, paragrafo 27			—
				Articolo 2, paragrafo 28			Articolo 63, paragrafo 1
				Articolo 2, paragrafo 29			—
				Articolo 2, paragrafo 30			Articolo 57, paragrafo 12
				Articolo 2, paragrafo 31			Allegato VII, parte 2, prima frase Allegato VIII, parte 2, punto 1
				Articolo 2, paragrafo 32			—
				Articolo 2, paragrafo 33			Articolo 57, paragrafo 13
				Articolo 3, paragrafo 2			Articolo 4, paragrafo 1, secondo comma

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
				Articolo 4, paragrafi da 1 a 3			Articolo 4, paragrafo 1, primo e secondo comma
				Articolo 4, paragrafo 4			Articolo 63, paragrafo 2
				Articolo 5, paragrafo 1			Articolo 59, paragrafo 1, primo comma
				Articolo 5, paragrafo 2			Articolo 59, paragrafo 1, primo comma, lettere a) e b)
				Articolo 5, paragrafo 3, primo comma, lettera a)			Articolo 59, paragrafo 2
				Articolo 5, paragrafo 3, primo comma lettera b)			Articolo 59, paragrafo 3
				Articolo 5, paragrafo 3, secondo comma			Articolo 59, paragrafo 4
—	—	—	—	—	—	—	Articolo 59, paragrafo 5
				Articolo 5, paragrafo 4			—
				Articolo 5, paragrafo 5			Articolo 59, paragrafo 6
				Articolo 5, paragrafo 6			Articolo 58
				Articolo 5, paragrafo 7			Allegato VII, parte 4, punto 1
				Articolo 5, paragrafo 8, primo comma			Allegato VII, parte 4, punto 2
				Articolo 5, paragrafo 8, secondo comma			—
				Articolo 5, paragrafo 9			—
				Articolo 5, paragrafo 10			Articolo 59, paragrafo 7
				Articolo 5, paragrafi 11, 12 e 13			—
				Articolo 6			—
				Articolo 7, paragrafo 1, frase introduttiva e primo, secondo, terzo e quarto trattino			Articolo 64

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
				Articolo 7, paragrafo 1, frase conclusiva			—
				Articolo 7, paragrafo 2			—
				Articolo 8, paragrafo 1			Articolo 14, paragrafo 1, lettera d) e articolo 60
—	—	—	—	—	—	—	Articolo 61
				Articolo 8, paragrafo 2			Allegato VII, parte 6, punto 1
				Articolo 8, paragrafo 3			Allegato VII, parte 6, punto 2
				Articolo 8, paragrafo 4			Allegato VII, parte 6, punto 3
				Articolo 8, paragrafo 5			—
				Articolo 9, paragrafo 1, primo comma, frase introduttiva			Articolo 62, primo comma, frase introduttiva
				Articolo 9, paragrafo 1, primo comma, primo, secondo e terzo trattino			Articolo 62, primo comma, lettere a), b) e c)
				Articolo 9, paragrafo 1, secondo comma			Articolo 62, secondo comma
				Articolo 9, paragrafo 1, terzo comma			Allegato VII, parte 8, punto 4
				Articolo 9, paragrafo 2			Articolo 63, paragrafo 3
				Articolo 9, paragrafo 3			Allegato VII, parte 8, punto 1
				Articolo 9, paragrafo 4			Allegato VII, parte 8, punto 2
				Articolo 9, paragrafo 5			Allegato VII, parte 8, punto 3
				Articolo 10	Articolo 4, paragrafo 9		Articolo 8, paragrafo 2
				Articolo 11, paragrafo 1, dalla terza alla sesta frase			—
				Articolo 12, paragrafo 1, secondo comma			Articolo 65, paragrafo 1, primo comma
				Articolo 12, paragrafo 1, terzo comma			Articolo 65, paragrafo 1, secondo comma
				Articolo 12, paragrafo 2			Articolo 65, paragrafo 2

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
				Articolo 12, paragrafo 3			Articolo 65, paragrafo 3
				Articolo 13, paragrafi 2 e 3			—
				Articolo 14	Articolo 19	Articolo 16	Articolo 79
				Allegato I, prima e seconda frase della frase introduttiva			Articolo 56
				Allegato I, terza frase della frase introduttiva e elenco delle attività			Allegato VII, parte 1
				Allegato II A,			Allegato VII, parti 2 e 3
				Allegato II A, parte II, ultima frase del paragrafo 6			—
				Allegato II B, punto 1, prima e seconda frase			Articolo 59, paragrafo 1, primo comma, lettera b)
				Allegato II B, punto 1, terza frase			Articolo 59, paragrafo 1, secondo comma
				Allegato II B, punto 2			Allegato VII, parte 5
				Allegato II B, punto 2, secondo comma, punto i) e tabella			—
				Allegato III, punto 1			—
				Allegato III, punto 2			Allegato VII, parte 7, punto 1
				Allegato III, punto 3			Allegato VII, parte 7, punto 2
				Allegato III, punto 4			Allegato VII, parte 7, punto 3
					Articolo 1, primo paragrafo		Articolo 42
					Articolo 1, secondo paragrafo		—
					Articolo 2, paragrafo 1		Articolo 42, paragrafo 1, primo comma

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
—	—	—	—	—	—	—	Articolo 42, paragrafo 1, commi da 1 a 5
					Articolo 2, paragrafo 2, frase introduttiva		Articolo 42, paragrafo 2, frase introduttiva
					Articolo 2, paragrafo 2, lettera a), frase introduttiva		Articolo 42, paragrafo 2, lettera a), frase introduttiva
					Articolo 2, paragrafo 2, lettera a), punti da i) a v)		Articolo 42, paragrafo 2, lettera a), punto i)
					Articolo 2, paragrafo 2, lettera a), punto vi)		Articolo 42, paragrafo 2, lettera a), punto ii)
					Articolo 2, paragrafo 2, lettera a), punto vii)		Articolo 42, paragrafo 2, lettera a), punto iii)
					Articolo 2, paragrafo 2, lettera a), punto viii)		Articolo 42, paragrafo 2, lettera a), punto iv)
					Articolo 2, paragrafo 2, lettera b)		Articolo 42, paragrafo 2, lettera b)
					Articolo 3, paragrafo 2, primo comma		Articolo 3, paragrafo 38
					Articolo 3, paragrafo 2, secondo comma		—
					Articolo 3, paragrafo 3		Articolo 3, paragrafo 39
					Articolo 3, paragrafo 4, primo comma		Articolo 3, paragrafo 40
					Articolo 3, paragrafo 4, secondo comma		Articolo 42, paragrafo 1, terzo comma
—	—	—	—	—	—	—	Articolo 42, paragrafo 1, quanto comma
					Articolo 3, paragrafo 5, primo comma		Articolo 3, paragrafo 41
					Articolo 3, paragrafo 5, secondo comma		Articolo 42, paragrafo 1, quinto comma
					Articolo 3, paragrafo 5, terzo comma		Articolo 42, paragrafo 1, terzo comma

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
					Articolo 3, paragrafo 6		Allegato VI, parte 1, lettera a)
					Articolo 3, paragrafo 7		Articolo 3, paragrafo 42
—	—	—	—	—	—	—	Allegato VI, parte 1, lettera b)
					Articolo 3, paragrafo 10		Articolo 3, paragrafo 43
					Articolo 3, paragrafo 13		Articolo 3, paragrafo 43
					Articolo 4, paragrafo 2		Articolo 44
					Articolo 4, paragrafo 4, frase introduttiva e lettere a) e b)		Articolo 45, paragrafo 1, frase introduttiva e lettere a) e b)
					Articolo 4, paragrafo 4, lettera c)		Articolo 45, paragrafo 1, lettera e)
					Articolo 4, paragrafo 5		Articolo 45, paragrafo 2
					Articolo 4, paragrafo 6		Articolo 45, paragrafo 3
					Articolo 4, paragrafo 7		Articolo 45, paragrafo 4
					Articolo 4, paragrafo 8		Articolo 54
					Articolo 5		Articolo 52
					Articolo 6, paragrafo 1, primo comma		Articolo 50, paragrafo 1
					Articolo 6, paragrafo 1, secondo comma e articolo 6, paragrafo 2		Articolo 50, paragrafo 2
					Articolo 6, paragrafo 1, terzo comma		Articolo 50, paragrafo 3, primo comma
					Articolo 6, paragrafo 1, prima parte del quarto paragrafo		—
					Articolo 6, paragrafo 1, seconda parte del quarto comma		Articolo 50, paragrafo 3, secondo comma
					Articolo 6, paragrafo 3		Articolo 50, paragrafo 4
					Articolo 6, paragrafo 4, prima e seconda frase del primo comma e articolo 6, paragrafo 4, prima e seconda frase del secondo comma		Articolo 51, paragrafo 1

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
					Articolo 6, paragrafo 4, terza frase del primo comma		Articolo 51, paragrafo 2
—	—	—	—	—	Articolo 6, paragrafo 4, terza frase del secondo comma	—	Articolo 51, paragrafo 3, primo comma
					Articolo 6, paragrafo 4, terzo comma		Articolo 51, paragrafo 3, secondo comma
					Articolo 6, paragrafo 4, quarto comma		Articolo 51, paragrafo 4
					Articolo 6, paragrafo 5, prima parte della frase		—
					Articolo 6, paragrafo 5, seconda parte della frase		Articolo 46, paragrafo 1
					Articolo 6, paragrafo 6		Articolo 50, paragrafo 5
					Articolo 6, paragrafo 7		Articolo 50, paragrafo 6
					Articolo 6, paragrafo 8		Articolo 50, paragrafo 7
					Articolo 7, paragrafo 1 e articolo 7, paragrafo 2, primo comma		Articolo 46, paragrafo 2, primo comma
					Articolo 7, paragrafo 2, secondo comma		Articolo 46, paragrafo 2, secondo comma
					Articolo 7, paragrafo 3 e articolo 11, paragrafo 8, primo comma, frase introduttiva		Allegato VI, parte 6, prima parte del punto 2.7
					Articolo 7, paragrafo 4		Articolo 46, paragrafo 2, secondo comma
					Articolo 7, paragrafo 5		—
					Articolo 8, paragrafo 1		Articolo 45, paragrafo 1, lettera c)
					Articolo 8, paragrafo 2		Articolo 46, paragrafo 3
					Articolo 8, paragrafo 3		—
					Articolo 8, paragrafo 4, primo comma		Articolo 46, paragrafo 4, primo comma

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
					Articolo 8, paragrafo 4, secondo comma		Allegato VI, parte 6, punto 3.2
					Articolo 8, paragrafo 4, terzo comma		—
					Articolo 8, paragrafo 4, quarto comma		—
					Articolo 8, paragrafo 5		Articolo 46, paragrafo 4, secondo e terzo comma
					Articolo 8, paragrafo 6		Articolo 45, paragrafo 1, lettere c) e d)
					Articolo 8, paragrafo 7		Articolo 46, paragrafo 5
					Articolo 8, paragrafo 8		—
					Articolo 9, primo comma		Articolo 53, paragrafo 1
					Articolo 9, secondo comma		Articolo 53, paragrafo 2
					Articolo 9, terzo comma		Articolo 53, paragrafo 3
					Articolo 10, paragrafi 1 e 2		—
					Articolo 10, paragrafo 3, prima frase		Articolo 48, paragrafo 2
					Articolo 10, paragrafo 3, seconda frase		—
					Articolo 10, paragrafo 4		Articolo 48, paragrafo 3
					Articolo 10, paragrafo 5		Allegato VI, parte 6, seconda parte del punto 1.3
					Articolo 11, paragrafo 1		Articolo 48, paragrafo 1
					Articolo 11, paragrafo 2		Allegato VI, parte 6, punto 2.1
					Articolo 11, paragrafo 3		Allegato VI, parte 6, punto 2.2
					Articolo 11, paragrafo 4		Allegato VI, parte 6, punto 2.3
					Articolo 11, paragrafo 5		Allegato VI, parte 6, punto 2.4

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
					Articolo 11, paragrafo 6		Allegato VI, parte 6, punto 2.5, primo comma
—	—	—	—	—	—	—	Allegato Vi, parte 6, punto 2.5, secondo comma
					Articolo 11, paragrafo 7, prima parte della prima frase del primo comma		Allegato VI, parte 6, punto 2.6, frase introduttiva
					Articolo 11, paragrafo 7, seconda parte della prima frase del primo comma		Allegato VI, parte 6, punto 2.6, lettera a)
					Articolo 11, paragrafo 7, seconda frase del primo comma		—
					Articolo 11, paragrafo 7, secondo comma		—
					Articolo 11, paragrafo 7, lettera a)		Allegato VI, parte 6, punto 2.6, lettera b)
					Articolo 11, paragrafo 7, lettere b) e c)		—
					Articolo 11, paragrafo 7, lettera d)		Allegato VI, parte 6, punto 2.6, lettera c)
					Articolo 11, paragrafo 7, lettere e) ed f)		—
					Articolo 11, paragrafo 8, primo comma, lettere a) e b)		Allegato VI, parte 3, punto 1
					Articolo 11, paragrafo 8, primo comma, lettera c) e secondo comma		Allegato VI, parte 6, secondo comma del punto 2.7
					Articolo 11, paragrafo 8, primo comma, lettera d)		Allegato VI, parte 4, punto 2.1, secondo comma
					Articolo 11, paragrafo 9		Articolo 48, paragrafo 4
					Articolo 11, paragrafo 10, lettere a), b) e c)		Allegato VI, parte 8, punto 1.1
					Articolo 11, paragrafo 11		Allegato VI, parte 8, punto 1.2
					Articolo 11, paragrafo 12		Allegato VI, parte 8, punto 1.3

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
					Articolo 11, paragrafo 13		Articolo 48, paragrafo 5,
—	—	—	—	—	—	—	Articolo 49
					Articolo 11, paragrafo 14		Allegato VI, parte 6, punto 3.1
					Articolo 11, paragrafo 15		Articolo 45, paragrafo 1, lettera e)
					Articolo 11, paragrafo 16		Allegato VI, parte 8, punto 2
					Articolo 11, paragrafo 17		Articolo 8, paragrafo 2, lettera a)
					Articolo 12, paragrafo 1		Articolo 55, paragrafo 1
					Articolo 12, paragrafo 2, prima e seconda frase		Articolo 55, paragrafo 2
					Articolo 12, paragrafo 2, terza frase		Articolo 55, paragrafo 3
					Articolo 13, paragrafo 1		Articolo 45, paragrafo 1, lettera f)
					Articolo 13, paragrafo 2		Articolo 47
					Articolo 13, paragrafo 3		Articolo 46, paragrafo 6
					Articolo 13, paragrafo 4		Allegato VI, parte 3, punto 2
					Articolo 14		—
					Articolo 15		—
					Articolo 16		—
					Articolo 20		—
					Allegato I		Allegato VI, parte 2
					Allegato II, prima parte (senza numerazione)		Allegato VI, parte 4, punto 1
					Allegato II, punto 1, frase introduttiva		Allegato VI, parte 4, punto 2.1
					Allegato II, punti 1.1 e 1.2		Allegato VI, parte 4, punti 2.2 e 2.3
—	—	—	—	—	—	—	Allegato VI, parte 4, punto 2.4
					Allegato II, punto 1.3		—
					Allegato II, punto 2.1		Allegato VI, parte 4, punto 3.1

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
—	—	—	—	—	—	—	Allegato VI, parte 4, punto 3.2
					Allegato II, punto 2.2		Allegato VI, parte 4, punti 3.3 e 3.4
					Allegato II, punto 3		Allegato VI, parte 4, punto 4
					Allegato III		Allegato VI, parte 6, punto 1
					Allegato IV, tabella		Allegato VI, parte 5
					Allegato IV, ultima frase		—
					Allegato V, lettera a), tabella		Allegato VI, parte 3, punto 1.1
					Allegato V, lettera a), ultime frasi		—
					Allegato V, lettera b), tabella		Allegato VI, parte 3, punto 1.2
					Allegato V, lettera b), ultima frase		—
					Allegato V, lettera c)		Allegato VI, parte 3, punto 1.3
					Allegato V, lettera d)		Allegato VI, parte 3, punto 1.4
					Allegato V, lettera e)		Allegato VI, parte 3, punto 1.5
					Allegato V, lettera f)		Allegato VI, parte 3, punto 3
					Allegato VI		Allegato VI, parte 7
						Articolo 1	Articolo 28, primo comma
						Articolo 2, paragrafo 2	Allegato V, parte 1, punto 1 e parte 2, punto 1, primo comma
—	—	—	—	—	—	—	Allegato V, parte 1, punto 1 e parte 2, punto 1, secondo comma
						Articolo 2, paragrafo 3, seconda parte	Allegato V, parte 1, punto 1 e parte 2, punto 1, primo comma

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
—	—	—	—	—	—	—	Allegato V, parte 1, punto 1 e parte 2, punto 1, secondo comma
						Articolo 2, paragrafo 4	—
						Articolo 2, paragrafo 6, prima parte	Articolo 3, paragrafo 24
						Articolo 2, paragrafo 6, seconda parte	Articolo 28, secondo comma, punto j)
						Articolo 2, paragrafo 7, primo comma	Articolo 3, paragrafo 25
						Articolo 2, paragrafo 7, secondo comma, prima frase	—
						Articolo 2, paragrafo 7, secondo comma, seconda frase e lettere da a) e i)	Articolo 28, secondo comma e lettere da a) a i)
						Articolo 2, paragrafo 7, secondo comma, lettera j)	—
						Articolo 2, paragrafo 7, terzo comma	—
—	—	—	—	—	—	—	Articolo 29, paragrafo 1
						Articolo 2, paragrafo 7, quarto comma	Articolo 29, paragrafo 2
—	—	—	—	—	—	—	Articolo 29, paragrafo 3
						Articolo 2, paragrafo 8	Articolo 3, paragrafo 32
						Articolo 2, paragrafo 9	—
						Articolo 2, paragrafo 10	—
						Articolo 2, paragrafo 11	Articolo 3, paragrafo 31
						Articolo 2, paragrafo 12	Articolo 3, paragrafo 33
						Articolo 2, paragrafo 13	—
						Articolo 3	—
						Articolo 4, paragrafo 1	—
						Articolo 4, paragrafo 2	—

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
						Articolo 4, paragrafi da 3 a 8	
						Articolo 5, paragrafo 1	Allegato V, parte 1, punto 2, secondo comma
							Allegato V, parte 1, punto 2, primo, terzo e quarto comma
						Articolo 5, paragrafo 2	—
						Articolo 6	—
						Articolo 7, paragrafo 1	Articolo 37
						Articolo 7, paragrafo 2	Articolo 30, paragrafo 5
						Articolo 7, paragrafo 3	Articolo 30, paragrafo 6
						Articolo 8, paragrafo 1	Articolo 40, paragrafo 1
						Articolo 8, paragrafo 2, prima parte del primo comma	Articolo 40, paragrafo 2, prima parte del primo comma
						Articolo 8, paragrafo 2, seconda parte del primo comma	—
—	—	—	—	—	—	—	Articolo 40, paragrafo 2, seconda parte del primo comma
—	—	—	—	—	—	—	Articolo 40, paragrafo 2, secondo comma
—	—	—	—	—	—	—	Articolo 40, paragrafo 3
—	—	—	—	—	—	—	Articolo 41
						Articolo 8, paragrafo 2, secondo comma	—
						Articolo 8, paragrafi 3 e 4	—
						Articolo 9	Articolo 30, paragrafo 1
—	—	—	—	—	—	—	Articolo 30, paragrafi 2, 3 e 4
						Articolo 9 *bis*	Articolo 36
						Articolo 10, paragrafo 1, prima frase	Articolo 30, paragrafo 7, prima frase

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
—	—	—	—	—	—	—	Articolo 30, paragrafo 7, seconda frase
—	—	—	—	—	—	—	Articolo 30, paragrafi 8 e 9
—	—	—	—	—	—	—	Articoli da 31 a 35
						Articolo 10, paragrafo 1, seconda frase	—
						Articolo 10, paragrafo 2	—
						Articolo 12, prima frase	Articolo 38, paragrafo 1
						Articolo 12, seconda frase	—
—	—	—	—	—	—	—	Articolo 38, paragrafi 2, 3 e 4
—	—	—	—	—	—	—	Articolo 39
						Articolo 13	Allegato V, parte 3, terza parte del punto 8
						Articolo 14	Allegato V, parte 4
—	—	—	—	—	—	—	Allegato V, parte 5, 6 e 7
						Articolo 15	—
						Articolo 18, paragrafo 2	—
						Allegato I	—
						Allegato II	—
						Allegati III e IV	Allegato V, punto 2 della parte 1 e parte 2
						Allegato V A	Allegato V, parte 1, punto 3
						Allegato V B	Allegato V, parte 2, punto 3
						Allegato VI A	Allegato V, parte 1, punti 4 e 6
—	—	—	—	—	—	—	Allegato V, parte 1, punto 5
						Allegato VI B	Allegato V, parte 2, punti 4 e 6
—	—	—	—	—	—	—	Allegato V, parte 2, punto 5

Direttiva 78/176/CEE	Direttiva 82/883/CEE	Direttiva 92/112/CEE	Direttiva 2008/1/CE	Direttiva 1999/13/CE	Direttiva 2000/76/CE	Direttiva 2001/80/CE	Presente direttiva
						Allegato VII A	Allegato V, parte 1, punti 7 e 8
						Allegato VII B	Allegato V, parte 2, punti 7 e 8
						Allegato VIII A punto 1	—
						Allegato VIII A punto 2	Allegato V, parte 3, prima parte del punto 1 e punti 2, 3 e 5
—	—	—	—	—	—	—	Allegato V, parte 3, seconda parte del punto 1
—	—	—	—	—	—	—	Allegato V, parte 3, punto 4
						Allegato VIII A punto 3	—
						Allegato VIII A punto 4	Allegato V, parte 3, punto 6
						Allegato VIII A punto 5	Allegato V, parte 3, punti 7 e 8
						Allegato VIII A punto 6	Allegato V, parte 3, punti 9 e 10
—	—	—	—	—	—	—	Allegato V, parte 3, punto 11
—	—	—	—	—	—	—	Allegato V, parte 4
						Allegato VIII B	—
						Allegato VIII C	—
			Allegato VI			Allegato IX	Allegato IX
			Allegato VII			Allegato X	Allegato X

EUROPEAN COMMISSION

Integrated Pollution Prevention and Control

Reference Document on Best Available Techniques in the Smitheries and Foundries Industry

May 2005

This document is one of a series of reference documents foreseen to be produced in the EIPPCB work plan as below (at the time of writing, not all the documents have been drafted):

Full title	BREF code
Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs	ILF
Reference Document on the General Principles of Monitoring	MON
Reference Document on Best Available Techniques for the Tanning of Hides and Skins	TAN
Reference Document on Best Available Techniques in the Glass Manufacturing Industry	GLS
Reference Document on Best Available Techniques in the Pulp and Paper Industry	PP
Reference Document on Best Available Techniques on the Production of Iron and Steel	I&S
Reference Document on Best Available Techniques in the Cement and Lime Manufacturing Industries	CL
Reference Document on the Application of Best Available Techniques to Industrial Cooling Systems	CV
Reference Document on Best Available Techniques in the Chlor – Alkali Manufacturing Industry	CAK
Reference Document on Best Available Techniques in the Ferrous Metals Processing Industry	FMP
Reference Document on Best Available Techniques in the Non Ferrous Metals Industries	NFM
Reference Document on Best Available Techniques for the Textiles Industry	TXT
Reference Document on Best Available Techniques for Mineral Oil and Gas Refineries	REF
Reference Document on Best Available Techniques in the Large Volume Organic Chemical Industry	LVOC
Reference Document on Best Available Techniques in the Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector	CWW
Reference Document on Best Available Techniques in the Food, Drink and Milk Industry	FM
Reference Document on Best Available Techniques in the Smitheries and Foundries Industry	SF
Reference Document on Best Available Techniques on Emissions from Storage	ESB
Reference Document on Best Available Techniques on Economics and Cross-Media Effects	ECM
Reference Document on Best Available Techniques for Large Combustion Plants	LCP
Reference Document on Best Available Techniques in the Slaughterhouses and Animals By-products Industries	SA
Reference Document on Best Available Techniques for Management of Tailings and Waste-Rock in Mining Activities	MTWR
Reference Document on Best Available Techniques for the Surface Treatment of Metals	STM
Reference Document on Best Available Techniques for the Waste Treatments Industries	WT
Reference Document on Best Available Techniques for the Manufacture of Large Volume Inorganic Chemicals (Ammonia, Acids and Fertilisers)	LVIC-AAF
Reference Document on Best Available Techniques for Waste Incineration	WI
Reference Document on Best Available Techniques for Manufacture of Polymers	POL
Reference Document on Energy Efficiency Techniques	ENE
Reference Document on Best Available Techniques for the Manufacture of Organic Fine Chemicals	OFC
Reference Document on Best Available Techniques for the Manufacture of Specialty Inorganic Chemicals	SIC
Reference Document on Best Available Techniques for Surface Treatment Using Solvents	STS
Reference Document on Best Available Techniques for the Manufacture of Large Volume Inorganic Chemicals (Solids and Others)	LVIC-S
Reference Document on Best Available Techniques in Ceramic Manufacturing Industry	CER

EXECUTIVE SUMMARY

The Smitheries and Foundries BREF (Best Available Techniques reference document) reflects an information exchange carried out under Article 16(2) of Council Directive 96/61/EC. This executive summary is intended to be read in conjunction with the BREF's Preface, which explains the structure of the document, its objectives, usage and legal terms. The executive summary describes the main findings, the principal BAT conclusions and the associated emission/consumption levels. It can be read and understood as a stand-alone document but, as a summary, it does not present all the complexities of the full BREF text. It is therefore not intended as a substitute for the full BREF text in BAT decision making.

Scope of this BREF

This document reflects the exchange of information on the activities covered by Annex I, categories 2.3 (b), 2.4 and 2.5 (b) of the IPPC Directive, i.e.

"2.3. Installations for the processing of ferrous metals:
(b) smitheries with hammers the energy of which exceeds 50 kilojoule per hammer, where the calorific power used exceeds 20 MW
2.4. Ferrous metal foundries with a production capacity exceeding 20 tonnes per day
2.5. Installations
(b) for the smelting, including the alloyage, of non-ferrous metals, including recovered products, (refining, foundry casting, etc.) with a melting capacity exceeding 4 tonnes per day for lead and cadmium or 20 tonnes per day for all other metals."

After comparing the above descriptions to the actual capacitites of existing installations in Europe, the TWG outlined a working scope, which covered the following:

- the casting of ferrous materials, e.g. lamellar cast iron, malleable and nodular iron, steel
- the casting of non-ferrous materials, e.g. aluminium, magnesium, copper, zinc, lead and their alloys.

Smitheries were excluded from this document's scope since no European smitheries were reported which met the conditions stated in Annex I 2.3.(b). This document therefore only discusses foundry processes. Cadmium, titanium and precious metals foundries, as well as bell casting and art casting foundries were also excluded on capacity grounds. Continuous casting (into sheets and slabs) has already been covered in the BREF documents related to iron and steel production and non-ferrous metal industries, and therefore, it is not dealt with in this document. In covering non-ferrous metals in this document, the process is considered to start with the melting of ingots and internal scrap or with liquid metal.

From a process point of view, the following foundry process steps are covered in this document:

- pattern making
- raw materials storage and handling
- melting and metal treatment
- mould and core production, and moulding techniques
- casting or pouring and cooling
- shake-out
- finishing
- heat treatment.

The foundry industry

Foundries melt ferrous and non-ferrous metals and alloys and reshape them into products at or near their finished shape through the pouring and solidification of the molten metal or alloy into a mould. The foundry industry is a differentiated and diverse industry. It consists of a wide range of installations, from small to very large; each with a combination of technologies and unit operations selected to suit the input, size of series and types of product produced by the specific installation. The organisation within the sector is based on the type of metal input, with the main distinction being made between ferrous and non-ferrous foundries. Since castings in general are semi-finished products, foundries are located close to their customers.

The European foundry industry is the third largest in the world for ferrous castings and second largest for non-ferrous. The annual production of castings in the enlarged European Union amounts to 11.7 million tonnes of ferrous and 2.8 million tonnes of non-ferrous castings. Germany, France and Italy are the top three production countries in Europe, with a total annual production of over two million tonnes of castings each. In recent years, Spain has taken over the fourth position from Great Britain, with both having a production of over one million tonnes of castings. Together, the top five countries produce more than 80 % of the total European production. Although the production volume has remained relatively stable over the past few years, there has been a decline in the total number of foundries (now totalling around 3000 units), which is also reflected in the employment numbers (now totalling around 260000 people). This can be explained by progressive upscaling and automation in the foundry units. However, the foundry industry is predominantly still an SME industry, with 80 % of companies employing less than 250 people.

The main markets served by the foundry industry are the automotive (50 % of market share), general engineering (30 %) and construction (10 %) sectors. A growing shift of the automotive industry towards lighter vehicles has been reflected in a growth in the market for aluminium and magnesium castings. While iron castings mostly (i.e. >60 %) go to the automotive sector, steel castings find their market in the construction, machinery and valve making industries.

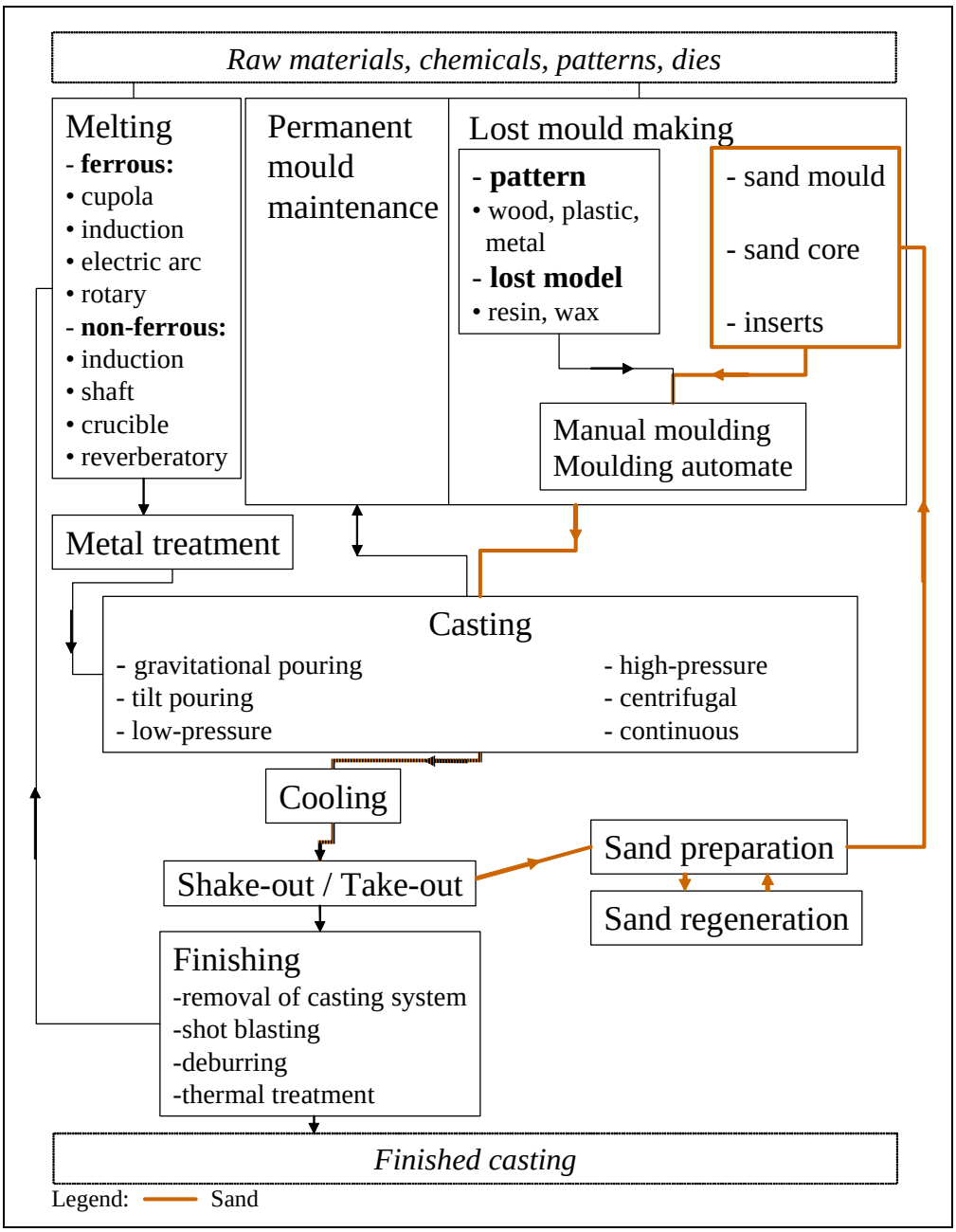
The foundry process

A general flow chart of the foundry process is depicted in the figure below. The process can be divided into the following major activities:

- melting and metal treatment: the melting shop
- preparation of moulds and cores: the moulding shop
- casting of the molten metal into the mould, cooling for solidification and removing the casting from the mould: the casting shop
- finishing of the raw casting: the finishing shop.

Various process options can be taken, depending on the type of metal, size of series and type of product. Generally, the main division within the sector is based on the type of metal (ferrous or non-ferrous) and the type of moulding used (lost moulds or permanent moulds). While any combination is possible, typically ferrous foundries largely use lost moulds (i.e. sand moulding) and non-ferrous foundries mainly use permanent moulds (i.e. die-casting). Within each of these basic process options a variety of techniques exist according to the type of furnace used, the moulding and core-making system (green sand or various chemical binders) applied, and the casting system and finishing techniques applied. Each of those have their own technical, economic and environmental properties, advantages and disadvantages.

Chapters 2, 3 and 4 of this document follow a process-flow approach to describe the various operations, from pattern making to finishing and heat treatment. Applied techniques are described, emission and consumption levels given and techniques to minimise the environmental impact are discussed. The structure of Chapter 5 is based on a distinction between the type of metal and the type of moulding.



The foundry process

Key environmental issues

The foundry industry is a major player in the recycling of metals. Steel, cast iron and aluminium scrap is remelted into new products. Most possible negative environmental effects of foundries are related to the presence of a thermal process and the use of mineral additives. Environmental effects therefore are mainly related to the exhaust and off-gases and to the re-use or disposal of mineral residues.

Emissions to air are the key environmental concern. The foundry process generates (metal-laden) mineral dusts, acidifying compounds, products of incomplete combustion and volatile organic carbons. Dust is a major issue, since it is generated in all process steps, in varying types and compositions. Dust is emitted from metal melting, sand moulding, casting and finishing. Any dust generated may contain metal and metal oxides.

The use of cokes as fuels, or the heating of crucibles and furnaces with gas or oil-fired burners can cause emissions of combustion products, such as NO_x and SO_2. Additionally, the use of cokes and the presence of impurities (e.g. oil, paint, …) in scrap can cause the production of some products of incomplete combustion or recombination (such as PCDD/F) and dust.

In the making of moulds and cores, various additives are used to bind the sand. In binding the sand and pouring the metal, reaction and decomposition products are generated. These include inorganic and organic (e.g. amines, VOCs) compounds. The generation of decomposition products (mainly VOCs) further continues during the casting cooling and de-moulding operations. These products can also cause an odour nuisance.

In the foundry process, emissions to air will typically not be limited to one (or several) fixed point(s). The process involves various emission sources (e.g. from hot castings, sand, hot metal). A key issue in emission reduction is not only to treat the exhaust and off-gas flow, but also to capture it.

Sand moulding involves the use of large sand volumes, with sand-to-liquid-metal weight ratios generally ranging from 1:1 up to 20:1. The used sand can be regenerated, re-used or disposed of. Additional mineral residues such as slag and dross are generated in the melting stage when removing impurities from the melt. These can be either re-used or disposed of.

Since foundries deal with a thermal process, energy efficiency and management of the generated heat are important environmental aspects. However, due to the high amount of transport and handling of the heat carrier (i.e. the metal) and its slow cooling, the recovery of heat is not always straightforward.

Foundries may have a high water consumption e.g. for cooling and quenching operations. In most foundries, water management involves an internal circulation of water, with a major part of the water evaporating. The water is generally used in the cooling systems of electric furnaces (induction or arc) or cupola furnaces. In general, the final volume of waste water is very small. Nevertheless, when wet dedusting techniques are used, the generated waste water requires special attention. In (high) pressure die-casting, a waste water stream is formed, which needs treatment to remove organic (phenol, oil) compounds before its disposal.

Consumption and emission levels

A general overview of the inputs and outputs of the foundry process is given in the figure below. The ‘Casting’ step mentioned in the centre of the picture covers also all necessary moulding operations. The major input streams are metal, energy, binders and water. The key emissions are dust, amines and VOCs, and for specific furnace types also SO_2, dioxins and NO_x.

The melting stage uses 40 – 60 % of the energy input. For a certain metal type, the energy use is dependent on the type of furnace used. The melting energy input ranges from 500 to 1200 kWh/t metal charge for ferrous metals and from 400 to 1200 kWh/t metal charge for aluminium.

The amounts and types of binders, chemicals and sand used are very dependent on the type of casting made, especially regarding its size and shape, as well as whether serial or batch wise production is used.

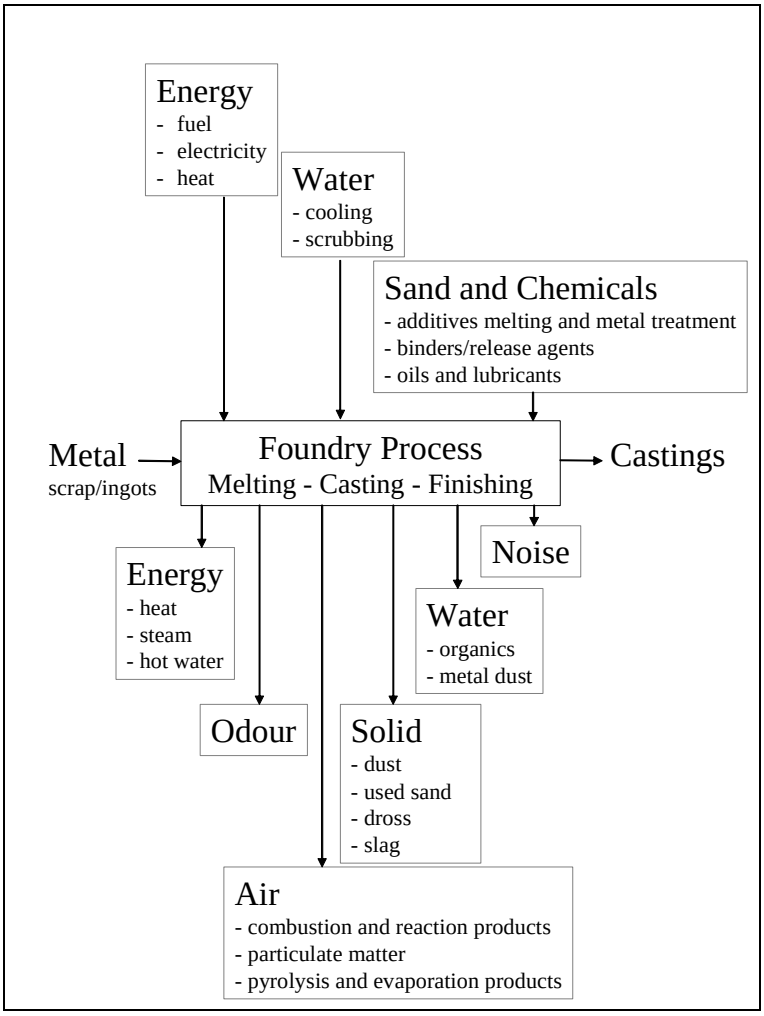
Water consumption is largely dependent on the type of furnace used, the type of flue-gas cleaning applied and the casting method applied.

Dust is generated in each of the process steps, albeit with different levels of mineral oxides, metals and metal oxides. Dust levels for metal melting range from below detection limit, for certain non-ferrous metals, to above 10 kg/tonne, for the cupola melting of cast iron. The high

amount of sand used in lost mould casting results in dust emissions during the various moulding stages.

Amines are used as a catalyst in the most commonly used core-making system. This results in guided emissions from the core-shooting machines and diffuse emissions from core-handling.

Volatile organic compounds emissions (mainly solvents, BTEX and to a lesser extent phenol, formaldehyde, etc.) result from the use of e.g. resins, organic solvents, or organic-based coatings in moulding and core-making. Organic compounds are thermally decomposed during metal pouring and are emitted further during shake-out and cooling. Emission levels between 0.1 – 1.5 kg/tonne of casting are presented in this document.



Mass stream overview of the foundry process

Techniques to consider in the determination of BAT

The minimisation of emissions, efficient raw material and energy usage, optimum process chemical utilisation, the recovering and recycling of waste and the substitution of harmful substances are all important principles of the IPPC Directive. For foundries the focal points are air emissions, the efficient use of raw materials and energy, and waste reduction, in conjunction with any recycling and re-use options.

The environmental issues as mentioned above are addressed by using a variety of process-integrated and end-of-pipe techniques. Over 100 techniques for pollution prevention and control are presented in this document, ordered under the following 12 thematic headings, which are largely based on the process flow:

1. *Raw material storage and handling*: Materials storage and handling techniques aim at the prevention of soil and water pollution and optimisation of the internal recycling of scrap metal.
2. *Metal melting and molten metal treatment*: For each furnace type, different techniques may be considered for optimisation of the furnace efficiency and minimisation of any residue production. These mainly involve in-process measures. Environmental considerations can also be taken into account in the selection of the furnace type. Special attention is paid to cleaning of the aluminium melt and the melting of magnesium, due to the high pollution potential of the products used until recently (HCE and SF_6).
3. *Mould- and core-making, including sand preparation*: Best practice measures and techniques for minimising the consumption may be applied for each type of binder system and for die-casting release agents. For the reduction of VOCs and odour emissions from lost mould systems, water-based coatings and inorganic solvents may be considered. While water-based coatings are commonly used, the applicability of inorganic solvents in core-making is still limited. Another approach is the use of different moulding methods. However, those techniques are used only in specific fields of application.
4. *Metal casting*: In order to improve the efficiency of the casting process, measures aimed at increasing the metal yield (i.e. the mass ratio of molten metal over finished casting) may be considered.
5. *Fume, flue-gas and exhaust air capture and treatment*: Dealing with the emissions to air in all the different foundry stages requires an adequate capture and treatment system to be in place. According to the unit operation, various techniques may be considered, depending on the type of compounds emitted, the off-gas volume and the ease of capture. Techniques applied for off-gas capture play an important role in the reduction of fugitive emissions. Additionally, for fugitive emissions, good practice measures may be considered.
6. *Waste water prevention and treatment*: In many cases, waste water can be prevented or minimised by taking in-process measures. Waste water that cannot be prevented, will contain mineral or metal dust, amines, suphates, oil or lubricants, depending on its source within the process. The applicable treatment techniques differ for each of these compounds.
7. *Energy efficiency:* Metal melting consumes 40 – 60 % of the energy input of a foundry. Energy efficiency measures should therefore take both the melting and the other processes (e.g. air compression, plant actuation, hydraulics) into account. The need for furnace and off-gas cooling generates a hot water or hot air stream, which may allow an internal or external utilisation of the heat.
8. *Sand: regeneration, recycling, re-use and disposal:* Since foundries make intensive use of sand as an inert primary material, the regeneration or re-use of this sand is an important point of consideration as part of its environmental performance. Various techniques are applied for regeneration of the sand (i.e. treatment and internal re-use as moulding sand), the selection of which depends on the binder type and the sand flow compostion. If sand is not regenerated, then external re-use may be considered in order to prevent the need for its disposal. Its application in various areas has been demonstrated.
9. *Dust and solid residues: treatment and re-use:* In-process techniques and operational measures may be considered for the minimisation of dust and residues. The collected dusts, slags and other solid residues may find an internal or external re-use.
10. *Noise reduction:* Various foundry activities are point sources of noise. For foundries near housing, this may cause a nuisance to the neighbours. The setting up and implementation of a noise reduction plan, covering both general and source-specific measures, may therefore be considered.
11. *Decommissioning*: The IPPC Directive requests attention be paid to consideration of the possible pollution upon decommissioning of the plant. Foundries present a specific risk for soil pollution at this stage. There are a number of general measures, which apply more widely than just to foundries, which may be considered to prevent pollution at the decommissioning stage.
12. *Environmental management tools*: Environmental management systems are a useful tool to aid the prevention of pollution from industrial activities in general. Their presentation is therefore a standard part of each BREF document.

BAT for foundries

The BAT chapter (Chapter 5) identifies those techniques that the TWG considered to be BAT in a general sense for the foundry industry, based upon the information in Chapter 4 and taking account of the Article 2(11) definition of "best available techniques" and the considerations listed in Annex IV to the Directive. The BAT chapter does not set or propose emission limit values but suggests emission levels that are associated with the use of BAT.

During the information exchange by the TWG, many issues were raised and discussed. A selection of these are highlighted in this summary.The following paragraphs summarise the key BAT conclusions relating to the most relevant environmental issues.

The BAT elements will need to be adapted to the foundry type. A foundry basically consists of a melting shop and a casting shop, both with their own supply chain. For lost mould casting this supply chain includes all activities related to moulding and core-making. In the BAT chapter, a distinction is made between the melting of either ferrous or non-ferrous metal, and for casting in either lost or permanent moulds. Each foundry may be classified as a combination of a particular melting with an associated moulding class. BAT is presented for each class. Generic BAT, which are common to all foundries, are also presented.

Generic BAT

Some BAT elements are generic and apply for all foundries, regardless of the processes they utilise and the type of products they produce. These concern material flows, finishing of castings, noise, waste water, environmental management and decommissioning.

BAT is to optimise the management and control of internal flows, in order to prevent pollution, prevent deterioration, provide adequate input quality, allow recycling and re-use and to improve the process efficiency. The BREF refers to storage and handling techniques covered in the Storage BREF, but also adds some foundry specific BAT related to storage and handling, such as the storage of scrap on an impermeable surface with a drainage and collection system (although applying a roof can reduce the need for such a system), the separate storage of incoming materials and residues, the use of recyclable containers, optimisation of the metal yield, and good practice measures for molten metal transfer and ladle handling.

BAT are given for finishing techniques that generate dust and for heat treatment techniques. For abrasive cutting, shot blasting and fettling, BAT is to collect and treat the finishing off-gas using a wet or dry system. For heat treatment, BAT is to use clean fuels (i.e. natural gas or low-level sulphur content fuel), automated furnace operation and burner/heater control and also to capture and evacuate the exhaust gas from heat treatment furnaces.

Concerning noise reduction, BAT is to develop and implement a noise reduction strategy, with general and source-specific measures, being applicable, such as using enclosure systems for high-noise unit operations such as shake-out and using additional measures depending on and according to local conditions.

BAT for waste water management includes prevention, separation of the waste water types, maximising internal recycling and applying an adequate treatment for each final flow. This includes techniques utilising e.g. oil interceptors, filtration or sedimentation.

Fugitive emissions arise from uncontained sources (transfers, storage, spills) and the incomplete evacuation of contained sources. BAT is to apply a combination of measures concerning material handling and transport and to optimise exhaust gas capture and cleaning through one or more capture techniques. Preference is given to collection of the fume nearest to the source.

BAT is to implement and adhere to an Environmental Management System (EMS) that incorporates, as appropriate to individual circumstances, features concerning e.g. the commitment of top management, planning, establishing and implementing procedures, performance checking with corrective actions and reviews.

BAT is to apply all necessary measures to prevent pollution upon decommissioning. These include minimisation of the risks during the design stage, implementation of an improvement programme for existing installations and development and utilisation of a site closure plan for new and existing installations. In these measures, at least the following process parts are considered: tanks, vessels, pipework, insulation, lagoons and landfills.

Ferrous metal melting

For the operation of cupola furnaces, BAT includes techniques which can give increased efficiency, such as divided blast operation, oxygen enrichment, continuous blowing or long campaign operation, good melting practice measures, and control of the coke quality. BAT is to collect, cool and dedust the off-gas, and to apply post combustion and heat recovery under specific conditions. Several dedusting systems are BAT but wet dedusting is preferable when melting with basic slag and in some cases as one of the measures to prevent and minimise dioxin and furan emissions. Industry has expressed doubts on the implementation of secondary measures for dioxin and furan abatement that have only been proven in other sectors and in particular questions their applicability for smaller foundries. For cupolas, BAT for residue management includes minimising slag forming, pretreating the slags in order to allow their external re-use and collecting and recycling coke breeze.

For the operation of electric arc furnaces, BAT includes applying reliable and efficient process controls to shorten the melting and treatment time, using the foamy slag practice, efficiently capturing the furnace off-gas, cooling the furnace off-gas and dedusting using a bag filter. BAT is to recycle the filter dust into the EAF furnace.

For the operation of induction furnaces, BAT is to melt clean scrap; use good practice measures for the charging and operation; use medium frequency power and, when installing a new furnace, to change any mains frequency furnace to medium frequency; to evaluate the possibility of waste heat recuperation and under specific conditions to implement a heat recovery system. For exhaust capture and treatment from induction furnaces, BAT is to use a hood, lip extraction or cover extraction on each induction furnace to capture the furnace off-gas and maximise the off-gas collection during the full working cycle; to use dry flue-gas cleaning; and to keep dust emissions below 0.2 kg/tonne molten iron.

For the operation of rotary furnaces, BAT is to implement a combination of measures to optimise furnace yield and to use an oxyburner. BAT is to collect the off-gas close to the furnace exit, apply post combustion, cool it using a heat-exchanger and then to apply dry dedusting. For the prevention and minimisation of dioxin and furan emissions, BAT is to use a combination of specified measures. Similarly to the situation with cupola furnaces, industry has expressed doubts on the implementation of secondary measures for dioxin and for an abatement that have only been proven in other sectors and in particular questions their applicability for smaller foundries.

The actual metal treatment applied depends on the type of product made. BAT is to collect the exhaust gas from AOD converters using a roof canopy and to collect and treat the off-gas from nodularisation, using a bag filter. BAT is also to make the MgO-dust available for recycling.

Non-ferrous metal melting

For the operation of induction furnaces for melting aluminium, copper, lead and zinc, BAT is to use good practice measures for the charging and operation; to use medium frequency power and, when installing a new furnace, change any mains frequency furnace to medium frequency; to evaluate the possibility of waste heat recuperation and under specific conditions to implement a heat recovery system. For exhaust capture from these furnaces, BAT is to minimise emissions and if needed to collect the off-gas, maximising the off-gas collection during the full working cycle and applying dry flue-gas cleaning.

For the other furnace types, BAT mainly focuses on the efficient collection of furnace off-gas and/or the reduction of fugitive emissions.

For non-ferrous metal treatment, BAT is to use an impeller station for the degassing and cleaning of aluminium. BAT is to use SO_2 as a covering gas for magnesium melting in installations with an annual output of 500 tonnes and more. For small plants (<500 tonnes Mg parts output/year) BAT is to use SO_2 or to minimise the use of SF_6. In the case where SF_6 is used, the BAT associated consumption level is <0.9 kg/tonne casting for sand casting and <1.5 kg/tonne casting for pressure die-casting.

Lost mould casting

Lost mould casting involves moulding, core-making, pouring, cooling and shake-out. This includes the production of green sand or chemically-bonded sand moulds and chemically-bonded sand cores. BAT elements are presented in three categories: green sand moulding, chemical sand moulding and pouring/cooling/shake-out.

For green sand preparation, BAT items deal with exhaust capture and cleaning and the internal or external recycling of the captured dust. In line with the goal of minimising waste for disposal, BAT is to apply a primary regeneration of green sand. Regeneration ratios of 98 % (monosand) or 90 – 94 % (green sand with incompatible cores) are associated with the use of BAT.

For chemically-bonded sand, the proposed BAT cover a variety of techniques, and deal with a broad range of environmental issues. BAT is to minimise the binder and resin consumption and sand losses, to minimise fugitive VOC emissions by capturing the exhaust gas from core-making and core handling, and to use water-based coatings. The use of alcohol-based coatings is BAT in a limited number of applications, where water-based coatings cannot be applied. In this case, the exhaust should be captured at the coating stand, whenever this is feasible. A specific BAT is given for amine-hardened urethane-bonded (i.e. cold-box) core preparation, to minimise amine emissions and optimise amine recovery. For these systems both aromatic and non-aromatic solvents are BAT. BAT is to minimise the amount of sand going to disposal, primarily by adopting a strategy of regeneration and/or re-use of chemically-bonded sand (as mixed or monosand). In the case of regeneration, the BAT conditions are given in the table below. Regenerated sand is re-used only in compatible sand systems.

Sand type	**Technique**	**Regeneration ratio[1] (%)**
Cold setting monosand	Simple mechanical regeneration	75 – 80
Silicate monosand	Heating and pneumatic treatment	45 – 85
Monosands of cold-box, SO_2, hot-box, croning Mixed organic sands	Cold mechanical or thermal regeneration	in cores: 40 – 100 in moulds: 90 – 100
Mixed green and organic sand	Mechanical-thermal-mechanical treatment, grinding or pneumatic chafing	in cores: 40 – 100 in moulds: 90 – 100
(1) mass of regenerated sand/total mass of sand used		

BAT for chemically-bonded sand regeneration (mixed and monosand)

Alternative moulding methods and inorganic binders are considered to have a promising potential for minimisation of the environmental impacts of moulding and casting processes.

Pouring, cooling and shake-out generate emissions of dust, VOCs and other organic products. BAT is to enclose pouring and cooling lines and provide exhaust extraction, for serial pouring lines, and to enclose the shake-out equipment, and treat the exhaust gas using wet or dry dedusting.

Permanent mould casting

Due to the different nature of the process, the environmental issues for permanent mould casting require a different focus than those for lost mould techniques, with water as a more prominent item. Emissions to air are in the form of an oil mist, rather than the dust and combustion products encountered in the other processes. BAT therefore focusses on prevention measures involving minimisation of the water and release agent consumption. BAT is to collect and treat run-off water and leakage water, using oil interceptors and distillation, vacuum evaporation or biological degradation. If oil mist prevention measures do not allow a foundry to reach the BAT associated emission level, BAT is to use hooding and electrostatic precipitation for the exhaust of HPDC machines.

BAT for chemically-bonded sand preparation is analogous to the elements mentioned for lost mould casting. BAT for used sand management is to enclose the de-coring unit and to treat the exhaust gas using wet or dry dedusting. If a local market exists, BAT is to make the sand from de-coring available for recycling.

BAT associated emission levels

The following emission levels are associated to the BAT measures stated above.

Activity	**Type**	**Parameter**	**Emission level (mg/Nm^3)**
Finishing of castings		Dust	5 – 20
Ferrous metal melting	General	Dust (1) PCDD/PCDF	5 – 20 ≤ 0.1 ng TEQ/Nm^3
	Hot Blast Cupola	CO SO_2 NO_x	20 – 1000 20 – 100 10 – 200
	Cold Blast Cupola	SO_2 NO_x NM - VOC	100 – 400 20 – 70 10 – 20
	Cokeless Cupola	NO_x	160 – 400
	Electric Arc Furnace	NO_x CO	10 – 50 200
	Rotary Furnace	SO_2 NO_x CO	70 – 130 50 – 250 20 – 30
Non-ferrous metal melting	General	Dust	1 – 20
	Aluminium melting	Chlorine	3
	Shaft furnace for Al	SO_2 NO_x CO VOC	30 – 50 120 150 100 – 150
	Hearth type furnace for Al	SO_2 NO_x CO TOC	15 50 5 5
Moulding and casting using lost moulds	General	Dust	5 – 20
	Core shop	Amine	5
	Regeneration units	SO_2 NO_x	120 150
Permanent mould casting	General	Dust Oil mist, measured as total C	5 - 20 5 - 10
(1) the emission level of dust depends on the dust components, such as heavy metals, dioxins, and its mass flow.			

Emissions to air associated with the use of BAT for the various foundry activities

All associated emission levels are quoted as an average over the practicable measuring period. Whenever continuous monitoring is practicable, a daily average value is used. Emissions to air are based on standard conditions, i.e. 273 K, 101.3 kPa and dry gas.

While the BAT reference documents do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels when using specified techniques. The appropriate limit values for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

Emerging techniques

Some new techniques for minimisation of the environmental impacts are currently still in the research and development phase or are only just beginning to enter the market these are considered to be emerging techniques. Five of these techniques are discussed in Chapter 6, namely: the use of low combustible materials in cupola melting, the recycling of metal-bearing filter dust, amine recovery by waste-gas permeation, the separate spraying of release agent and water in aluminium die-casting, and inorganic binder material for core-making. The latter technique was especially pointed out by the TWG as promising, although the current limited scale of testing and implementation does not allow it to be yet incorporated as a technique to consider in the selection of BAT.

Concluding remarks on the exchange of information

Information exchange

The BREF document is based on more than 250 sources of information. Foundry research institutes provided an important share of this information and played an active role in the information exchange. Local BAT notes from various Member States gave the information exchange a firm basis. The majority of the documents provided in the information exchange dealt with processes and techniques as applied in ferrous foundries. Throughout the writing of the BREF the non-ferrous foundry processes have been underrepresented. This is reflected in a lower level of detail in the BAT conclusions for non-ferrous foundries.

Level of consensus

A good general level of consensus was reached on the conclusions and no split views were recorded. The industry representation added a comment, expressing their doubt on the ease of implementation of secondary measures for dioxin abatement.

Recommendations for future work

The information exchange and the result of this exchange, i.e. this document, present an important step forward in achieving the integrated prevention and control of pollution from the foundry industry. Future work could continue this purpose by focusing on the collection and assessment of information that was not provided during this information exchange. In particular, in future work should cover in more detail the following topics:

- *Techniques for VOC abatement*: There is a need for data and information on methods applied for the efficient capture and treatment of VOC-laden exhaust gases from foundries. The use of alternative binder and coating materials may prove to be an important prevention measure in this respect
- *Waste water treatment*: There is a need for data from a broad range of water treatment systems in foundries, this should also show emission levels in relation to the inputs and treatment techniques applied

- *Melting of non-ferrous metals*: Emission data for non-ferrous foundries are presented in this document only for some specific installations. There is a need for more complete information on both guided and fugitive emissions from non-ferrous metal melting in foundries. This should be based on operational practice and expressed both as emission levels and mass flows..
- *Economic data for BAT techniques*: There is a lack of economic information for many of the techniques presented in Chapter 4. This information needs to be collected from projects dealing with the implementation of the presented techniques.

Suggested topics for R&D projects

The information exchange has also exposed some areas where additional useful knowledge could be gained from research and development projects. These relate to the following subjects:

- *Dioxin monitoring and abatement:* There is a need for a better understanding of the influence of process parameters on the formation of dioxins. This requires the monitoring of dioxin emissions for various installations and under varying conditions. Additionally, there is a need for research on the use and effectiveness of secondary measures for dioxin abatement in the foundry industry
- *Mercury emissions:* The high volatility of mercury may cause gaseous emissions, which are not related to dust. In view of the implementation of a European policy on mercury emissions, there is a need for research into the emissions of mercury from melting processes in general and from (non-ferrous) foundries in particular
- *Oxygas burners and their use in cupola furnaces:* The TWG reported that new applications have been set-up as a result of ongoing research. There is scope for further research and development here, to bring this technique up to a development level that allows its further dissemination.
- *Alternative replacement gases for SF_6 in magnesium melting*: Alternative cover gases to replace SF_6 such as HFC-134a and Novec612 have been developed and successfully tested but have not found industrial implementation. These gases may present an alternative for the substitution by SO_2. There is a need for research and demonstration projects that provide knowledge on the protective properties, decomposition behaviour and emission pattern of these compounds. This should allow a clearer indication of the applicability and may support industrial implementation.

The EC is launching and supporting, through its RTD programmes, a series of projects dealing with clean technologies, emerging effluent treatment and recycling technologies and management strategies. Potentially these projects could provide a useful contribution to future BREF reviews. Readers are therefore invited to inform the EIPPCB of any research results which are relevant to the scope of this document (see also the preface of this document).

PREFACE

1. Status of this document

Unless otherwise stated, references to "the Directive" in this document means the Council Directive 96/61/EC on integrated pollution prevention and control. As the Directive applies without prejudice to Community provisions on health and safety at the workplace, so does this document.

This document forms part of a series presenting the results of an exchange of information between EU Member States and industries concerned on best available technique (BAT), associated monitoring, and developments in them. It is published by the European Commission pursuant to Article 16(2) of the Directive, and must therefore be taken into account in accordance with Annex IV of the Directive when determining "best available techniques".

2. Relevant legal obligations of the IPPC Directive and the definition of BAT

In order to help the reader understand the legal context in which this document has been drafted, some of the most relevant provisions of the IPPC Directive, including the definition of the term "best available techniques", are described in this preface. This description is inevitably incomplete and is given for information only. It has no legal value and does not in any way alter or prejudice the actual provisions of the Directive.

The purpose of the Directive is to achieve integrated prevention and control of pollution arising from the activities listed in its Annex I, leading to a high level of protection of the environment as a whole. The legal basis of the Directive relates to environmental protection. Its implementation should also take account of other Community objectives such as the competitiveness of the Community's industry thereby contributing to sustainable development.

More specifically, it provides for a permitting system for certain categories of industrial installations requiring both operators and regulators to take an integrated, overall look at the polluting and consuming potential of the installation. The overall aim of such an integrated approach must be to improve the management and control of industrial processes so as to ensure a high level of protection for the environment as a whole. Central to this approach is the general principle given in Article 3 that operators should take all appropriate preventative measures against pollution, in particular through the application of best available techniques enabling them to improve their environmental performance.

The term "best available techniques" is defined in Article 2(11) of the Directive as "the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole." Article 2(11) goes on to clarify further this definition as follows:

"techniques" includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;

"available" techniques are those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;

"best" means most effective in achieving a high general level of protection of the environment as a whole.

Furthermore, Annex IV of the Directive contains a list of "considerations to be taken into account generally or in specific cases when determining best available techniques … bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention". These considerations include the information published by the Commission pursuant to Article 16(2).

Competent authorities responsible for issuing permits are required to take account of the general principles set out in Article 3 when determining the conditions of the permit. These conditions must include emission limit values, supplemented or replaced where appropriate by equivalent parameters or technical measures. According to Article 9(4) of the Directive, these emission limit values, equivalent parameters and technical measures must, without prejudice to compliance with environmental quality standards, be based on the best available techniques, without prescribing the use of any technique or specific technology, but taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In all circumstances, the conditions of the permit must include provisions on the minimisation of long-distance or transboundary pollution and must ensure a high level of protection for the environment as a whole.

Member States have the obligation, according to Article 11 of the Directive, to ensure that competent authorities follow or are informed of developments in best available techniques.

3. Objective of this Document

Article 16(2) of the Directive requires the Commission to organise "an exchange of information between Member States and the industries concerned on best available techniques, associated monitoring and developments in them", and to publish the results of the exchange.

The purpose of the information exchange is given in recital 25 of the Directive, which states that "the development and exchange of information at Community level about best available techniques will help to redress the technological imbalances in the Community, will promote the worldwide dissemination of limit values and techniques used in the Community and will help the Member States in the efficient implementation of this Directive."

The Commission (Environment DG) established an information exchange forum (IEF) to assist the work under Article 16(2) and a number of technical working groups have been established under the umbrella of the IEF. Both IEF and the technical working groups include representation from Member States and industry as required in Article 16(2).

The aim of this series of documents is to reflect accurately the exchange of information which has taken place as required by Article 16(2) and to provide reference information for the permitting authority to take into account when determining permit conditions. By providing relevant information concerning best available techniques, these documents should act as valuable tools to drive environmental performance.

4. Information Sources

This document represents a summary of information collected from a number of sources, including in particular the expertise of the groups established to assist the Commission in its work, and verified by the Commission services. All contributions are gratefully acknowledged.

5. How to understand and use this document

The information provided in this document is intended to be used as an input to the determination of BAT in specific cases. When determining BAT and setting BAT-based permit conditions, account should always be taken of the overall goal to achieve a high level of protection for the environment as a whole.

The rest of this section describes the type of information that is provided in each chapter of the document.

Chapters 1 and 2 provide general information on the industrial sector concerned and on the industrial processes used within the sector.

Chapter 3 provides data and information concerning current emission and consumption levels, reflecting the situation in existing installations at the time of writing.

Chapter 4 describes in more detail the emission reduction and other techniques that are considered to be most relevant for determining BAT and BAT-based permit conditions. This information includes the consumption and emission levels considered achievable by using the technique, some idea of the costs and the cross-media issues associated with the technique, and the extent to which the technique is applicable to the range of installations requiring IPPC permits, for example new, existing, large or small installations. Techniques that are generally seen as obsolete are not included.

Chapter 5 presents the techniques and the emission and consumption levels that are considered to be compatible with BAT in a general sense. The purpose is thus to provide general indications regarding the emission and consumption levels that can be considered as an appropriate reference point to assist in the determination of BAT-based permit conditions or for the establishment of general binding rules under Article 9(8). It should be stressed, however, that this document does not propose emission limit values. The determination of appropriate permit conditions will involve taking account of local, site-specific factors such as the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. For existing installations, the economic and technical viability of upgrading them also needs to be taken into account. Even the single objective of ensuring a high level of protection for the environment as a whole will often involve making trade-off judgements between different types of environmental impact, and these judgements will often be influenced by local considerations.

Although an attempt is made to address some of these issues, it is not possible for them to be considered fully in this document. The techniques and levels presented in Chapter 5 will therefore not necessarily be appropriate for all installations. On the other hand, the obligation to ensure a high level of environmental protection, including the minimisation of long-distance or transboundary pollution, implies that permit conditions cannot be set on the basis of purely local considerations. It is therefore of the utmost importance that the information contained in this document is fully taken into account by permitting authorities.

Since the best available techniques change over time, this document will be reviewed and updated as appropriate. All comments and suggestions should be made to the European IPPC Bureau at the Institute for Prospective Technological Studies at the following address:

Edificio Expo, c/ Inca Garcilaso, s/n, E-41092 Seville, Spain
Telephone: +34 95 4488 284
Fax: +34 95 4488 426
e-mail: JRC-IPTS-EIPPCB@cec.eu.int
Internet: http://eippcb.jrc.es

Best Available Techniques Reference Document on Smitheries and Foundries

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SCOPE

This document reflects the exchange of information on the activities covered by Annex I categories 2.3 (b), 2.4 and 2.5 (b) of the IPPC Directive, i.e.

"2.3. Installations for the processing of ferrous metals:
(b) smitheries with hammers the energy of which exceeds 50 kilojoule per hammer, where the calorific power used exceeds 20 MW

2.4. Ferrous metal foundries with a production capacity exceeding 20 tonnes per day

2.5. Installations
(b) for the smelting, including the alloyage, of non-ferrous metals, including recovered products, (refining, foundry casting, etc.) with a melting capacity exceeding 4 tonnes per day for lead and cadmium or 20 tonnes per day for all other metals."

In setting up the working scope for this document, the TWG considered the possible interpretation of the threshold values. The TWG compared the pre-defined IPPC scope to the actual existence of installations that meet the above descriptions, in the European Union and in the Candidate Countries. This comparison resulted in a working scope which covers the following:

- the casting of ferrous materials, e.g. grey cast iron, malleable and ductile iron, steel
- the casting of non-ferrous materials, e.g. aluminium, magnesium, copper, zinc, lead and their alloys.

Smitheries were excluded from the scope of the document since no European smitheries were reported which meet the conditions stated in Annex I 2.3 (b), i.e. "Smitheries with hammers the energy of which exceeds 50 kJ per hammer, (and) where the calorific power used exceeds 20 MW". Accordingly, cadmium, titanium and precious metals foundries, as well as bell and art casting foundries were excluded on capacity grounds.

Continuous casting (into sheets and slabs) has already been covered in the BREF documents on iron and steel production and on non-ferrous metal industries. Therefore it is not dealt with in this document.

Smelting, alloying and the refining of non-ferrous metals are covered in the BREF document on non-ferrous metal industries and will therefore be excluded from the scope of this document. In covering non-ferrous metals in this document, the process is considered to start with the melting of ingots and internal scrap or with liquid metal.

From a process point of view, the following foundry process steps are covered by the scope of this document:

- pattern making
- raw materials storage and handling
- melting and metal treatment
- mould and core production, and moulding techniques
- casting or pouring and cooling
- shake-out
- finishing
- heat treatment.

1 GENERAL INFORMATION ON FOUNDRIES

1.1 Sector overview

1.1.1 Foundry industry

Foundries melt ferrous and non-ferrous metals and alloys and reshape them into products at or near their finished shape through the pouring and solidification of the molten metal or alloy into a mould. The foundry industry is a differentiated and diverse industry. It consists of a wide range of installations, from small to very large; each with a combination of technologies and unit operations selected to suit the input, size of series and types of product produced in the specific installation. The organisation within the sector is based on the type of metal input, with the main distinction being made between ferrous and non-ferrous foundries.

The European foundry industry is the third largest in the world for ferrous castings and the second largest for non-ferrous. The total production of castings in various European countries are given in Table 1.1 and Table 1.2. Data for Northern Ireland, Luxemburg and some of the Accession Countries have not been provided, however it is known that activity in these regions is low compared to the listed regions. Germany, France and Italy are the top three production countries in Europe, with a total annual production of over two million tonnes of castings each. In recent years Spain has taken over the fourth position from Great Britain, with both having a production of over one million tonnes of castings. Together, the top five countries produce more than 80 % of the total European production.

The total European production tonnage of ferrous castings has been stable over the past five years, although some fluctuations have occurred for individual countries. For instance, the figures for Great Britain indicate a general declining trend in production output, whereas the trend for Spain is one of growth. The non-ferrous foundry sector has undergone steady growth since 1998. The total figure for 2001 is obscured by the lack of data from Great Britain. In general, it can be seen from Table 1.2 that in most countries production has risen. This holds not just for the major producing countries but also for those countries with low amounts of production.

Country	1998	1999	2000	2001	2002	2000:2001	2001:2002
						% change	
Austria	190.1	181.7	191.4	192.4	181.2	0.5	-5.8
Belgium	144.4	149.3	149.8	149.5	143.7	-0.2	-3.9
Czech Republic	493	379.1	390.3	415.3	381.6	6.4	-8.1
Denmark	85.8	86	96.4	85.7	87.3	-11.1	1.9
Estonia	n.d	n.d	0.94	1.07	1.1	13.8	2.8
Finland	122.6	109	117.6	119.5	112.5	1.6	-5.8
France	2250.8	2146.6	2283.1	2147.4	2128.6	-5.9	-0.9
Germany	3662.9	3555.2	3758.2	3801.4	3749.7	1.1	-1.4
Great Britain	1076.3[a]	949.2[a]	968.2[a]	906.3[a]	886.3[a]	-6.4	-2.2
Hungary	78.1	68.7	74.8	62.8	67.9	-16.0	8.2
Ireland	450	480	520	275	n.d	-47.1	
Italy	1508.4	1492.6	1516.4	1433.3	1460.9	-5.5	1.9
Netherlands	140.6	121	136	132.3	123.7	-2.7	-6.5
Norway	65.3	67.7	70.1	73.4	67.3	4.7	-8.3
Poland	675	610.2	671.2	673	598.0	0.3	-11.1
Portugal	98.6	97.7	102.3	100	96.7	-2.2	-3.3
Slovakia	n.d	n.d	n.d	47.5	n.d		
Slovenia	89.8	81.9	86.9	96.3	n.d	10.8	
Spain	706.6	759.3	950.5	955.7	992.9	0.5	3.9
Sweden	264.2	253.2	266.7	244.7	234.6	-8.2	-4.1
Switzerland	122.8[b]	122[b]	119.9[b]	105.5[b]	81.8[b]	-12.0	-22.5
Total	**12225**	**11710**	**12471**	**12018**	**11396**		
Full total [c]				***12018***	***11815***		

a) Without steel castings
b) Without steel and malleable iron castings
c) Full total calculated by taking most recent available number for the years for which no data are given

Table 1.1: European production data for ferrous castings, i.e. iron, steel and malleable iron castings (in kilotonnes)
[168, CAEF, 2002], [202, TWG, 2002]

For ferrous foundries, the progress of material substitution in recent years has caused the share of iron castings in the output total to decline slightly, dropping from 58.9 % in 2001 to 58.2 % in 2002. At the same time, producers of nodular-iron castings held a share of 34.3 % in the production total in 2002, marking an increase of 0.5 percentage points compared to 2001. Producers of malleable castings were able to expand their share from 1.1 % in 2001 to 1.3 % in 2002, while the share of steel castings in the output total ranged around 5.8 % in 2002 (5.9 % in 2001).

Country	1998	1999	2000	2001	2002	2000:2001	2001:2002
						% change	
Austria	90.4	92.4	105.9	113.3	116.2	7.0	2.6
Belgium	25.3	23.8	27.2	26.3	26.7	-3.3	1.6
Czech Republic	44.8	48	57.7	58.1	59.6	0.7	2.6
Denmark	1.7[a]	4	4	4.8	4.6	20.0	-3.2
Estonia	n.d	n.d	0	0	0		
Finland	10.5	10	10	10	9.7	0.0	-3.3
France	338.2	343.8	373.9	394.7	390.3	5.6	-1.1
Germany	783.9	777	842.1	849.6	845.8	0.9	-0.4
Great Britain	121[a]	n.d	n.d	n.d	n.d		
Hungary	24.8	35	44.8	58.4	68.3	30.4	16.9
Ireland [b]	25.8	25.8	26	26.6	n.d	2.3	
Italy	832.3	832.1	959.1	960	979.7	0.1	2.1
Netherlands	n.d	n.d	n.d	n.d	n.d		
Norway	22.2	25.2	26.4	30.9	26.7	17.0	-13.5
Poland	66.5	84	84	72.2	76.3	-14.0	5.7
Portugal	17.5	21.2	22.6	25.4	25.6	12.4	0.6
Slovakia	n.d	n.d	n.d	7.6	n.d		
Slovenia	15.9	17.3	23.6	24.8	n.d	5.1	
Spain	140.7	153.6	121.1	142.1	149.9	17.3	5.5
Sweden	51.8	55.7	58.5	53.3	52.9	-8.9	-0.8
Switzerland	22.3	22.9	25.1	24.1	21.1	-4.0	-12.3
Total	**2636**	**2572**	**2812**	**2481**	**2853**		
Full total [c]				***2602***	***3033***		

a) Only aluminium
b) Only lead sheet production
c) Full total calculated by taking most recent available number for the years for which no data are given

Table 1.2: European production data for non-ferrous metal castings (in kilotonnes) [168, CAEF, 2002], [202, TWG, 2002]

The output of non-ferrous metal alloys is still dominated by light metal castings at a share of 75.1 %, despite a decline by 3.5 percentage points compared to the year before. The share of copper alloys went down from 10.1 to 9.8 %, and the share held by the producers of zinc alloys similarly shrank from 8.7 to 7.3 %. The difference was absorbed by miscellaneous non-ferrous metals and processes that are not detailed in the statistics.

Data on the number of foundries are given in Table 1.3 and Table 1.4. These data show that there has been a general decline in the number of foundries since 1998, with the loss of about 5 % of the existing foundries each year. This decline is also reflected in the employment numbers, as given in Table 1.5 and Table 1.6.

Country	1998	1999	2000	2001	2002	2000:2001	2001:2002
						% change	
Austria	28	26	25	24	41	-4.0	70.8
Belgium	40[a]	25	24	21	21	-12.5	0.0
Czech Rep.	n.d	n.d	n.d	140	143		2.1
Denmark	n.d	n.d	12	12	12	0.0	0.0
Estonia	n.d	n.d	1	1	1	0.0	0.0
Finland	19	23	20	19	19	-5.0	0.0
France	169	167	167	163	159	-2.4	-2.5
Germany	324	310	299	288	273	-3.7	-5.2
Great Britain	228[b]	214[b]	198[b]	188[b]	179[b]	-5.1	-4.8
Hungary	34	34	32	33	n.d	3.1	
Ireland	n.d	n.d	n.d	1	n.d		
Italy	310	307	293	291	281	-0.7	-3.4
Netherlands	22	n.d	n.d	28	n.d		
Norway	12	12	12	11	11	-8.3	0.0
Poland	234	230	230	220	190	-4.3	-13.6
Portugal	62	61	61	61	61	0.0	0.0
Slovakia	n.d	n.d	n.d	12	n.d		
Slovenia	n.d	n.d	n.d	n.d	n.d		
Spain	224	221	105	102	98	-2.9	-3.9
Sweden	48	49	49	49	50	0.0	2.0
Switzerland	23	23	23	22	20	-4.3	-9.1
Total	**1777**	**1702**	**1551**	**1686**	**1559**		
Full total [c]			***1732***	***1686***	***1633***		

a) Only members
b) Without steel castings
c) Full total calculated by taking most recent available number for the years for which no data are given

Table 1.3: Number of foundries (production units) for iron, steel and malleable iron casting [168, CAEF, 2002], [202, TWG, 2002]

Country	Total		Pressure Die Casting		Other Light casting		Other Heavy metal alloy casting	
	2001	**2002**	**2001**	**2002**	**2001**	**2002**	**2001**	**2002**
Austria	63	61	20	21	28	25	15	15
Belgium	12	10	3	3	6	5	3	2
Czech Rep.	58	63	39[a]	40	n.d	n.d	n.d	23
Denmark	8	8	n.d	n.d	n.d	n.d	n.d	
Estonia	0	0	0	0	0	0	0	0
Finland	22	25	4	6	11	12	7	7
France	288	283	n.d	n.d	n.d	n.d	n.d	n.d
Germany	414	400	n.d	n.d	n.d	n.d	n.d	n.d
Great Britain	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Hungary	78	n.d	23	n.d	35	n.d	20	n.d
Italy	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Netherlands	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Norway	10	13	3	3	7	6		4
Poland	290	280	n.d	n.d	n.d	n.d	n.d	n.d
Portugal	67	54	38	32	12	9	17	13
Slovakia	7	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Slovenia	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Spain	55[b]	57	n.d	n.d	n.d	n.d	n.d	n.d
Sweden	84	84	43	n.d	29	n.d	12	n.d
Switzerland	49	48	15	14	23	23	11	11
Total	**1505**	**1386**	**149**	**119**	**151**	**80**	**85**	**75**

a) Incl. all light casting
b) Only members

Table 1.4: Number of foundries (production units) for non-ferrous metal casting [168, CAEF, 2002], [202, TWG, 2002]

Country	1998	1999	2000	2001	2002	2000:2001	2001:2002
						% change	
Austria	3465	3314	3342	3936	3067	17.8	-22.1
Belgium	2823	2299	3260	1847	1936	-43.3	4.8
Czech Republic	n.d	n.d	n.d	17536	14847		-15.3
Denmark	n.d	n.d	1481	1393	1290	-5.9	-7.4
Estonia	n.d	n.d	125	133	129	6.4	-3.0
Finland	2326	2058	2027	2090	2045	3.1	-2.2
France	26407[a]	25714	25613	24871	24651	-2.9	-0.9
Germany	46944	45157	44896	44796	42748	-0.2	-4.6
Great Britain	24000[b]	20000[b]	18000[b]	16500[b]	15900[b]	-8.3	-3.6
Hungary	3485	3285	3175	2734	n.d	-13.9	
Ireland	502	503	509	309	n.d	-39.3	
Italy	22050	22200	22100	21400	20630	-3.2	-3.6
Netherlands	2462	2122	2119	2148	1830	1.4	-14.8
Norway	1864	1706	1730	1754	1564	1.4	-10.8
Poland	33600	28500	26800	26370	24500	-1.6	-7.1
Portugal	2649	2800	2782	2780	2710	-0.1	-2.5
Slovakia	n.d	n.d	n.d	1925	n.d		
Slovenia	n.d	n.d	n.d	n.d	n.d		
Spain	13860	14040	11803	11006	11385	-6.8	3.4
Sweden	3650	3650	3650	3800	3800	4.1	0.0
Switzerland	2400	2300	2400	2400	1930	0.0	-19.6
Total	**192487**	**179648**	**175812**	**189728**	**174962**		
Full total [c]			***195273***	***189728***	***179930***		

a) Break in continuity of series
b) Without steel castings
c) Full total calculated by taking most recent available number for the years for which no data are given

Table 1.5: Employment in the foundry industry for iron, steel and malleable iron casting [168, CAEF, 2002], [202, TWG, 2002]

Country	1998	1999	2000	2001	2002	2000:2001	2001:2002
						% change	
Austria	4029	4179	4349	4585	4398	5.4	-4.1
Belgium	1824	803	800	n.d	558		
Czech Republic	n.d	n.d	n.d	5083	5374		5.7
Denmark	n.d	n.d	377	372	349	-1.3	-6.2
Estonia	n.d	n.d	0	0	0		
Finland	708	744	884	718	730	-18.8	1.7
France	17926	17821	17651	17932	17720	1.6	-1.2
Germany	32000	33000	33000	34500	34390	4.5	-0.3
Great Britain	n.d	n.d	n.d	n.d	n.d		
Hungary	3208	3941	5503	4702	n.d	-14.6	
Ireland[a]	70	70	70	70	n.d	0.0	
Italy	n.d	n.d	n.d	n.d	n.d		
Netherlands	n.d	n.d	n.d	n.d	n.d		
Norway	1271	1411	1483	1491	1307	0.5	-12.3
Poland	4433	6500	6200	4130	4100	-33.4	-0.7
Portugal	1200	1230	1280	1380	1350	7.8	-2.2
Slovakia	n.d	n.d	n.d	845	n.d		
Slovenia	n.d	n.d	n.d	n.d	n.d		
Spain	5650	5620	4810	5034	4994	4.7	-0.8
Sweden	3700	3700	3700	3700	3700	0.0	0.0
Switzerland	1900	2000	2100	2200	1900	4.8	-13.6
Total	**77919**	**81019**	**82207**	**86742**	**80870**		
Full Total [b]			***88135***	***87300***	***86487***		

a) Only lead
b) Full total calculated by taking most recent available number for the years for which no data are given

Table 1.6: Employment in the foundry industry for non-ferrous casting [168, CAEF, 2002], [202, TWG, 2002]

The tables show that European production levels are relatively stable or are slightly rising but that this production now results from fewer units and less employees. This can be explained by progressive upscaling and automation in the foundry units. The relationship between unit size, production and employment is well illustrated in Figure 1.1. This shows that the larger West-European producers (Germany, France) are attaining higher productivities with fewer people. The more labour-intensive units are found in the Eastern and Southern part of Europe (Poland, Hungary, Portugal).

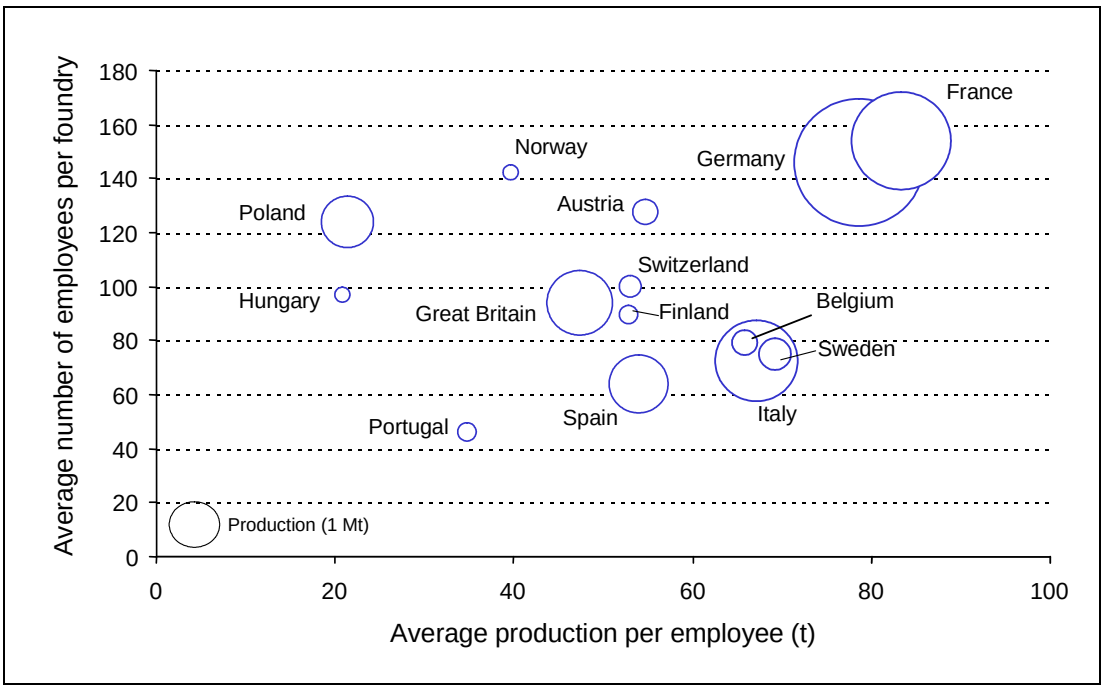

Figure 1.1: Ferrous foundry productivity data for various European countries the size of the circle represents the total production in the specified country

The casting of metal is an ancient activity, dating back to more than 3000 BC. The development of the European foundry industry is linked with the development of both the metal and the automotive industries. Present foundries often have a history dating back to the beginning of the 20th century. Originally they were usually located on the outskirts of towns, but as villages and cities have grown around them they are now often surrounded by habitation. The foundry industry is basically an SME industry, with 80 % of companies employing less than 250 people. Since castings in general are semi-finished products, foundries are located close to their customers.

1.1.2 Foundry markets

The main markets served by the foundry industry are the automotive, general engineering and construction sectors. The relative shares of these sectors as markets for the foundry industry are given in Figure 1.2. The high dependence on the automotive sector has a major influence on activities in the foundry sector, and concerns various aspects, such as economy, location, quality standards, environmental standards, new developments, etc. One example of this dependency is that the automotive industry's shift towards lighter vehicles, is reflected in the foundry industry by an increased demand (and thus market) for aluminium and magnesium casting, thus enabling the growth of these sectors.

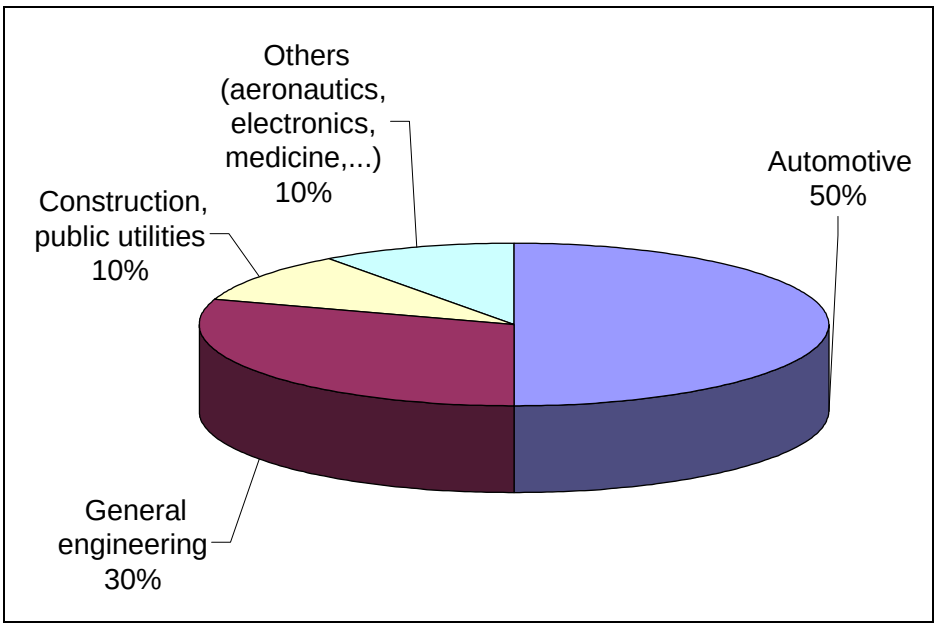

Figure 1.2: Relative sectoral market shares

The market shares differ according to the type of metal. This is illustrated by data from the Spanish foundry market, as shown in Figure 1.3 and Figure 1.4. The automotive sector takes up more than 60 % of all iron castings from Spanish foundries. Steel castings on the other hand (including low alloyed as well as stainless and other alloys) are used for machine parts and in valve making, and therefore serve a broader range of sectors. Indeed, the largest share of the market for valve making is taken up by stainless castings.

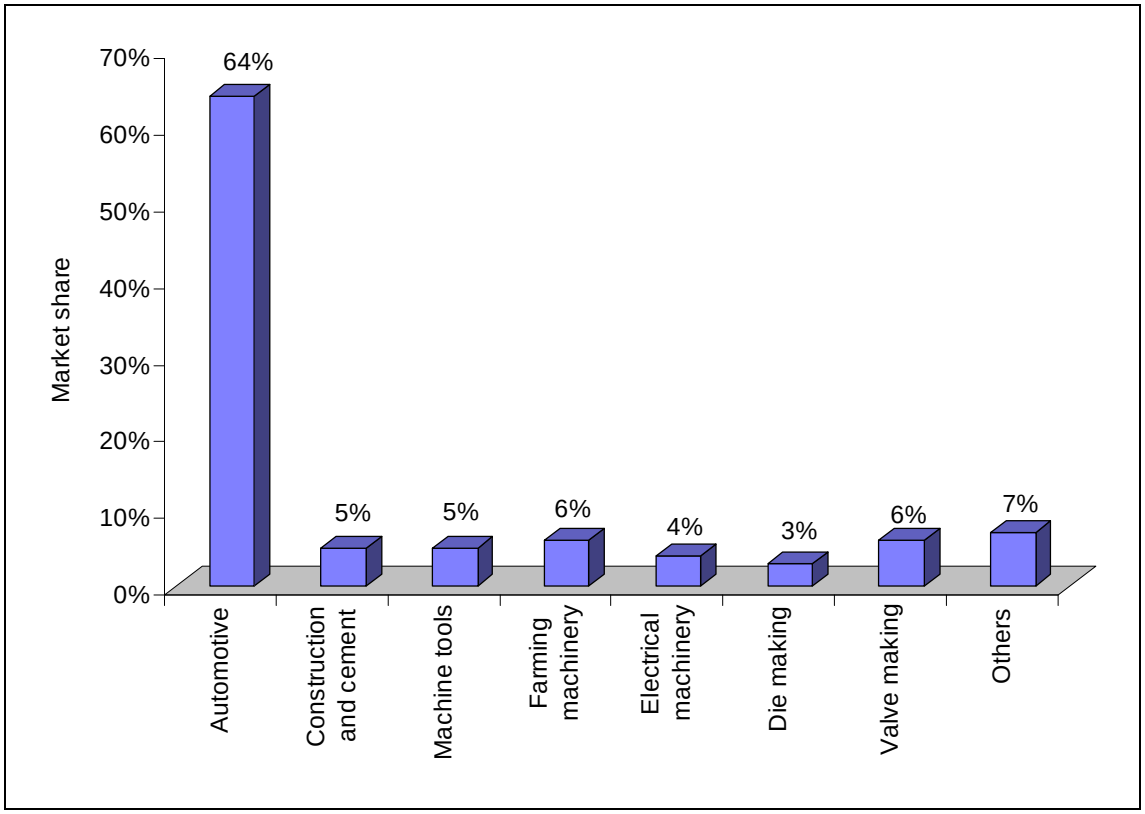

Figure 1.3: Market shares for iron castings (data for Spanish market) [108, FEAF, 1999]

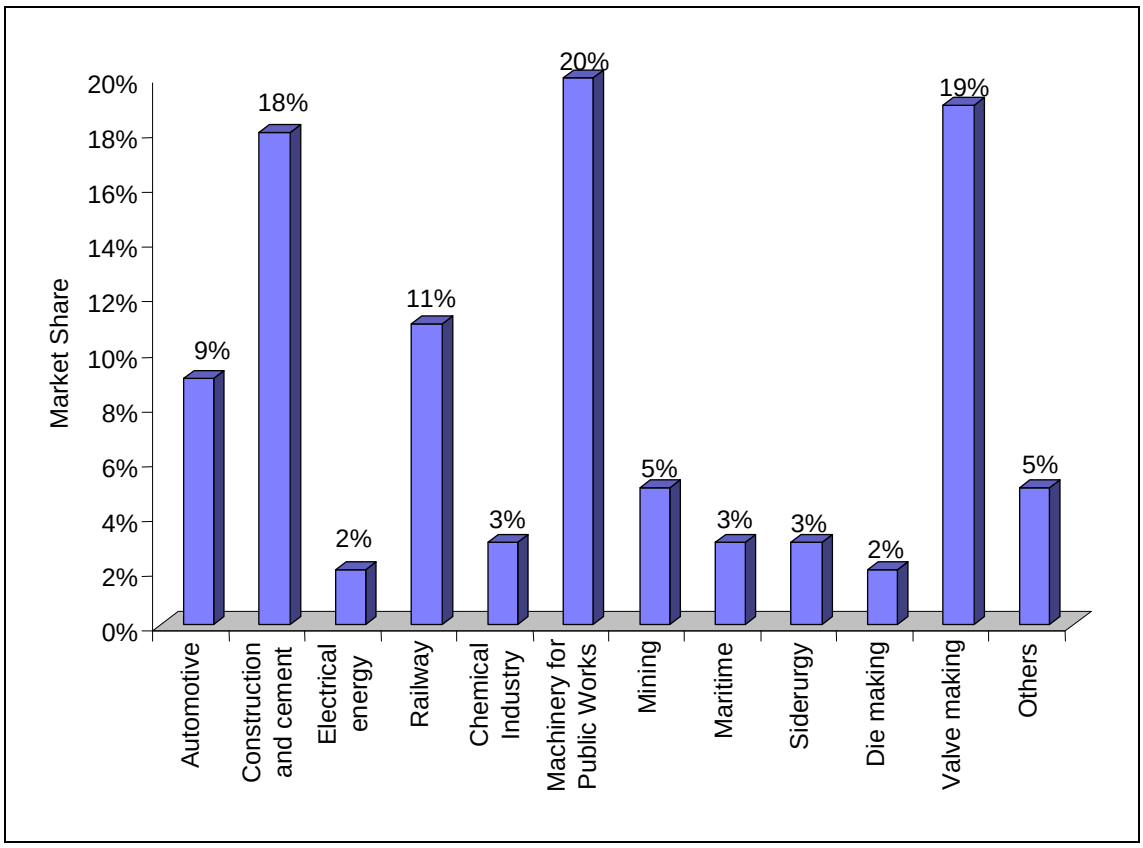

Figure 1.4: Market shares for steel castings (data for Spanish market) [108, FEAF, 1999]

The opening of Europe towards the East has led to the big European producers showing a growing interest in the existing foundry activity in countries such as Poland, the Czech Republic and Hungary. Some of the big European companies have invested in these regions. For the East European countries, the opening of their markets combined with inward foreign investment has allowed the implementation of new techniques, thereby increasing productivity and reducing their effects on the environment. Due to the low labour costs in these countries, their competitive strength lies in jobbing foundries, mainly producing large castings, and in foundries producing a broad range of products. To compete on the world market, West-European foundries now focus on their technological skills, selecting niche markets which require complex castings with high precision, specific quality requirements, or those that require quick or just-in-time delivery.

1.1.3 Foundry types

Besides the metal type (i.e. ferrous/non-ferrous) the foundry layout is largely dependent on the size of castings and the series size. A small series foundry is termed a ‘jobbing foundry’ and a large series one is termed a ‘series foundry’. Foundries may be also be classified according to the type of metal manufactured, i.e. either a ferrous or a non-ferrous foundry. There is a large difference between a zinc foundry producing a large series of frames for toy cars and a cast iron foundry producing rotor housings for wind turbines. Foundries apply different degrees of automation according to their series size and the repeatability of the work. Concerning applied techniques, the main distinction is made by the type of melting furnace used (e.g. cupola, electrical, rotary, …) and the type of mould (e.g. sand moulding, die-casting). These will be described and discussed further in Chapter 2.

1.2 Environmental issues

The foundry industry is a major player in the recycling of metals. Steel, cast iron and aluminium scrap can all be remelted into new products. The possible negative environmental effects of foundries result from the presence of a thermal process and the use of mineral additives. The environmental effects of a foundry process therefore mainly relate to the exhaust and off-gases and to the re-use or disposal of mineral residues.

1.2.1 Air

Noxious emissions from the melting and treatment of metals are generally related to the use of additives and fuels or to impurities in the feed. The use of cokes as fuels or the heating of crucibles with gas or oil-fired burners can cause emissions of combustion products. Also the application of additives in metal treatment processes generates reaction products. The presence of impurities (e.g. oil, paint, …) in scrap used for re-melting can potentially cause the production of the products of incomplete combustion or recombination and dust. Also any dust generated may contain metal and metal oxides. The evaporation of elements with a high vapour pressure occurs during melting and small particles of metal escape from the bath. Metallic particles are also generated during grinding and finishing operations.

In the making of moulds and cores, various additives are used to bind the sand. In the binding of the sand and pouring of the metal, reaction and decomposition products are generated. These include both inorganic and organic products. The generation of decomposition products further continues during the casting cooling and de-moulding operations.

Dust and particles' releases are a general issue in all stages of the foundry process, and for all processes used. Dust is generated in the production and processing of sand moulds and cores, as well as in the finishing of the castings (both from lost moulds and permanent moulds).

In the foundry process, emissions to air are not limited to one (or several) fixed point(s). The process involves various emission sources (e.g. from hot castings, sand, hot metal). A key issue in emission reduction is not only to treat the exhaust and off-gas flow, but also to capture it.

1.2.2 Residues

Sand moulding involves the use of large sand volumes, with sand-to-liquid-metal weight ratios generally ranging from 1:1 up to 20:1. At the end of the moulding process the used sand can be regenerated, re-used or disposed off. Additional mineral residues such as slag and dross are generated in the melting stage when removing impurities from the melt. These should also be considered for either re-use or disposal.

1.2.3 Energy

Since foundries deal with a thermal process, energy efficiency and management of the generated heat are important environmental aspects. However, due to the high amount of transport and handling of the heat carrier (i.e. the metal) and due to its slow cooling, the recovery of heat is not always straightforward.

1.2.4 Water

In most foundries, water management involves an internal circulation of water, but a major part of the water still evaporates. The water is generally used in the cooling systems of electric furnaces (induction or arc) and cupola furnaces. In general, the outgoing waste water stream is therefore very small. For (high) pressure die-casting, a waste water stream is formed, which needs treatment to remove organic (phenol, oil) compounds before disposal.

2 APPLIED PROCESSES AND TECHNIQUES IN FOUNDRIES

2.1 Overview

2.1.1 The foundry process

A general flow chart of the foundry process is depicted in Figure 2.1. The process can be divided into the following major activities:

- melting and metal treatment: the melting shop
- preparation of moulds: the moulding shop
- casting of the molten metal into the mould, cooling for solidification and removing the casting from the mould: the casting shop
- finishing of the raw casting: the finishing shop.

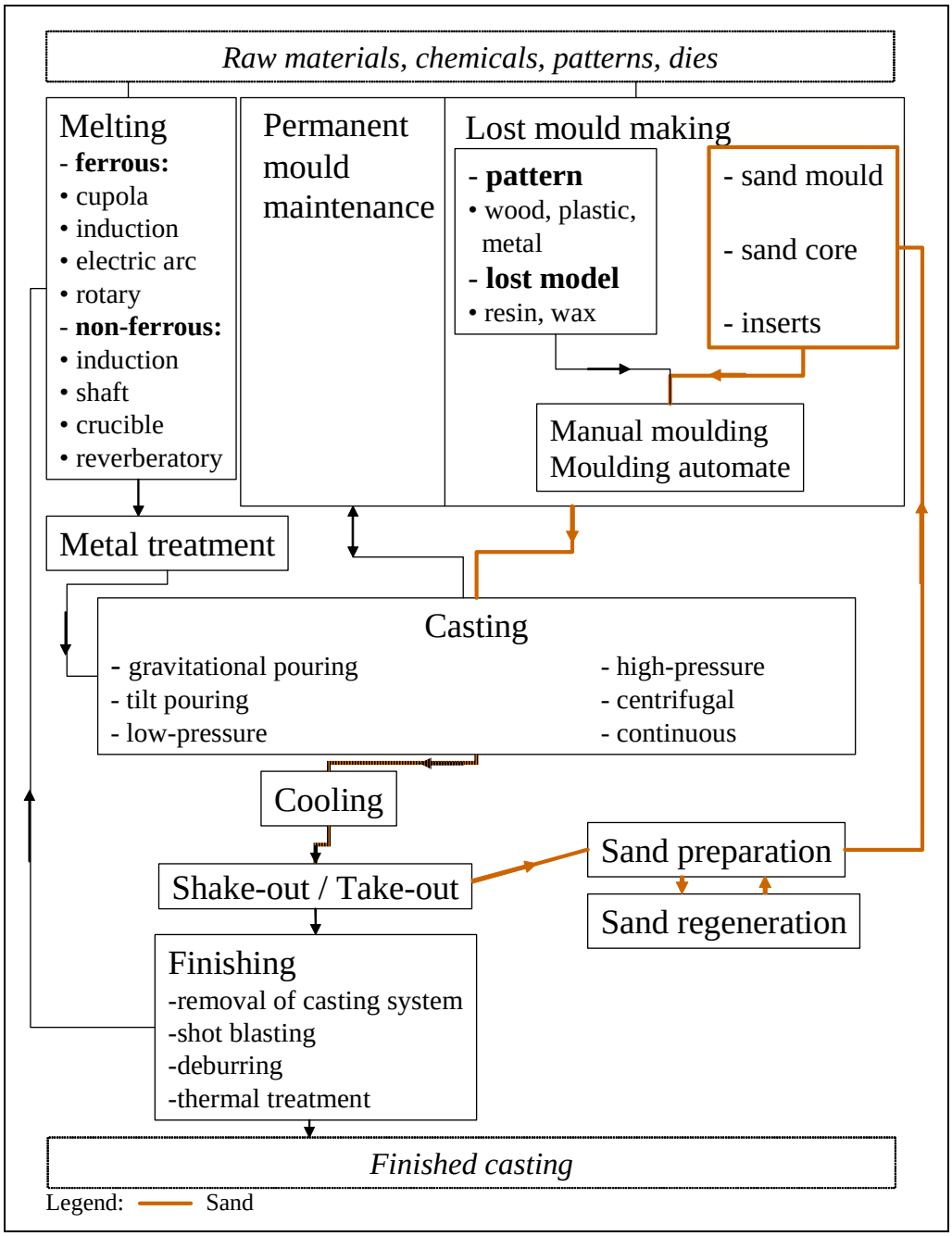

Figure 2.1: The foundry process

Starting from foundry scrap (selected scrap according to a certain chemical composition) or ingots, the foundry produces finished castings. Usually these are components which will require further treatment or assembly to yield a final product.

On the moulding side, a basic distinction is made between permanent and lost moulds. Foundries casting in permanent moulds, buy these metal moulds (dies) externally, but typically operate an in-house mould repair and maintenance shop. Foundries casting in lost moulds, often buy wooden, metal or plastic patterns (for their mould design) and operate an in-house pattern maintenance and repair shop. Moulds, cores and lost models are generally produced as part of the foundry process.

Traditionally in the foundry sector the main distinction made is between ferrous and non-ferrous foundries. This is mainly because the applied processes in both sectors differ. Non-ferrous foundries often apply die-casting techniques. These allow a better surface finish, which is important for many of the aluminium and brass applications. Due to the high cooling rate, castings with a high mechanical strength are produced. However, this technique does not allow the production of massive or large pieces, which require sand casting techniques. Sand casting techniques are applied in non-ferrous foundries for those products that are not produced in large series. The non-ferrous metals (and their alloys) discussed in this document are:

- aluminium
- magnesium
- copper
- zinc
- lead.

Ferrous foundries generally apply the lost mould techniques. Due to their greater stiffness and strength, ferrous alloys are used in different applications to non-ferrous alloys. The size of the products that can be produced is almost unlimited. Ferrous metals have a higher melting point and therefore require different melting techniques. The ferrous metals and alloys discussed in this document are the various types of cast iron (which may be classified according to their properties or by the graphite type) and cast steel.

Superalloys with a high content of alloying elements, such as nickel, will also be discussed.

Foundries utilise mechanisation and automation depending on the need for reproductivity and on the series sizes. The most flexible installation is typically the jobbing foundry. This produces a variety of products in small numbers (<100). In general, this type of foundry applies manual moulding techniques with resin-bonded sand moulds. The melting furnace works batch wise to allow an easy change of alloy. This implies the use of induction or rotary furnaces.

For medium-sized series (<1000 parts), mechanised moulding and casting lines are used. Lost mould foundries utilise mould making machines. This implies the use of green sand, which allows fast mould making. The size of the mould making machine limits the maximum size of the castings. Casting can be performed manually or by using a pouring machine. Auxiliary side processes, such as sand preparation, are operated in a semi-automated way with remote control. Both continuous furnaces (cupola, shaft) and batch furnaces are used. For non-ferrous alloys, die-casting techniques are applied.

Large series of small castings are made in flaskless green sand moulding. For specific applications, die-casting also can be used in ferrous foundries if the final casting quality requires it, although in reality the technique finds only limited implementation. The main difference for medium-sized series is the further automation of the finishing, the quality control and the mould assembly. For die-casting in non-ferrous alloy facilities, further automation is often applied, this is especially the case in pressure die-casting shops.

Specific casting techniques, such as full mould casting, centrifugal casting and continuous casting are applied where the product type requires it.

2.1.2 Iron casting

Cast iron is an iron-carbon alloy, containing usually between 2.4 and 4 % carbon. The minimum carbon content is 1.8 %. Silicon, manganese, sulphur and phosphorus are also present in various amounts. Special grades of iron are produced which contain various levels of nickel, chrome and other metals. Due to its high carbon content, cast iron has a low melting point and a good casting ability as compared to steel. Its ductility is low and does not allow rolling or forging. Variations in properties can be achieved by varying the ratio of carbon to silicon, by alloying, and by heat treatment.

Depending on the concentration and form of the carbon (lamellar, spheroidal or compact), various types of cast iron may be defined:
- lamellar iron: carbon in the form of flakes
- nodular iron: carbon in spheroidal form
- compact graphite iron: carbon in bonded form.

The classification of cast iron is often made according to its material properties:
- grey iron: iron with a grey fracture surface. Although this applies for lamellar, nodular and compact graphite iron, the term is commonly used as a synonym for lamellar iron
- ductile iron: cast iron with an increased ductility. This is one of the effects caused by nodularisation, but it also applies to malleable iron. The term is commonly used as a synonym for nodular iron
- malleable iron: iron that is capable of extension or of being shaped under the hammer. This property is related to a low carbon content, which leaves most of the carbon in bonded form.

Cast iron can be melted in the cupola furnace, induction furnace (generally of coreless type, but very occasionally can be the channel type) or in the rotary furnace. The electric arc furnace is only very rarely used for the preparation of cast iron. Figure 2.2 gives process flow diagrams for the melting and metal treatment of cast iron in the three different furnace types. The process generally consists of melting – tapping – metal treatment – pouring. The various aspects of melting and metal treatment are discussed in the following sections. Metal treatment involves various steps such as desulphurisation, nodularisation, inoculation and deslagging. The desulphurisation step in cupola melting may also be incorporated into the nodularisation, e.g. by using a nodularisation process which simultaneously takes up the sulphur, such as the core wired process.

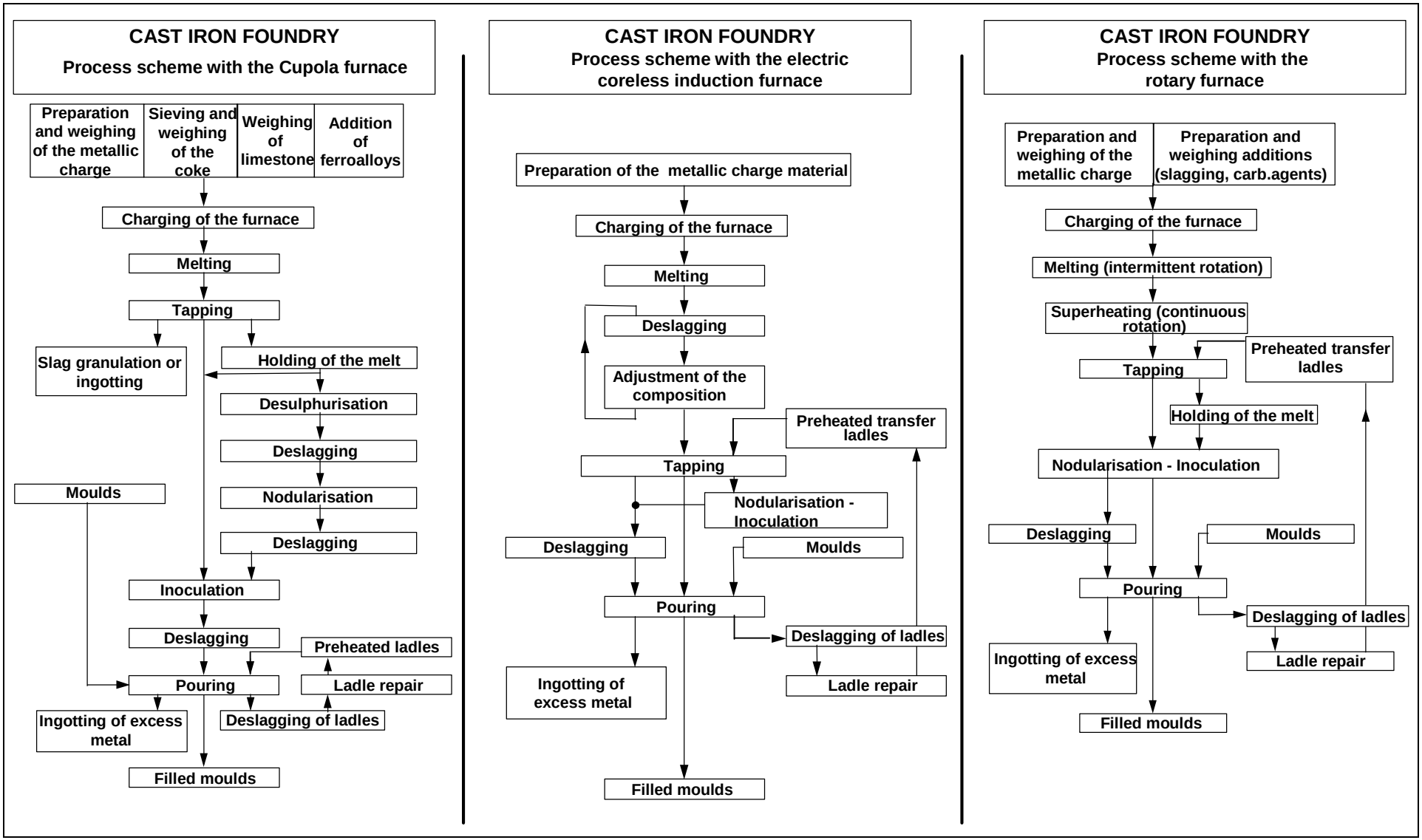

Figure 2.2: Process flow diagrams for the melting and metal treatment of cast iron [32, CAEF, 1997]

The cupola is the leading device for re-melting iron in Europe. It is responsible for some 55 % of the tonnage of iron castings produced in Western Europe. Nowadays, the cupola is increasingly facing major challenges to its market domination. This is partially due to its flue-gas quality, which requires treatment. Faced with the possible financial burden of investing in, and then depreciating, a stack gas treatment installation, many small and medium sized units have turned to electric or oxygas melting units. Thus the number of cupolas used in foundries is falling, but their average size is increasing. There have been major changes in the market for cupolas in Europe in recent years, particularly due to the restructuring of the coke industry, leading to a decreased number of suppliers and a need to import coke into Europe. Another major change is the smaller number of cupola manufacturers, with one German firm having a quasi-monopoly in the hot blast type.

The majority of repetitive iron castings are made in green sand moulds with resin-bonded cores. The cold-box amine and hot-box techniques are most widely used. The 'Croning resin shell' moulding process is used where a high precision and good surface finish are needed. The Lost Foam process is used to a limited extent, for repetition castings. Castings made in smaller numbers are made in chemically-bonded sand moulds. Special sand processes, such as vacuum moulding and full moulding are used for certain iron castings. There are also a few permanent moulding (die-casting) foundries making iron castings, but the short die-life of a mould limiting it to making only a few thousand components has restricted the use of ferrous die-casting.
[156, Godinot, 2001], [174, Brown, 2000]

2.1.3 Steel casting

Steel is a material of which the (mass) content of iron is bigger than that of any other element, with a carbon content generally lower than 2%, and which also usually contains other elements. A limited number of chromium steel types may contain over 2 % carbon, but 2 % is the usual cut-off limit used to distinguish steel from cast iron [201, CEN, 2000]. One particularly useful aspect of steel is that it can be hot worked. Low alloy cast steel contains elements such as Mn, Cr, Ni, and Mo in amounts less than 5 %. High alloy steel includes more than 5 % of alloying elements, e.g. 12 % Cr and 8 % Ni. Special steel grades are produced with enhanced properties, such as higher strength; higher magnetic permeability; better resistance to corrosion, fatigue or wear; and improved behaviour during welding or at high or low temperatures.

Cast steel is normally melted in electric arc furnaces (EAF) or in coreless induction furnaces (IF). Once melted, the liquid metal can be refined (i.e. removal of carbon, silicon, sulphur and or phosphorus) and deoxidised (i.e. reduction of metallic oxides), depending on the base material and the quality requirement of the finished product . Figure 2.3 gives process flow diagrams for the melting and metal treatment of cast steel in the different furnace types.
[32, CAEF, 1997]

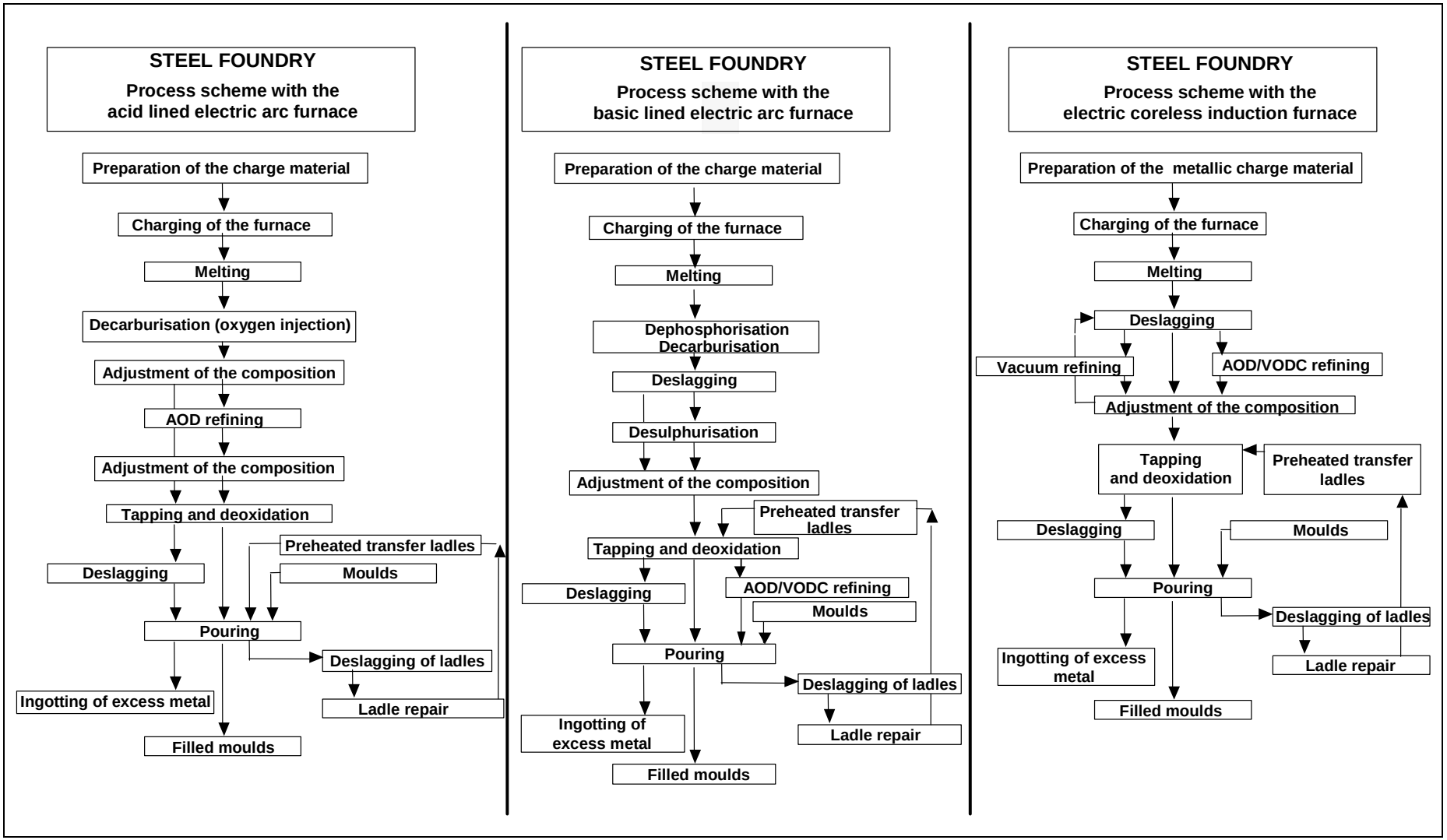

Figure 2.3: Process flow diagrams for the melting and metal treatment of steel [32, CAEF, 1997]

2.1.4 Aluminium casting

About two-thirds of all aluminium castings are used in the automotive industry, e.g. in cars, buses, lorries, trains and aircraft. The need to reduce vehicle fuel consumption and weight has increased the interest in aluminium. The total mass of aluminium in a European car roughly doubled between 1990 and 2000. This growing use of aluminium in its major user sector clearly has an effect on the overall number of castings produced.

Aluminium is mainly cast into permanent moulds. The relative shares of applied casting techniques for Al are given in Table 2.1:

Casting type	Relative share (%)
Pressure die-casting	59
Low-pressure die-casting & gravity casting	37
Sand casting	3
Others	1

Table 2.1: Relative shares of applied casting techniques for Al [143, Inasmet and CTIF, 2002], [225, TWG, 2003]

Many different types of melting furnaces are used in aluminium foundries the choice depending on individual requirements. Directly and indirectly heated furnaces, using fuel and electricity, are applied. The fossil fuels currently used are natural gas, liquid petroleum gas (LPG) and oil. Natural gas is favoured by most foundries on convenience grounds. Electrical heating may be provided by either resistance elements or by induction. Capacity is one of the most important parameters for melting and holding furnaces. Today induction furnaces are normally used when a high melting capacity, e.g. above 10 tonnes/hour, is needed. Shaft melting and holding furnaces, as well as crucible furnaces, are often used when the melting capacity is less than five tonnes/hour. Small and medium crucible furnaces are often used when it might be necessary to be able to change the alloy easily or if the production rate is low.

For holding, electric furnaces have the advantage of not producing burner off-gases and being able to sustain a homogeneous temperature over the whole molten volume, at a relatively low energy expense.

Aluminium melting in foundries generally uses alloyed ingots as a starting material, although in some cases the metal is delivered already as a liquid. The secondary melting of aluminium scrap is usually not performed in foundries and falls outside the scope of this document. It is discussed in the BAT reference document for the non-ferrous metals industries.
[48, ETSU, 1994] [148, Eurofine, 2002], [155, European IPPC Bureau, 2001]

2.1.5 Magnesium casting

Magnesium alloy castings are used for aerospace, automotive and electronic applications. The main advantage for using them is their light weight; typically magnesium alloys have a density of 1.8 g/ml compared with 2.7 g/ml for aluminium alloys. Aluminium is the principle alloying constituent of magnesium-based casting alloys, with zinc and manganese also present in small amounts. Pressure die-casting is the most commonly used casting process, due to the low casting temperature (650 – 700 ºC); both hot chamber and cold chamber die-casting machines are used. Sand moulding is applied to a lesser extent. Magnesium die-castings can be made with thinner walls than aluminium, but their use is limited by stiffness problems. The thinner walls allow the overall weight of the components to be substantially reduced, thus compensating for the higher alloy cost per kilogram. Gravity die-casting and sand casting are also used, particularly for more highly stressed castings. The use of magnesium alloy die-castings in automotive components is growing rapidly, with some vehicles already containing 10 – 20 kg of Mg components. The most popular parts made at present are instrument panel substrates, cross car beams, wheeldrives and seat frames.

Molten magnesium alloys attack firebrick and refractory furnace linings, resulting in harmful silicon contamination. Therefore steel crucibles are used. Iron is also slightly soluble in magnesium but it has a much less harmful effect than silicon. Scrap is usually cleaned and if possible shot blasted to remove any adhering sand as a further precaution against silicon pick-up. To eliminate ladling, the molten alloy is, if possible, poured direct from the melting pot.

Due to its very easy oxidation, magnesium alloys are melted under a cover using a cleansing flux or cover gas, to avoid oxidation losses and to prevent inclusions. Inhibitor powders are used to cover any exposed metal during holding and pouring, and are added to moulding-sand to prevent chemical reactions. The fluxless melting of Mg alloys requires another form of melt protection. For this purpose, sulphur hexafluoride (SF_6) is used, as it promotes the formation of a protective film on liquid magnesium, which prevents oxidation. It is used at low concentration (<0.3 vol %) in a mix with air or air/CO_2. SF_6 is a greenhouse gas, considered harmful to the atmosphere and falls under the Kyoto protocol, which requires its use to be minimised. Austria and Denmark have issued regulations to ban the use of SF_6 by 2003 and 2006, respectively.

Magnesium alloys benefit from grain refinement, which is carried out by inoculation with carbonaceous materials. This used to be done with hexachloroethane, but since 1 July 2003 this product is banned in Europe generally to ensure environmental protection and for health and safety reasons. This applies both for magnesium and aluminium alloys.
[175, Brown, 1999], [225, TWG, 2003]

2.1.6 Copper casting

Copper is cast in the form of various groups of alloys, each having copper as the main element. Short descriptions of some of these are given below:

- *High conductivity coppers*: These are used mainly for their high electrical and thermal conductivities. Applications include tuyères for blast furnaces and hot blast cupolas, water-cooled electrode clamps, switchgear, etc.
- *Brasses*: Cu-Zn-alloys, where zinc is the major alloying element. These are easy to cast, with excellent machinability and good resistance to corrosion in air and fresh water. They are widely used for plumbing fittings. High tensile brasses are more highly alloyed and find uses in marine engineering. Brasses are cast both in sand and in permanent moulds
- *Tin bronzes*: Cu-Sn-alloys, where tin is the major alloying element. With tin contents of 10 – 12 %, tin bronze castings are more expensive than brass. They have high corrosion resistance and are suitable for handling acidic waters, boiler feed-waters, etc. High tin alloys are also used in wear-resistant applications. Their applied casting techniques are sand and centrifugal casting
- *Phosphor bronzes*: Cu-Sn-alloys, with an addition of about 0.4 – 1.0 % P. These are harder than tin bronzes but have lower ductility. They are used for bearings where loads and running speeds are high and for gears such as worm wheels
- *Lead bronzes*: Cu-Sn-Pb-alloys. These are used almost exclusively for bearings, where loads and speeds are moderate
- *Gunmetals*: Cu-Sn-Zn-Pb-alloys. These are the optimal alloys for sand casting. They have a good combination of castability, machinability and strength, and good corrosion resistance. They are used for intricate, pressure-tight castings, such as valves and pumps. They are also used for bearings, where loads and speeds are moderate
- *Aluminium bronzes*: Cu-Al-alloys, where Al is the major alloying element. These combine a high strength with high resistance to corrosion. Their applications range from decorative architectural features to highly stressed engineering components. They have many marine uses, including propellers, pumps, valves. They are also used for the manufacture of non-sparking tools. Al casting techniques are applied
- *Copper-Nickels*: Cu-Ni-alloys, where Ni is the major alloying element. These are used for e.g. pipework for marine applications in severe conditions

- *Copper-beryllium alloys*: Beryllium is cast as a copper-beryllium alloy for the production of parts that require resistance to corrosion and very high mechanical characteristics. These include plunger tips for die-casting machines, precision parts for the electrical and mechanics industry, in watchmaking, for tooling, and for measurements instruments. Two alloy types are used: a copper-beryllium alloy with 2 % Be, and a copper-cobalt-beryllium alloy with 0.5 % Be. There is a tendency to reduce or exclude beryllium in alloys due to its known carcinogenic character. Casting is done in permanent moulds using pressure or gravity die-casting. For precision parts casting, the investment casting technique is used.

[175, Brown, 1999]

2.1.7 Zinc casting

Zinc casting almost exclusively uses the pressure die-casting technique. In the EU, there are mainly two alloys in use, their compositions are given in Table 2.2. They are also referred to as Zamac, which in origin is a trade name. The basis of these alloys is pure zinc.

Symbol	Alloy number	Al	Cu	Mg
ZnAl4Cu1	ZP0410	3.7 – 4.3	0.7 – 1.2	0.025 – 0.06
ZnAl4	ZP0400	3.7 – 4.3	0.25	0.025 – 0.06

Table 2.2: Most common zinc alloys, contents in %

The zinc alloy is almost exclusively melted in a casting machine, of the hot chamber type. In rare cases, and only when high production capacity is needed, centralised melting may be applied.

Zinc alloys have comparable material properties to aluminium. The main differences are the lower melting point and the higher density of the zinc alloys (6.7 g/cm³ versus 2.6 – 2.7 g/cm³). They are mostly used for small pieces requiring high precision and a low wall thickness. They also allow a higher casting speed to be utilised and result in a 10 times longer die life (800000 to 1200000 shots), which makes them more suitable for large series (of small pieces). The zinc alloys are melted in an electrically or fuel heated cast iron crucible and cast using hot-chamber die-casting machines. The products are used in e.g. automotive and electronics components and in machine construction applications.

2.1.8 Lead casting

Lead is a low melting (melting point 327 ºC) heavy metal. Lead is relatively soft, corrosion-resistant and has good self-lubricating properties. The uses of lead castings include accumulator sheets, shielding material for X-rays and nuclear applications, and in ballast and counterweight materials. Mainly pressure and gravity die-casting techniques are applied.

2.1.9 Casting of superalloys

The superalloys are typically Ni, Ni-Fe, and Co based alloys with Cr, Ti, W, Al additions. They were originally used for high temperature applications (over 810 ºC) or in severe corrosive media. Superalloys can be distinguished from high alloyed steels (see definition in Section 2.1.3). Since iron is not the major compound (as defined in [201, CEN, 2000]), they are considered non-ferrous materials. The casting of superalloys may occur in certain investment casting foundries, as well as partly in foundries which specialise in high alloyed steel qualities.

The nickel base alloys are produced from a group of alloys which have chemical compositions generally over 50 % nickel and less than 10 % iron. They are mainly strengthened by intermetallic precipitation in an austenitic matrix. The cobalt base alloys have a high Co content (40 to 70 %), high Cr (over 20 %), high W (7 to 15 %) and they are strengthened by a combination of carbides and solid solution hardeners.

Some superalloys, particularly Ni-Fe and Co based alloys, are directly melted in electric furnaces by classical methods usually applicable to stainless steels. However for Ni and special Ni-Fe superalloys, vacuum induction melting is required in order to reduce the content of interstitial gases (O, H, N) to a very low level. This enables foundries to achieve high and controlled contents of oxidisable elements such as Ti or Al.

The control of interstitial gases and oxidisable elements is very important for the product's mechanical properties, the corrosion resistance and its reliability. In general, superalloys are cast into complex final shapes where machining is not possible. Therefore, they are mainly produced by investment casting (i.e. using a ceramic mould). This casting process produces a product of very precise dimensions with a very smooth surface. Additional processes, such as HIP (hot isostatic pressing), can be used to eliminate the internal porosity that can appear in large castings. In aircraft gas turbine manifolds, directional casting technology is commonly applied. This technology eliminates the grain boundaries and greatly increases the strength of the material.

Initially superalloys were developed for high temperature applications. However, their field of application continues to expand and now covers areas such as cryogenic temperature appliances and orthopaedic and dental prostheses. In general, superalloys are mainly used in aircraft and industrial gas turbines, in nuclear reactors, in aircraft and spacecraft structures, in petrochemical production and in medical applications.
[202, TWG, 2002]

2.2 Pattern making

2.2.1 General pattern making

Pattern making, or foundry tooling as it is also called, requires a high level of skill to achieve the close tolerances required of the patterns and coreboxes. This step is critical in the casting process since the castings produced can be no better than the patterns used to make them. Patterns are made by means of hand tools, universal machines, or by a CAD/CAM system on computer-numerical-controlled (CNC) machines. In some pattern making shops, computer-aided design (CAD) is used in the design of patterns. Cutter tool paths are designed with computer-aided manufacturing (CAM). The numerical output from these computers is conveyed to CNC machine tools, which then cut the production patterns to shape. Such computer-aided systems have better dimensional accuracy and consistency than manual methods.

Patterns (Figure 2.4) and corebox materials (Figure 2.5) are typically metal, plastic, wood or plaster. Wax and polystyrene are used in the investment and Lost Foam casting processes, respectively. Pattern makers have a wide range of tools available to them, including woodworking and metal machining tools. Mechanical connectors and glues are used to join pattern pieces together. Wax, plastic or polyester putty is used as a filler to fill or round the inside of square corners.
[42, US EPA, 1998]

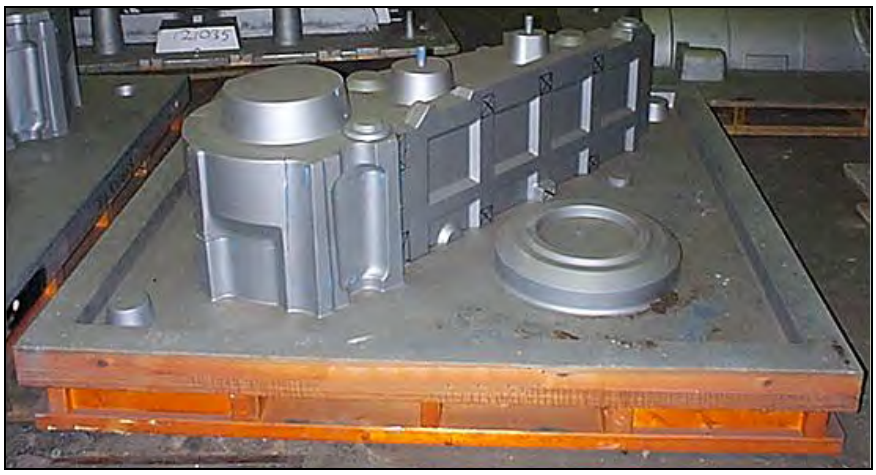

Figure 2.4: Wooden pattern
[237, HUT, 2003]

Figure 2.5: Coreboxes
[237, HUT, 2003]

2.2.2 Rapid prototyping (RP)

Rapid prototyping is a technique to pass very quickly from a product concept to a cast prototype. The term 'Rapid Prototyping' includes all technical and organisational measures from the formulation of the concept of a product to the manufacture of the product. Rapid prototyping can be used for every stage of product development, i.e. for concept models, geometrical prototypes, functional prototypes or for technical or sales prototypes. All the currently available techniques allow the fabrication of a prototype part from a three-dimensional drawing. They are also used for the direct sintering of sands for the production of moulds or cores. The technique consists of building an object to a design pattern by joining particles or layers of raw material such as polymer resin, wax, paper or ceramic powder. An example picture of a wax pattern is given in Figure 2.6

Figure 2.6: Thermopolymer (wax) patterns in an RP machine
[237, HUT, 2003]

There are 4 basic steps to rapid prototyping:
1. the creation of a 3D-CAD model
2. making the interface between the 3D-CAD system and the rapid prototyping system. For example the CAD data may be converted to the STL (Standard transformation format) file format
3. slicing the STL file into thin cross–sectional layers
4. realisation of the RP-model.

The advantages of Rapid Prototyping, particularly for complex forms, include:
- shorter development time and the possibility of rapid modifications during the development
- saving of costs, materials and time
- early error detection.

[202, TWG, 2002], [203, Linxe, 2002]

A survey of available techniques is given in Table 2.3.

Process	Principle	Materials	Special features
Liquid – solid	Polymerisation by local UV exposure of a photosensitive resin	Photosensitive resins Acrylates, epoxydes	- shrinkage and deformations - model needs supports
Solid – solid	Contours of a layer are cut out from a foil	Paper, metals, polymers	- no supports - consumption of base material
	Deposition of a material showing thermal fusion	ABS, wax, elastomers	- model needs supports
	Material jet	Waxes, polymers	- model needs supports
Powder – solid	Agglomeration of powder by sintering	Metals, ceramics, sand, polystyrene, nylon, polyamide, wax	- no supports - porosity - shrinkage
	Agglomeration of powder by binder projection	Alumina	- no supports - porosity

Table 2.3: Description of rapid prototyping techniques
[203, Linxe, 2002]

2.3 Raw materials and raw material handling

The main flows of raw materials entering the foundry are metal ingots, foundry scrap and sand. A distinction can be made between ferrous and non-ferrous foundries. Non-ferrous foundries generally melt only internal return material and alloy ingots (Figure 2.7). The re-melting of external scrap is generally considered a separate activity, usually forming part of the secondary metal production. If external scrap is acquired, it is first subjected to a spectroscopy analysis in order to determine the alloy type. Ferrous foundries use pig iron and selected iron and steel scrap as starting materials, besides internal return material. The various qualities of metal feeds are stored in separate areas in order to allow the controlled feeding of the melting furnace.

Figure 2.7: Aluminium scrap(l.) and ingots (r.)
[237, HUT, 2003]

Raw materials, including fluxes in lump and powder form; foundry cokes for cupola furnaces; deoxidants; and refractories are normally stored under cover. Following delivery, handling is kept to a minimum. Powdered materials may be stored in sealed silos and conveyed pneumatically or kept and handled in sealed bags, as displayed in Figure 2.8.

Figure 2.8: Pneumatic conveyors and silos for powdered materials
[237, HUT, 2003]

Sand is normally delivered in bulk and discharged directly to a silo via a pneumatic conveyor, conveyor belt or grab. Specialist sands may arrive in bags or by tanker. Used sands are stored in silos for regeneration and in silos or heaps for transport for external re-use or disposal.

Liquid binders and oil products are delivered in drums, by bulk container or by road tanker. They are stored in their delivery containers or, in the case of rail tankers, discharged direct into a dedicated storage. The containers are connected by pipe directly to the sand/resin/catalyst-mixing unit. Some catalysts and co-reactants are used in a gaseous form, but these are also delivered as liquids and handled in a similar fashion before being vaporised and mixed with a carrier gas. Evaporation is enclosed and may be carried out by a variety of methods.

Refractories, release agents and other minor deliveries are stored indoors.

Coarse solid residues, such as used refractories and slags, are stored on separate heaps, in a subdivided storage area or in boxes. They are moved and handled using small lift trucks. Fine solid residues are collected at the filter unit into big bags or containers, which may be stored intermediately before transport for disposal. In order to avoid soil contamination from the various classes of materials, specific measures are taken. Potential impacts are listed in Table 2.5.

The metal charged in the melting furnace is carefully selected and weighed to ensure the correct composition. The charge composition is calculated based on the average chemical composition of each component, the oxidation losses during melting and the required final composition of the casting. The different charge elements are combined into a charging device (e.g. drop bottom skip, vibrating feeder, skip hoist) with a tilting magnet, usually equipped with a weighing system, to allow collection of the correct amount.

Additional alloying elements can be added to the charge as ferro-alloys such as FeSi, FeMn, FeCr, or pure such as Cu, C, Ni. However most alloys are added to the molten metal to prevent metallic losses due to oxidation. Alloying elements are usually present in the foundry in small quantities and are always stored inside the building, preferably close to the melting installation. [32, CAEF, 1997].

Activities	Contaminants of Concern		Potential Impact
Raw materials storage			
Scrap storage – external, often on soil	Loose materials from scrap - metals and coatings		Localised contamination of soil surface
	Oils - may include: - PAH from combustion engine oils - PCBs from capacitors (mainly in shredded scrap, unless PCB phase-out has taken place successfully)		Leaching into groundwater and nearby surface waters
	Cutting fluids - may be chlorinated		
Liquids in underground tanks	Petroleum products, e.g. fuel oil diesel		Leakage into soil with leaching into ground and surface waters
Raw materials handling, transfer and use			
Chemical binder products – accidental spillage or leaks	Phenolic resins	Free phenol content of 0.5 to 5 %	Water-soluble; can leach into groundwater. Rapid degradation if less than 400 ppm. Concentrated larger volume spills will be slower to degrade due to toxicity to bacteria
	Solvent carriers in resins	e.g. methanol, up to 20 % volume	Mostly water-soluble, can leach into groundwater
	Urethane resins	Aromatic solvents[1]	Solvents could leach into groundwater
	Furan hardeners	Toluene-, Xylene-, Benzene-sulphonic acids	Could leach into groundwater or alter soil properties, e.g. mobilisation of metals
	Urea-based resins	Ammonia	Can leach into ground and surface waters
	Silicate resins	Alkaline pH	Could leach into groundwater or alter soil properties, e.g. mobilisation of metals
Mould coatings	Isopropyl alcohol (IPA)		Water-soluble, can leach into groundwater
Fuels, maintenance products: - accidental spillage or leaks (particularly around filling points) - deliberate disposal to ground	Fuel oils, diesel, petrol with PAH & SO_4^{2-} post-combustion; Lubrication & hydraulic oils; Quench oils; Transformer oils (potential for PCBs)		Oils can leach into ground and surface waters. Air deposition of PAH and SO_4^{2-} from the combustion of fuel oils. SO_4^{2-} will leach down soil profile. PAH, PCBs will tend to absorb onto soils

[1] Former formulations contained PAH (mainly naphtalene), but naphtalene depleted formulations have been developed, which have eliminated this contaminant.

Table 2.4: Potential soil contamination from ferrous foundry raw materials [140, EU Thematic Network Foundry Wastes, 2001], [225, TWG, 2003]

2.4 Melting and metal treatment

The selection of a melting furnace is an important aspect in the setting up of a foundry process. Each furnace type has its own properties concerning feed requirements and alloying possibilities, which in turn will have repercussions on the full foundry process. On the other hand, the type of metal to be melted determines which furnace may or may not be used. The applicability of the various furnace types is given in Table 2.5.

	Cupola	Electric arc	Channel induction	Coreless induction	Rotary	Hearth type	Shaft	Crucible/ Ladle
Iron	m	m*	h	m, h	m*	m		h
Steel		m		m				h
Aluminium			m, h	m, h	m	m	m	m, h
Magnesium								m, h
Copper			h	m, h		m		m, h
Lead				m, h				m, h
Zinc				m, h				m, h
* Less common								

Table 2.5: Applicability of furnace types, for melting (m) and holding (h)

Iron foundries require metal of a controlled composition and temperature, supplied at a rate sufficient to match the varying demand of the moulding line. The metallic charge to be melted usually consists of foundry returns, iron and steel foundry scrap and pig iron, with alloying additions such as e.g. ferrosilicon, ferrophosphorus or ferromanganese. The charge is usually melted in a cupola or in an electric induction furnace. Induction furnaces are gradually gaining higher market preference compared to the cupola type. Coreless induction furnaces are used for melting. Channel induction furnaces are only used for holding, their main application being in combination with the cupola furnace, in the so-called duplex configuration. Gas-fired and oil-fired rotary furnaces can also be used, although their use is less common. Short-term holding, transport and metal treatment are performed in ladles.

Steel is melted in both electric arc and induction furnaces. Large steel foundries may use electric arc furnaces, but induction furnaces are more commonly used. Arc furnaces are capable of using low cost scrap charges, since refining takes place in the furnace. However, they have the limitation that there is always some carbon pick-up from the graphite electrodes, so very low carbon stainless steels (<0.03 % °C) cannot be made. In the induction furnace, refining is not possible, so a carefully selected charge must be used. However, any type of steel may be melted. Short-term holding, transport and metal treatment are performed in ladles.

The melting furnace used in non-ferrous melting is dependent on the foundry size. Non-ferrous foundries often use a variety of different alloys and/or have a limited melting capacity. Melting is done in small volume furnaces, for which the crucible furnace is most suited. Additionally, die-casting is the major casting technique. In this case, there often is no need for a centralised melting, as the melting (and holding) furnace is integrated into the casting machine. Non-ferrous foundries with a higher capacity and a need (or reason) for centralised melting typically use induction, hearth type or shaft furnaces for melting, and then distribute the molten metal to holding furnaces and casting crucibles.
[174, Brown, 2000], [225, TWG, 2003]

2.4.1 Cupola furnaces

2.4.1.1 Cold blast cupola furnace

2.4.1.1.1 Description

The cupola is a refractory lined shaft furnace where the metal charge is heated by the combustion of coke, which takes place in the lower part of the shaft (the “hearth”). Combustion air, supplied by fans, is injected in the hearth through a number of exhaust nozzles (“tuyères”). A ring and control valve allows a controlled and evenly distributed flow of combustion air through the tuyères. The metal (pig iron, steel scrap, scrap iron, foundry returns), coke, alloying elements (e.g. FeSi, SiC), slag forming (SiO_2) and fluxing agents (e.g. $CaCO_3$) are added to the shaft through a charging door at the upper part of the shaft. The combustion gases move upward from the hearth and exchange heat with the charge, before leaving the furnace through the cupola stack.

When the preheated charge reaches the combustion zone, the metallic parts melt due to the high temperatures, and the charged coke starts to burn in the presence of oxygen. The molten metal droplets run through the coke bed and gather in the zone called the well, which is below the combustion zone. All the impurities are trapped in the slag, which is mostly formed by SiO_2, CaO, Al_2O_3 and FeO. Fluxing agents lower the melting point and the viscosity of the slag. Due to its lower density, the slag floats on the molten metal in the well. Once the liquid metal in the well has reached a certain level, a tap-hole is opened. The metal flows discontinuously through the tap hole, via a refractory lined channel or launder into a separate collection vessel or ladle. Alternatively, the molten metal can be continuously directed to a holding furnace.

The slag is tapped separately by means of a dam and a slag spout placed at a higher level. It is collected discontinuously in pots, or continuously granulated in a water stream, or in a special installation for dry granulation.

In its basic configuration, the cupola is called a **cold blast cupola (CBC).** This is a cupola which uses the blast at atmospheric pressure and at normal environmental temperature.

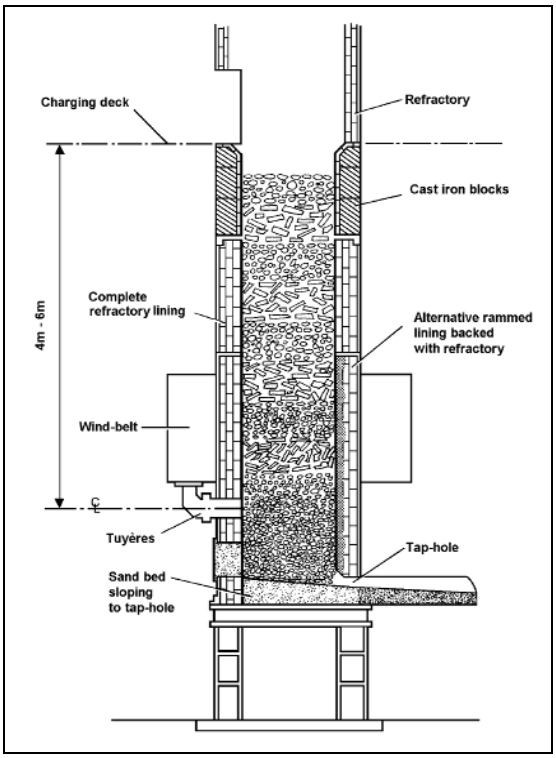

Figure 2.9: Schematic outline and miniature model of a (cold blast) cupola furnace [44, ETSU, 1993], [237, HUT, 2003]

In order to reduce the CO-emission and increase the energy efficiency, the conversion of cold blast furnaces to hot blast furnaces may be considered (see Section 4.5.2). However, for medium-sized foundries handling less than 2000 tonnes/month of good castings, the hot blast cupola will be difficult to consider because of the large investment it requires. The use of a hot blast cupola is also restricted to continuous melting, otherwise the running costs are too high. The cold blast cupola prevails for some types of production, e.g. enamelled iron castings, kitchenware, heating appliances, counterweights. These types of castings allow a high level of old cast irons to be used in the melting bed; a charge material still plentiful in the countries of the old industrial Europe and one that is well suited to the cold blast cupola.
[44, ETSU, 1993], [156, Godinot, 2001], [202, TWG, 2002]

2.4.1.1.2 Maintenance

One specific feature of the cupola furnace is that the lining material (quartz-clay-mixture) of the furnace at the melting and heating zone only lasts for one melting campaign. The intense heat and the presence of slag results in a chemical dissolution and mechanical wearing of the lining, which consequently converts it into slag. Cupola furnaces are therefore normally constructed in pairs. While one furnace is melting, the second one can be lined with new refractory material, with the operation being switched around the next day of use.
[110, Vito, 2001]

2.4.1.1.3 Advantages:

- the investment cost is EUR 125000 – 150000 per tonne installed per hour, inclusive of a dedusting installation
- different kinds of (cheap) scrap can be used due to the cleaning and carburising operation
- the thermal efficiency is acceptable if appropriate measures are utilised.

2.4.1.1.4 Disadvantages:

- the production regime is not flexible
- difficult production management because of the slowness of the system
- expensive charge with pig iron, and little steel scrap
- no quick alloy change possible
- sulphur pick-up/take-up in the cupola
- an environmental burden is caused by the foundry; i.e. lots of dust, slag and refractory lining
- big dedusting installations are needed because of the high flue-gas rate.

[110, Vito, 2001]

2.4.1.2 Hot blast cupola furnace

2.4.1.2.1 Description

In order to optimise the efficiency of the cupola furnace, the combustion air may be preheated. This principle is used in the **hot blast cupola** (HBC), i.e. a cupola which uses a preheated blast.

The advantages of the hot-blast operation may be summarised as follows:
- reduced coke consumption
- increased metal temperature
- increased melting rate
- reduced sulphur pick-up
- reduced melting losses
- increased carbon pick-up and hence the ability to substitute steel scrap for pig iron in the furnace charge.

It should be noted that not all these advantages can be attained at the same time. For example, an increase in the proportion of steel scrap in the furnace charge may require an increase in the proportion of coke for recarburisation; this in turn will reduce the melting rate and increase the sulphur pick-up.

Two methods of heating are:

- *Recuperative heating*: This involves the transfer of the residual ("latent") heat of the flue-gases to the combustion air. The flue-gases are collected at the top of the furnace, mixed with sufficient air and then burned in a post combustion unit. This provokes the exothermic oxidation of CO. The burnt gases are led through a heat-exchanger (recuperator) where the heat is transferred to the combustion air. Typically the blast air is heated at temperatures of 500 to 600 ºC. Above these temperatures, problems arise with the sintering of furnace dust on the surface of the recuperator
- *External heating*: Here the combustion air is heated by some external means, e.g. by a gas or fuel burner, by electrical resistance or by a plasma torch.

The combination of these two heating methods, permits the superheating of the blast air up to 1000 ºC. These high temperatures, however, require the use of more expensive refractory materials and may cause too high a melt temperature.

Recuperative systems offer increased energy and thermal efficiencies. The effect of air preheating on thermal efficiency and coke use is depicted in Figure 2.10. It should be noted that the coke quality may affect the overall blast efficiency.

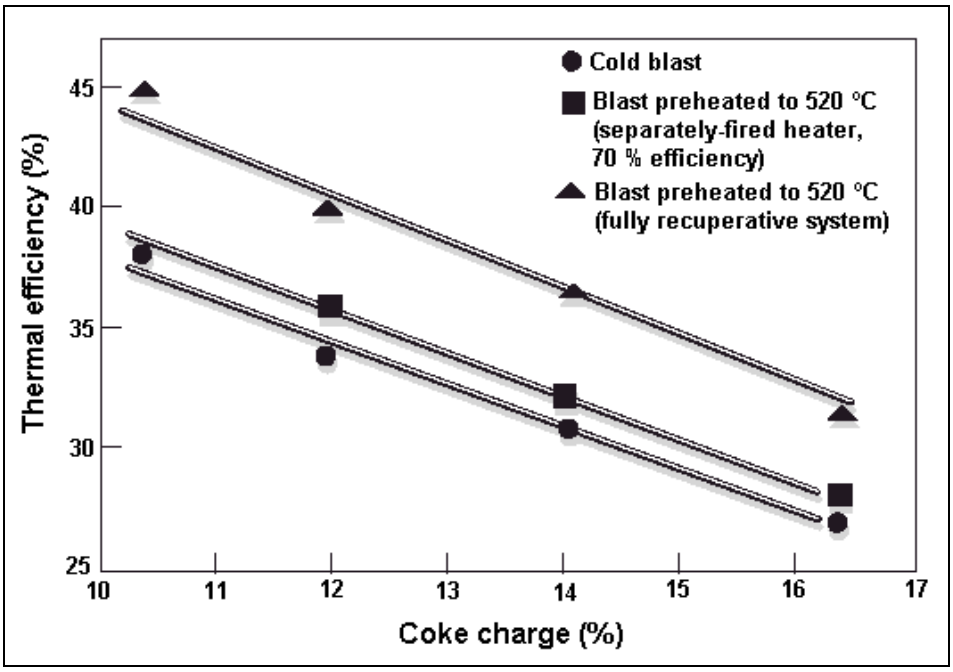

Figure 2.10: Effect of air preheating on blast furnace efficiency [44, ETSU, 1993]

For medium-sized foundries producing up to 2000 tonnes/month of good castings, the hot blast cupola is difficult to consider, in particular because of the large investment it requires. In these instances, the cold blast cupola prevails for some types of production. The hot blast cupola remains the most widely applied melting device for mass production foundries, e.g. for parts for the automobile industry, centrifugal casting, road accessories.
Hot blast cupolas are normally set up for long campaign operation, in order to minimise process switch overs and maintenance time and effort.
[32, CAEF, 1997], [44, ETSU, 1993], [156, Godinot, 2001]

2.4.1.2.2 Advantages:

- reduced coke consumption
- high tap temperature
- high melting capacity
- less sulphur pick-up in the cupola
- possibility to use different kinds of cheap lower grade ferrous scrap
- more scrap steel can be used because of the higher pick-up of the carbon by pig iron.

2.4.1.2.3 Disadvantages:

- very expensive investment, due to the additional environmental measures required
- production regime is not flexible
- difficult production management because of the slowness of the system
- limited to iron alloys only, no quick alloy change possible
- environmental burden caused by the foundry, e.g. lots of dust, slag and refractory lining
- big dedusting installations are needed because of the high flue-gas rate.

[110, Vito, 2001]

2.4.1.3 Long campaign cupola

A **long campaign cupola** is usually a water-cooled refractory lined cupola that may be hot blast or cold blast. Such cupolas are operated daily for one, two or three shifts and are very often used only as a single unit. This form has a campaign life of several weeks or months. The liningless cupola allows a much longer campaign life but heat losses through the furnace shell can be significant. Further developments in refractories and operating practices are continually being made which improve the life and cost effectiveness of the long campaign cupola. A schematic representation of a long campaign cupola with an in-shaft afterburner is given in Figure 2.11.

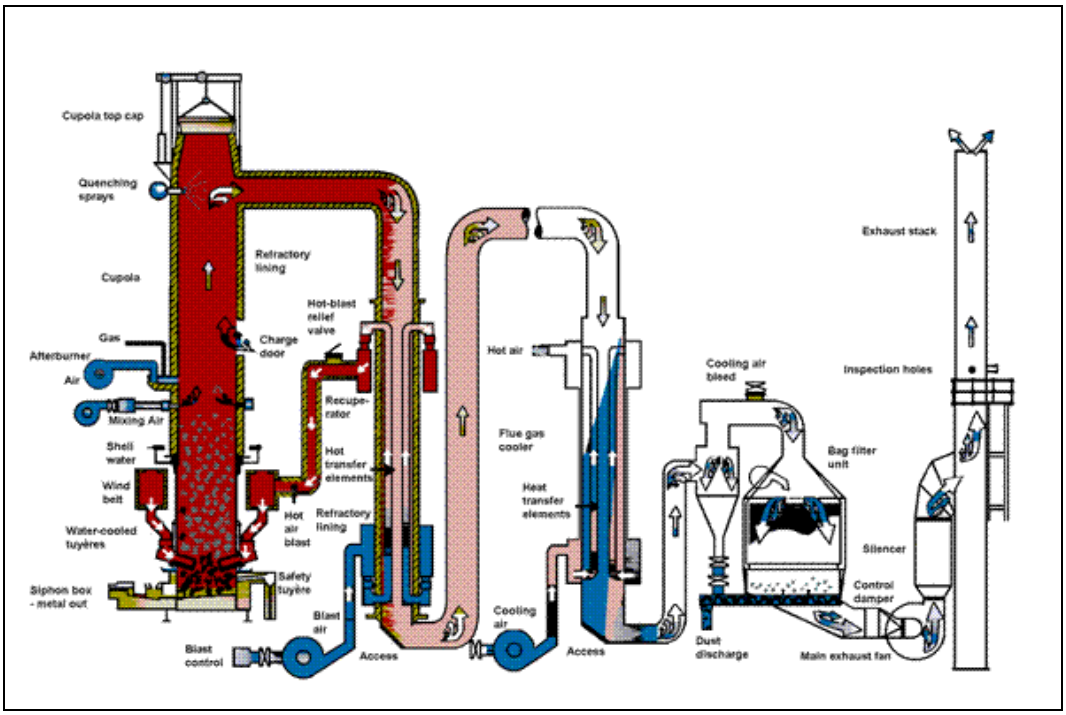

Figure 2.11: Schematic representation of a long campaign cupola
[150, ETSU, 1998]

To allow for long campaign operation the following measures need to be taken:
- apply a more persistent refractory lining of the shaft, bottom and the hearth
- apply water cooling of the furnace wall: this keeps the wall temperature low and thus prevents rapid wearing of the hearth lining
- use water-cooled blasting pipes that penetrate deeper into the furnace shaft. Here, the combustion zone is not in direct contact with the furnace lining. Water-cooling has also been used for reasons other than only reducing the consumption of refractories, such as:
  - to extend the duration of the melt
  - to enable the internal diameter of the furnace to be increased, thus allowing a higher melting rate.

In the liningless operation, the charge is in direct contact with the water-cooled steel furnace shell. Liningless operation is only used on relatively large capacity cupolas, melting for long campaigns. This results in the following advantages:
- only one cupola is required
- the cupola only requires internal repairs after one, or several, week's operation
- daily bed-coke consumption is reduced
- monitoring is easier throughout the campaign, because of the constant diameter and the more consistent melting conditions.

A specific type of long campaign cupola is the cokeless cupola. This is discussed in Section 4.2.1.8.
[32, CAEF, 1997], [44, ETSU, 1993], [110, Vito, 2001], [150, ETSU, 1998]

2.4.1.4 Nature of atmospheric emissions

Cupolas can be charged with a wide range of materials, many of which may contain loose particles such as rust, sand and non-ferrous materials. The metallurgical-coke can break and produce small pieces, as can the added fluxing materials. Breakage and mechanical abrasion during charge preparation, as well as during charging itself, generate particles, some of which are immediately emitted.

During melting, abrasion of the charge against the refractory lining will also generate dust.

A third source of particulate matter is coke ash, generated in the melting zone, which is not trapped by the slag phase.

Particulate matter of various sources, if light enough, can be entrained in the combustion gases of the cupola. Under certain conditions metallurgical-fume may be generated from the melting zone, leading to a visible plume from the cupola stack. The smoke particles consist of submicron agglomerates of spherical soot particles and metallic oxides, such as ZnO, PbO, etc., if the metals are present in the charged steel or iron scrap, such as in galvanised or painted scrap. The smoke emission will increase with the proportion of coke and contaminants in the charge, the blast temperature, and the oxygen injection rate.

Carbonaceous smoke is airborne matter formed by the incomplete combustion of organic matter in the cupola. Scrap contaminants such as oil and grease, wood, textiles and, rubber will form oily vapours in the stack gases. Vapours and partially burnt organic matter may carry unpleasant smells.

Again, scrap cleanliness and its nature significantly effect the nature of the emissions. The burning of coke creates odorous gas emissions containing CO_2, CO and SO_2. Decreasing the proportion of the coke charge (by increasing the thermal efficiency) or (partial or complete) substitution of the coke by natural gas can help reduce the levels of these substances.

2.4.2 Electric arc furnace (EAF)

2.4.2.1 Description

The EAF is a batch-melting furnace consisting of a large bowl shaped refractory lined body with a dish shaped hearth. The wide furnace shape allows the handling of bulky charge material and leads to efficient reactions between the slag and metal. Typically the shell diameter is 2 to 4 m. As shown in Figure 2.12, the furnace is covered by a refractory roof, which has ports for three graphite electrodes. The electrodes are supported by arms, which allow movement up and down. Most furnaces use roof charging: by moving the roof and electrodes aside, the furnace can be charged using a drop bottom charging bucket or a magnet. The metal charge is heated by an electric arc, which is created by a three phase alternate electrical current between the three graphite electrodes. These are positioned above the charge, which itself acts as the neutral.

Figure 2.12: EAF furnace
[237, HUT, 2003]

The furnace is tapped by tilting it, forcing the metal to flow out through the spout. Opposite the spout, an operable door allows deslagging and sampling operations to be carried out prior to tapping.

The lining of the furnace may be acidic (SiO_2 based refractory) or basic (MgO based refractory). A basic lining allows the use of virtually all kinds of steel scrap. The furnace can also be used for the production of high alloy and manganese steels. If scrap with high phosphor or sulphur conent is used, lime and limestone which are usually added for dephosphorisation and desulphurisation. An acidic lining would be attacked by these compounds. Therefore, the acidic type refractory is used for melting scrap with a low sulphur or phosphorus content only.

Electric arc furnaces are almost exclusively used for the melting of steel. Only in a few cases are they used for cast iron production, which requires an addition of coal dust to the melt. Electric arc furnaces designed for steel foundries' purposes usually range from 2 to 50 tonnes capacities. They can be run intermittently and are suitable for a wide range of steel analyses. They can provide steel at high temperatures, with typical meltdown times of about one to two hours, while achieving high thermal efficiencies of up to 80 %[1]. Power consumption varies from 500 to 800 kWh/tonne of molten steel, depending on the furnace capacity, the hot metal consumption, and the refining techniques, tapping temperature and pollution control equipment applied. The total melt time is typically 1 to 4 hours.

[1] Without taking into account the efficiency of electric power generation.

2.4.2.2 Melting and refining with the acidic lined EAF

Due to the chemical nature of the acid lining (SiO_2), the refining abilities of this type of furnace are restricted to decarburisation. Consequently considerable care has to be exercised in selecting the charge for acceptable sulphur and phosphorus levels, as these cannot be removed in the acid melting practice. The charge consists of balanced quantities of pig iron, foundry returns and purchased scrap. The carbon in the charge is held at a high enough level so that after melting it is 0.2 to 0.4 % above the final level.

The decarburisation starts by injecting oxygen into the metal bath. This creates a strong stirring action during which carbon in the melt is burned. At the same time the "boiling" burns out Si, and flushes out H_2 and N_2 from the metal bath. All impurities (oxides) are trapped in the slag. During melting, sand (SiO_2) may be added to bring the slag to the proper consistency. When the carbon reaches the proper concentration, oxygen injection is stopped, and silicon and manganese are added to halt the boiling reaction.

After slag removal the metal composition is controlled and adjusted if necessary. Finally the metal is deoxidised by adding aluminium or other agents into the melt stream during tapping, to prevent the formation of CO bubbles during solidification. Additional desulphurisation and or dephosphorisation refining can be executed in an AOD or VODC converter (see Section 2.4.9 and 2.4.10).
[32, CAEF, 1997], [161, UK Environment Agency, 2002]

2.4.2.3 Melting and refining with the basic lined EAF

The alkaline MgO based lining of this EAF makes it possible to refine the metal in the furnace itself. Therefore it is possible to charge the furnace with virtually any combination of scrap and foundry returns. The basic lining practice is used when the purchased scrap contains higher phosphorus and/or sulphur levels than desirable.

Dephosphorisation of the melt is performed by periodic additions of lime during meltdown. Upon the injection of oxygen in the bath, phosphorous oxide is formed and trapped in the slag, together with other metallic oxides and impurities. The lime keeps the slag very basic, which stabilises the phosphorous oxide. At the same time carbon is burnt out. After sufficient reaction time, the oxygen injection is stopped and the slag is fully removed.

Desulphurisation takes place in a second stage, in a similar way but at a higher temperature. Again, lime or limestone is added to the melt, reacting with sulphur to form insoluble CaS, that is trapped by the slag. Periodic additions of carbon, aluminium, or FeSi reduce the metallic oxides (e.g. manganese-, chromium oxides), and thereby minimise losses of these elements from the metal bath. All other impurities (oxides) are trapped in the slag and removed during the final deslagging operation.

After refining the metal composition is controlled and adjusted if necessary. Finally the metal is deoxidised by the addition of aluminium or other agents in the metal bath prior to tapping, to prevent the formation of CO bubbles during solidification. Further metal treatment, using an AOD or VODC converter (see Section 2.4.9 and 2.4.10) may be applied if the final alloy composition requires it.
[32, CAEF, 1997], [161, UK Environment Agency, 2002]

2.4.2.4 Nature of atmospheric emissions

The emissions from EAFs originate from the charging, melting, and refining operations and during tapping of the furnace.

During charging, dust and dirt will be emitted from the open furnace body. When charging a hot furnace (for instance when melting with a molten heel in particular), any combustibles such as grease, paint or oil ignite and give rise to smoke plumes of burnt and partially burnt organic material and dust particles. The mechanical abrasion of the furnace lining also generates additional dust.

During melting, heating of the scrap generates metal oxide fumes that significantly increase during the decarburisation treatment. The injection of oxygen gas into the molten metal develops significant quantities of iron oxide fumes, which leave the furnace as red clouds. The addition of slag forming materials increases the furnace emission, but only in small quantities and only for a short time.

Minor emissions occur during the transfer of the molten metal into a ladle or holding furnace.

Emissions from the melting operation itself are referred to as primary emissions. Secondary emissions are the fumes and dust originating from the charging and tapping.

In considering the nature and quantities of the emissions, the different sources of dust and fume emissions, as described above, demonstrate that large differences exist between foundries, depending on the cleanliness of the charged material, the applied charging procedure, the composition of the charge, the refining treatments and on the additions to the melt. Since no coal or fuel is burned in the furnace the emissions solely depend on these parameters.

2.4.3 Induction furnace (IF)

Induction furnaces are used to melt both ferrous and non-ferrous metals. There are several types of induction furnaces available, but all operate by utilising a strong magnetic field created by passing an electric current through a coil wrapped around the furnace. The magnetic field in turn creates a voltage across, and subsequently an electric current through, the metal to be melted. The electrical resistance of the metal produces heat, which in turn melts the metal. Induction furnaces are made in a wide range of sizes. Because there is no contact between the charge and the energy-carrier, the induction furnace is suited for the melting of steel, cast iron and non-ferrous metals, so long as a suitable lining material can be found.

Proper functioning of the water cooling circuits is crucial to prevent the coil from overheating. The water cooling systems are therefore designed to provide the highest level of reliability, and thus incorporate various thermostats and flow-meters.
[42, US EPA, 1998], [47, ETSU, 1992], [110, Vito, 2001]

2.4.3.1 Coreless induction furnace

2.4.3.1.1 Description

The coreless IF is a batch-melting furnace containing a water-cooled copper coil, the inside of which is internally refractory lined. The outside is insulated and enclosed in a steel shell. The furnace body is mounted in a frame equipped with a tilting mechanism. A coreless induction furnace is normally a refractory-lined bucket-shape refractory, the top of which is open for charging and deslagging operations (see Figure 2.13).

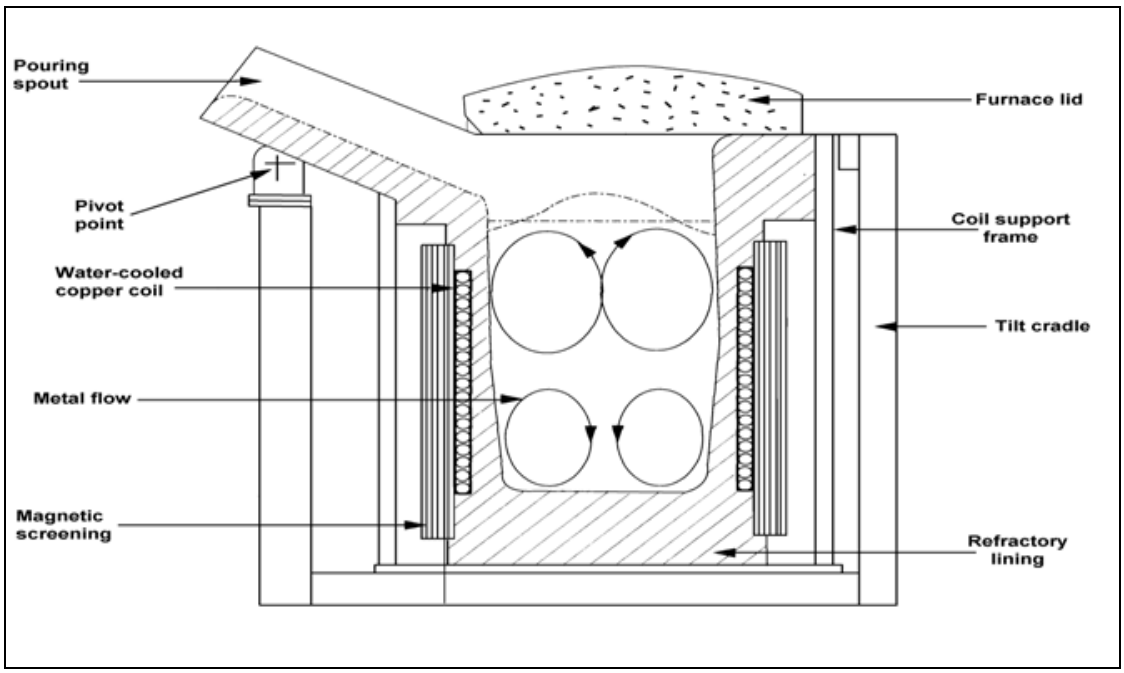

Figure 2.13: General arrangement of coreless induction furnace [47, ETSU, 1992]

According to the capacity, the furnace is charged by a lifting magnet, bucket skips, a vibrating conveyor or manually. A large number of foundries use induction furnaces for producing relatively small lots in a large variety of compositions. Furnace capacities range from 10 kg up to 30 tonnes. The core is fed by mains, medium or high frequency alternating current (50, 250 or 1000 Hz, respectively).

Depending on the installed power density and the melting practice the thermal efficiency can exceed 80 %[2], but usually ranges from 60 to 70 %. If the efficiency of the electric power generation is taken into account, an overall efficiency of 15 – 20 % results, which is rather low in comparison with other furnace types.

The coreless induction furnace can be designed to operate at any frequency from 50 Hz upwards. The induction heating of liquid metal causes a stirring effect. The lower the frequency of the primary current, the more intense is the stirring. Therefore, in a mains frequency furnace working at 50 or 60 Hz, the turbulence is greater than in one operating at higher frequency. Because of the high turbulence, the power input to a mains frequency furnace is restricted to around 250 kW per tonne of capacity. With higher frequencies, the power density can be increased to three or four times this level.

The frequency of operation also affects the current penetration. The higher the frequency, the lesser the penetration depth. This affects the minimal charge piece size and the effective furnace size. 50 Hz furnaces are not practicable at capacities below 750 kg. At 10 kHz, charge pieces less than 10 mm in diameter can be heated, so furnaces as small as 5 kg capacity can be used. The availability of reliable frequency converters has allowed the development of application specific units, as given in Table 2.6. Frequencies are usually limited to 250 to 350 Hz (in the case of variable frequencies), as at higher frequencies metal homogenisation becomes insufficient. Higher frequencies are used in special cases, such as with very small furnaces. Figure 2.14 shows coreless induction furnaces of various sizes.

[2] Without taking into account the efficiency for electric power generation.

Frequency (Hz)	Application
70	Brass swarf
100	Aluminium scalpings
100 – 150	Cast iron borings
250	Aluminium extrusion scrap
250	Iron from foundry returns and steel scrap
500 and 1000	Steel melting and melting of wet cast iron borings
1000 and 3000	Wide variety of copper alloys
3000	Investment casting
10000	Jewellery trade

Table 2.6: Field of application of available induction furnaces as related to their frequency [174, Brown, 2000]

Figure 2.14: Coreless induction furnaces [237, HUT, 2003]

Water cooling systems are essential for operation of the coreless induction furnace. Cooling the coil protects both the coil and the insulation from thermal damage, not only during normal operation but also during the cool-down period when the power has been switched off and the furnace emptied. Several types of cooling are available, using closed circuits with heat-exchangers or open evaporative systems. The availability of a cooling system opens up the possibilities for internal energy recovery.
[32, CAEF, 1997], [47, ETSU, 1992], [110, Vito, 2001], [174, Brown, 2000], [176, ETSU, 1998], [202, TWG, 2002]

2.4.3.1.2 Melting practice

The coreless induction furnace is used for melting but cannot be used for refining. Therefore, in steel foundries the induction furnace has to be charged with raw materials of the ‘correct’ chemical composition, i.e. that corresponding to the required composition of the melt; hence steel scrap is mainly used. If necessary, the metal can be refined after melting in an AOD converter or in special treatment ladles (see Section 2.4.12).

High powered furnaces allow melting following the “tap and charge” method. Here the furnace is tapped completely empty and charged with cold material to start the next melting cycle. The “molten heel” method is used on low powered (mains frequency) furnaces where approximately one third of the melt is tapped before the cold charge material is added. Because of the better electromagnetic coupling between the melt liquid and the coil compared to a less dense solid (cold) charge, the production rate increases significantly when using the latter method on low powered furnaces.

Steel grades containing more than 0.2 % of reactive elements such as Al, Ti and Zr cannot be melted in an oxidising environment such as air. They require an inert atmosphere or a vacuum melting and casting method. This is obtained by placing an induction furnace in a vacuum or airtight chamber. The application of a vacuum ensures very good degassing of the melt. Highly oxidisable elements are added in vacuum or after backfilling with an inert gas.

Induction furnaces are excellent melting units, but in general they are less efficient holders. When they are used for melting only, the molten metal is mostly moved to an efficient holding furnace as soon as it has reached the desired temperature. Many types of coreless induction furnaces are available, with fixed or removable crucibles. For aluminium, both channel and coreless induction furnaces are available for melting and holding. However, the channel type is seldom used, due to difficulties in keeping the channel open and due to the need to maintain a molten heel at all times.
[32, CAEF, 1997], [48, ETSU, 1994]

2.4.3.1.3 Advantages:

Due to its multiple advantages, the induction furnace is increasingly being implemented. Its main advantages are*:*

- higher flexibility in alloys and melting regime. As such it is an ideal melting technique for jobbing foundries and special alloys
- short meltdown times
- lower environmental burden caused by the foundry
- little maintenance, depending on the lifetime of the refractory lining
- good process control: computer support and fully automatic operation is possible, which allows optimal temperature control
- maximum thermal efficiency is possible, if process parameters are locally calculated and set-up
- intense stirring in the bath makes the melt homogeneous
- charging, sampling and deslagging of holding the liquid metal, though typically with low efficiencies, although high holding efficiencies have been reported for copper and aluminium.

2.4.3.1.4 Disadvantages:

- because of the monopoly of the local electricity supplier, the operator is fully dependent on the connection conditions of the local electricity grid, the energy costs and any possible extra costs (peak control, etc.)
- the energy costs are more expensive than the costs of using fossil fuels
- the cleaning action of the induction furnace on the melt is limited because of the small amount of slag and the relatively small contact area between the slag and melt. This requires the use of a high quality, and thus, more expensive charge than cupola or EAF furnaces
- the installation requires a high investment, although the operator can save on additional environmental investments. The net cost per tonne installed furnace content is around EUR 375000
- other melting techniques are more suitable for capacities >15 tonnes per hour. Depending on the intended alloy, the hot cupola or electric arc furnace may be considered
- it has a low efficiency during holding because of the heat losses in the water-cooled induction coil.

[110, Vito, 2001]

2.4.3.2 Channel induction furnace

2.4.3.2.1 Description

This type of furnace is mainly used for holding purposes, though it may also be used as a combined melting- and holding aggregate.

The channel induction furnace consists of a big, thermally isolated bucket, equipped with an isolated top-lid for introduction of the charge (Figure 2.15). The bottom is equipped with one or more U-channels. Around these channels is a water-cooled induction coil, which heats and circulates the metal. The induction current has the frequency of the local electricity grid. The furnace is generally mounted in an hydraulically tiltable frame for tapping or maintenance operations. Pressurised and non-tilting furnaces are also in use.

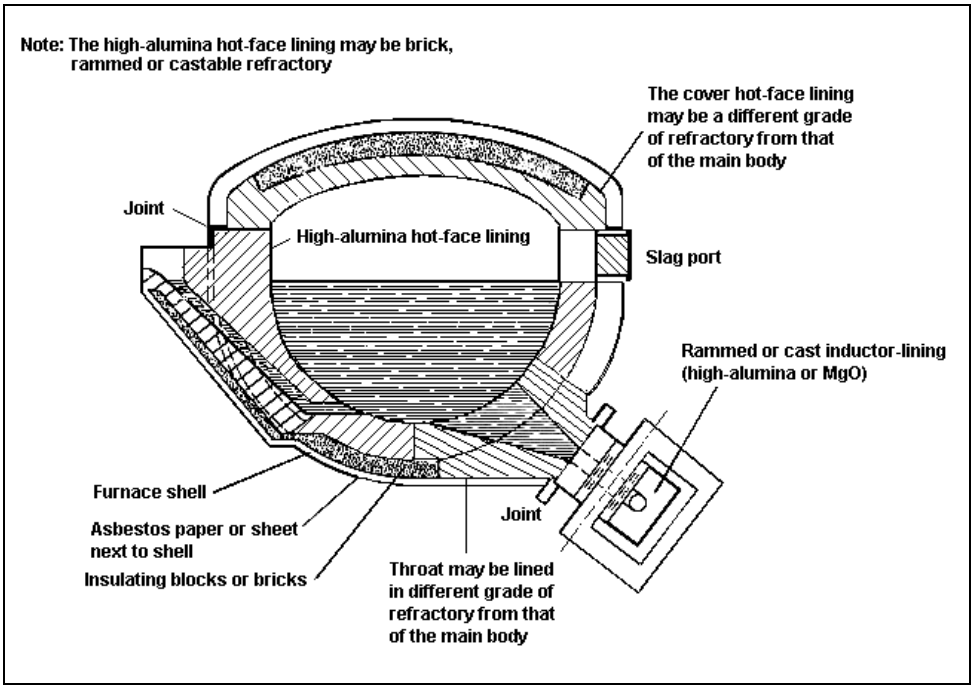

Figure 2.15: Typical construction of a bath channel furnace [55, ETSU, 1993]

In order to allow operation, a minimum amount of molten metal needs to stay inside the crucible and channel. The crucible needs to stay filled up to one third of its capacity. Two values are usually quoted when the capacity of a holding furnace is defined, these are total capacity and useful capacity; for example 60/35 tonnes. The difference between these two values represents the amount of metal that must be retained in the furnace.

Thermal losses through the cooling water and the furnace wall are low compared to those in the coreless induction furnace. Equipping the furnace with pouring channels according to the 'teapot principle' allows for a reduced oxidation of the melt and wearing of the refractory.

Due to the large content of the crucible, any changes in the melt composition are flattened out. This principle however counteracts the flexibility of the furnace, as changing to another melt composition requires a long transition period. In practice, the melt composition is therefore kept fairly constant.

Figure 2.16: Channel induction furnace
[237, HUT, 2003]

The channel induction furnace finds its main application as a holding furnace in iron foundries. An example picture is given in Figure 2.16. It is the furnace of choice for duplex operation with cupola furnaces. The capacity varies between 5 and more than 100 tonnes. The holding furnace serves as a buffer between the melting and casting shop. It is important to assess foundry and production requirements fully when considering whether to use a holding furnace. There may be more cost-effective and energy efficient methods of achieving the requirements, and it is advisable to investigate thoroughly all possible solutions before a decision is made. For aluminium, the channel type is seldom used, due to difficulties in keeping the channel open and due to the need to maintain a molten heel at all times.

Output requirements are an important consideration when deciding the size of a channel furnace. The choice of a smaller furnace may be advantageous. Although a smaller furnace is less efficient, the loss in efficiency will be offset by its reduced annual power consumption compared with larger furnaces.
[48, ETSU, 1994], [55, ETSU, 1993], [110, Vito, 2001],

2.4.3.2.2 Advantages:

- high thermal efficiency as a holding furnace
- minimal burn-out of the alloy elements
- little maintenance.

2.4.3.2.3 Disadvantages:

- a minimum amount of molten iron, but which may be a substantial part of the furnace capacity, has to be maintained in the furnace body in order to guarantee proper electrical functioning
- the furnace cannot perform a cold start because of the limited power density that can be achieved in the loop
- difficult to monitor the channel wear
- potential danger of accidental leaks, because of the induction coil on the bottom
- contact between the cooling water and metal is difficult to prevent.

[110, Vito, 2001]

2.4.3.3 Nature of emissions

Since no coal or fuel is burned in the induction furnace and no refining procedures are executed, the emissions solely depend on the cleanliness and the composition of the charged material. Two major categories of emissions can be distinguished. The first, and major, category relates to the charge cleanliness, e.g. rust, dirt, foundry sand, paint, oil, galvanised or soldered metal, all of which are elements which give rise to the emission of dust and fumes (organic or

metallic). The second category relates to chemical reactions at high temperatures, (e.g. while holding or adjusting the metal composition), which can give rise to metallurgical fume due to oxidation.

Additionally the refractory lining (acid SiO_2 based, neutral Al_2O_3 based, or basic MgO based) may add a small amount of dust particles to the emission.

It is difficult to obtain average emission data since the charge cleanliness, which is the dominant contributor to emissions, varies from foundry to foundry.

2.4.4 Radiant-roof furnace (resistance heated)

The radiant-roof furnace is a low-energy holding furnace with a heavily insulated box design with banks of resistance elements in a hinged, insulated roof. They are mainly used in non-ferrous (aluminium) pressure die-casting shops with centralised melting facilities. Typical units have a capacity of 250 – 1000 kg with a 5 kW to 12 kW connected load. Bale-out and charge wells are separated from the main bath by refractory walls with connectors at the bottom to allow clean metal to pass from one area to another. Figure 2.17 gives a schematic view of the radiant-roof principle.

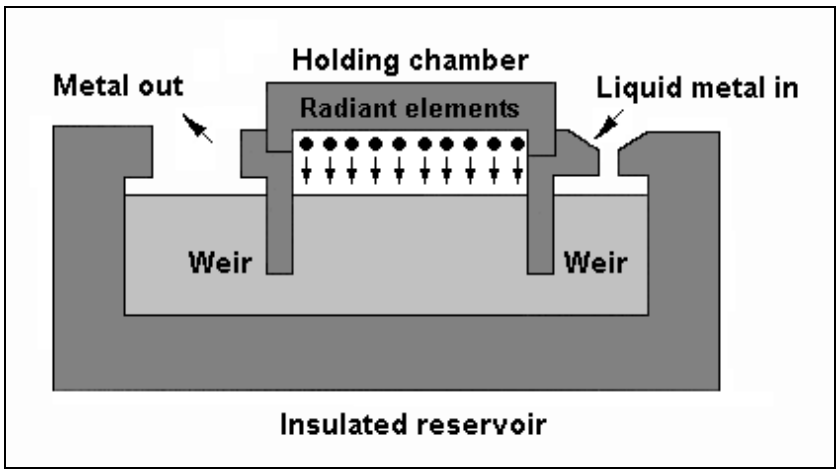

Figure 2.17: Radiant-roof furnace
[48, ETSU, 1994]

The advantages of radiant-roof furnaces are:
- no crucible required
- very low energy costs
- close temperature control
- clean, cool, silent working conditions.

Although most low-energy holding furnaces serve individual casting machines, some larger ones are used as buffers between bulk melters and machine furnaces. This latter use allows better use of the melter, which is seldom an efficient holder.

Some foundries use large radiant-roof furnaces with higher power as melters, for example to generate molten metal for low-pressure die-casting. Several manufacturers build versions of radiant-roof furnaces that can be fully sealed and pressurised by gas, in order to function as dosing furnaces. Dosing furnaces provide precise shots of metal for pressure or gravity die-casting and compete, to some extent, with mechanical ladle systems as automatic pouring systems. Provided that they are carefully maintained and used, radiant-roof furnaces can provide a valuable control of both temperature and shot weight and can improve yield.
[48, ETSU, 1994]

2.4.5 Rotary furnace

2.4.5.1 Description

The rotary furnace consists of a horizontal cylindrical vessel, in which the metallic charge is heated by a burner located at one side of the furnace. The flue-gases leave the oven through the opposite side. To generate the required heat, fuel or natural gas is used combined with air or pure oxygen.

A tilting mechanism allows the furnace to be lifted to a certain angle or into a vertical position. This position is used for charging of the furnace with a drop bottom bucket or a vibrating chute, and for lining repair or renewal. During heating and melting the furnace is rotated slowly to allow the heat transfer and distribution. The furnace atmosphere is controlled by the air (oxygen)/fuel ratio.

Once the metal is melted, and after a composition check and adjustment, a tap-hole in front of the furnace is opened and the melt in the furnace is discharged into ladles. Because of its lower density, the slag floats on the metal bath in the furnace and is finally collected through the tap-hole into slag pots.

A melting cycle spans 1½ to several hours. For continuous molten metal production, foundries install 2 to 4 rotary furnaces, which are operated consecutively. The thermal efficiency of the rotary furnace is very high, i.e. at 50 to 65 %[3], depending on the capacity. This high yield is achieved by using pure oxygen instead of air as the combustion medium.
[32, CAEF, 1997]

2.4.5.2 Melting practice

For cast iron melting, the furnace is charged with pig iron, foundry returns, steel scrap, slagging (e.g. sand, lime), and carburisation agents (e.g. graphite). The melting cycle starts with a slightly oxidising and short flame (air factor, λ = 1.03), which gives the highest energy input. The furnace is rotated stepwise through 90 º and the direction of the rotation is changed from time to time. This way, the furnace walls can exchange heat with the charge by convection. As soon as the charge is melted, the flame is reduced to prevent excessive oxidation of the alloying elements. During overheating and holding, a long and reducing flame is applied (λ = 0.9) and the furnace movement is changed to full and continuous rotation. The slag layer provides thermal insulation and prevents the burning-off of the alloying elements. After controlling and adjusting the melt composition and temperature, the tap-hole is opened and the metal is tapped into ladles. The slag floats on the metal bath and is collected separately after the metal is removed.

The lifespan of the refractory is largely dependent on the overheating temperature and the charge composition. In the charging operation, mechanical shocks and cold start-ups need to be prevented. The furnace atmosphere, the holding time, rotational speed and the burner position also affect the refractory life. In normal conditions the refractory life is 100 to 300 melting cycles.
[32, CAEF, 1997], [110, Vito, 2001]

2.4.5.3 Metallurgy

The rotary furnace has been used in non-ferrous melting for many years. In this application traditional oil-air burners can provide the relatively low melting temperatures. The development of oxygen-air burners has enabled the introduction of cast iron production, using a higher relative amount of steel scrap and applying graphite for carburisation.

[3] That is providing the energy for oxygen production is not taken into account. With oxygen production, the efficiency will be 10 to 15 % less.

A significant disadvantage of the rotary furnace is that it also burns Fe, C, Si, Mn and S. These losses have to be compensated for by the addition of alloying elements before or after melting. The efficiency of uptake of these elements is usually rather low. Concentration gradients may occur between the front and the back of the metal bath due to the absence of axial motion and due to inhomogeneities in radiation and the atmosphere above the wide bath surface.
[110, Vito, 2001]

2.4.5.4 Application

Due to its batch character, the rotary furnace provides an equal flexibility as the coreless induction furnace in the cast iron foundry. The investment costs however are lower. A 5 tonne furnace costs EUR 500000 – 600000, of which 30 % are for the exhaust system and dedusting. The rotary furnace is also a good alternative for the small-scale cold blast cupola, due to its higher flexibility and lower environmental costs. Rotary furnaces are used for melting volumes of 2 to 20 tonnes, with production capacities of 1 to 6 tonnes per hour.
[110, Vito, 2001]

2.4.5.5 Advantages:

- quick change of alloy possible
- melting without contamination, e.g. without sulphur pick-up
- low investment costs
- small dedusting system because of low flue-gas rate
- easy to maintain.

2.4.5.6 Disadvantages:

- easy burn-out of C, Si, Mn
- gas and oxygen use can be high if not operated continuously
- the energy consumption increases if more steel is added to the charge.

[110, Vito, 2001]

2.4.6 Hearth type furnace

The hearth type furnace is also known as a reverberatory or bale-out furnace. It is a static furnace with direct heating. Hot air and combustion gases from oil or gas burners are blown over the metal (melt) and exhausted out of the furnace. The hearth type furnace finds its main application in non-ferrous metal melting. A typical furnace design is given in Figure 2.18.

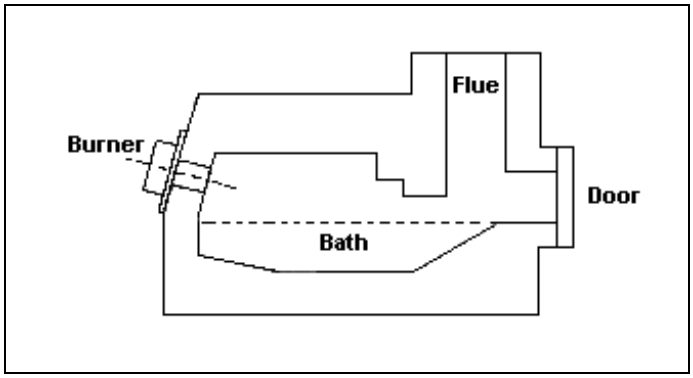

Figure 2.18: Cross-section of a hearth type furnace
[175, Brown, 1999]

This is a refractory lined, rectangular or circular bath furnace that is fired by wall or roof-mounted burners. Varieties of fuels are used and additionally oxy-fuel burners can be used to increase the melting rate. Extraction and treatment of the combustion gases is typically carried out and for this the furnaces are partially sealed. Hoods and covered launders provide extraction during tapping and charging. The furnace can be constructed in a number of configurations depending on the particular metal and application, variations include the provision of sloping hearths and side wells for specific melting purposes, tuyères and lances for the addition of gases. The furnaces can sometimes be tilted to pour or blow metal.

The melting efficiency of a hearth type furnace is usually not great because of the poor heat transfer from the burner. The efficiency has been improved in practice by the use of oxygen enrichment or by using combinations of gas and solid fuel to extend the flame length. These furnaces are used for batch melting, refining and for holding a variety of metals. Hearth type furnaces are mainly used to melt large quantities of non-ferrous metals [155, European IPPC Bureau, 2001].

Large hearth type furnaces give rapid melting and can handle bulky charge materials, but the direct contact between the flame and charge may lead to high metal losses, gas pick-up and to considerable oxide contamination. Temperature control can also be difficult. These difficulties can be overcome to some extent by good practice. For example, dross can be removed by applying suitable fluxing practice, and applying modern burners reduces problems with the temperature control. After tapping, filtering and degassing, further treatments can be applied as the metal is transferred to holding furnaces.
[42, US EPA, 1998], [48, ETSU, 1994], [155, European IPPC Bureau, 2001], [175, Brown, 1999]

2.4.7 Shaft furnace

2.4.7.1 Description

This is a simple vertical furnace with a collecting hearth (inside or outside the furnace) and burner system at the lower end and a material charging system at the top. The burners are usually gas-fired. Metal is fed into the top of the furnace and is melted as it passes down the shaft. Independent control of the fuel/air ratio is usually provided for each burner. Continuous CO or hydrogen monitoring is also provided for each row of burners and monitor the combustion gases from each burner in turn. Combustion gases are usually extracted and cleaned. An afterburner is sometimes used to decompose any carbon monoxide, oil, VOCs or dioxins that are produced. The addition of oxygen above the melting zone has been used to provide afterburning in the upper levels of shaft or blast furnaces.

The furnace is used to melt pure metal, but occasionally metal that is contaminated with organic material may be used. If oily metal is fed into the furnace, it passes through a temperature gradient existing between the charging area and the burners. The low temperature can produce a mist of partially burned organic material. The shaft furnace is also used to preheat the charge material before smelting. A typical representation of this furnace is given in Figure 2.19.

This furnace type is only used for non-ferrous metal melting, mainly for aluminium. Due to the complex construction and difficult renewal of the refractory, the furnace is only used for metals with low melting points. Therefore, the maintenance requirements of the furnace lining are rather limited. Typical refractory lifetimes are 4 to 8 years.

Modern furnace types with computer controlled burner systems reach an energy use of 650 kWh/tonne of melted Al. (at 720 ºC). The theoretical energy needed is 320 kWh/tonne. The thermal efficiency therefore is 50 %.

The shaft furnace is a continuous melting furnace with high capacity, ranging from 0.5 to 5 tonnes per hour and with a holding capacity of up to 50 tonnes. Due to its holding function, a change of alloy is difficult.
[48, ETSU, 1994], [155, European IPPC Bureau, 2001]

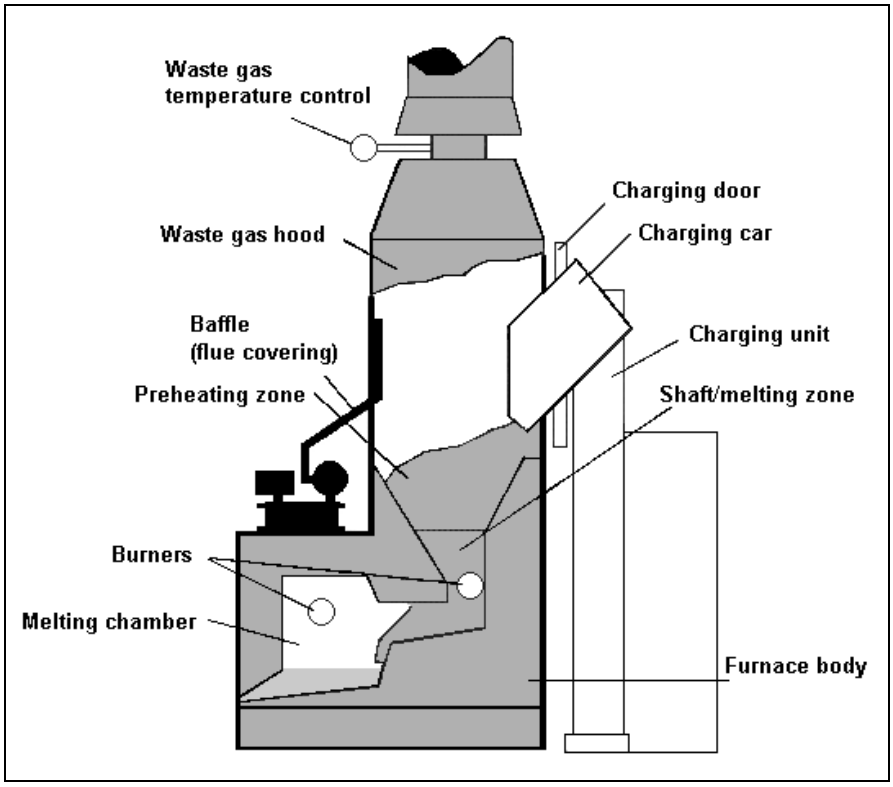

Figure 2.19: Shaft furnace
[48, ETSU, 1994]

2.4.7.2 Advantages:

- due to the long preheating, the charge is very well dried before the melting starts. This makes the furnace well suited for Al, due to the reduced risk of hydrogen uptake
- relatively low investment and operating costs. Operating costs are kept low by the effective preheating, automatic control and long refractory life
- technical advantages are: low gas pick-up, excellent temperature control and low metal loss.

2.4.7.3 Disadvantages:

- no flexibility regarding a possible change of alloy.

[110, Vito, 2001]

2.4.8 Crucible furnace

2.4.8.1 Description

These are simple crucibles that are heated externally by the combustion gases from gas or oil combustion, by electricity or, for lower temperatures, by thermal fluid. Contact with a direct flame is avoided to prevent there being local hot spots at the base of the crucible and so that good temperature control can be maintained in the melt, to prevent oxidation and vaporisation of the metal.

This furnace type is only used for non-ferrous metal melting. Due to the indirect heating (through the crucible wall) no burn-off or gas take-up can take place. These furnaces are used for the production of small amounts of molten metal (less than 500 kg per batch) and for low production capacities. Example furnaces are displayed in Figure 2.20.

Figure 2.20: Crucible furnaces
[237, HUT, 2003]

The crucible is tilted manually, with a crane, or automatically to pour the molten metal into the mould. For copper based materials, only graphite or carborundum (silicon carbide) crucibles are used, whereas aluminium can also be melted in cast iron crucibles.

Crucibles used for holding, transport and metal treatment in ferrous foundries are called ladles. [110, Vito, 2001], [126, Teknologisk, 2000], [225, TWG, 2003]

2.4.8.2 Melting practice

The cold load is brought into the crucible, and heating is started at full power in order to melt the load. At 50 to 100 ºC below the melting temperature, the power is switched off, and the load is heated further by the thermal inertia of the crucible. Afterwards, the temperature is levelled off using a control system. After deslagging, metal treatment can be performed. This involves oxygen removal, degassing, grain refining and the adjustment of volatile metals such as zinc and magnesium. The slag is then removed once more before casting takes place.

Besides regular renewal of the crucible, no maintenance is needed. The renewal time is primarily dependent on the alloy to be melted. Multiple alloy changes cause a more rapid crucible wear. SiC-crucibles, used for low melting alloys, have a useful life of 130 to 150 charges. For high melting alloys, the useful life is 50 to 80 charges.

Thermal efficiencies are 750 – 3000 kWh per tonne of aluminium, i.e. 15 - 30 % efficiency.
[34, Binninger, 1994], [110, Vito, 2001], [126, Teknologisk, 2000]

2.4.8.3 Advantages:

- simple technology
- low maintenance
- flexibility regarding change of alloy.

2.4.8.4 Disadvantages:

- low efficiency and production capacity.

[110, Vito, 2001]

2.4.9 Argon Oxygen Decarburisation (AOD) converter for steel refining

The AOD converter is a special vessel for refining steel. The molten metal is transferred directly from the melting furnace (generally electric arc or induction) into the converter. As shown in Figure 2.21, oxygen (for the removal of carbon, silicon) and argon gas (for the stirring action) can be injected into the converter by means of tuyères positioned in its lower part, to refine the metal. The converter is equipped with a tilting mechanism in order to allow filling and emptying. Steel with a precise chemistry can be produced using AOD, but at a high cost. This system is not widely used in steel foundries outside the US.

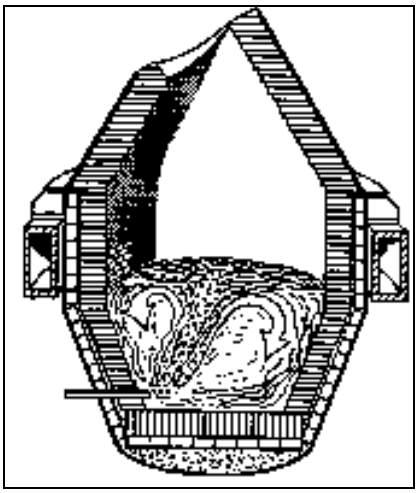

Figure 2.21: AOD converter
[237, HUT, 2003]

The first phase of the refining process consists of a decarburisation, through the injection of oxygen into the converter. This is a refining operation that holds the carbon content of the charge material within a specific range, as required. Decarburisation is initiated by injecting oxygen into the metal bath. This creates a strong stirring action during which carbon in the melt is burned. At the same time the “boiling” burns out silicon, and flushes out hydrogen and nitrogen from the metal bath. All impurities (oxides) are trapped in the slag. During melting, lime may be added to bring the slag to the proper basicity. When the carbon reaches the required concentration, oxygen injection is stopped and silicon and manganese are added to halt the boiling reaction, especially in the production of stainless steels. A dilution of the oxygen with argon or nitrogen assists the oxidation of carbon in preference to metallic elements such as iron, chromium, etc., leading to very good metallic yields. Consequently Al or Si and limestone are added to the metal and argon is injected in order to remove sulphur. The continuous gas injection causes a violent stirring action and an intimate mixing of slag and metal which can lower sulphur values to below 0.005 %. The residual gas content of the treated metal (hydrogen and nitrogen) is very low. All impurities are trapped in the slag and removed with it. After temperature and alloy adjustment the metal is transferred to ladles for pouring.
[174, Brown, 2000], [32, CAEF, 1997]

2.4.10 Vacuum Oxygen Decarburisation converter (VODC) for steel refining

The VODC (Vacuum Oxygen Decarburisation Converter) operates in such a way that molten steel is contained in the converter, which is attached to vacuum pumps, steam ejectors and an argon gas source. Two distinct processes are carried out in the vacuum treatment of stainless steel to obtain a higher quality level.

First, the steel is decarburised by introducing oxygen into the melt. At the same time, some argon is injected from the converter base. The converter uses vacuum pumps to lower the partial pressure of carbon monoxide, to such an extent that effective decarburisation can be carried out without oxidising too much of the chromium. This first process is similar to AOD decarburisation, but less argon is needed thanks to the lower total gas pressure and the process is much more efficient. The oxidised chromium is reduced back to liquid steel with aluminium.

The second process involves degassing. The converter is brought under deep vacuum (1 - 5 mbar) using a water ring pump and steam ejectors. Slight argon bubbling is continued in order to maintain an effective steel movement. At the very low pressure, gaseous impurities such as hydrogen and nitrogen are eliminated effectively. At the same time, the total oxygen content and the sulphur content are drastically decreased, which is beneficial for the mechanical properties of the end steel.

Low alloyed steels are normally only degassed.

The VODC process provides specific steel qualities, which cannot be obtained by other methods. The total oxygen content is also lower than what is typical for electric arc melted and AOD-treated steel, because a high level of oxide inclusions are removed form the melt during the VODC process, and most of the dissolved oxygen is further removed during the degassing phase.
[202, TWG, 2002]

2.4.11 Metal treatment of steel

In order to guarantee a good casting quality, cast steel needs further treatment to remove impurities and the possible causes of defects, i.e.:

- *Deoxidation*: Oxygen dissolves in liquid steel, in the form of FeO. During solidification, the oxygen can then combine with C in the steel to form CO. This process can thus change the composition of the steel and generate porosity. Deoxidation is therefore always necessary. Deoxidation is performed with an element that preferentially binds the oxygen. Silicon, calcium silicide, titanium, zirconium and aluminium are possible deoxidants, with aluminium being the most powerful and the one that is most generally used. Aluminium is added in the form of a stick or wire (see Figure 2.22). The treatment is usually performed in the furnace and in the ladle. The produced aluminium oxide is insoluble in the melt and mixes with the slag.

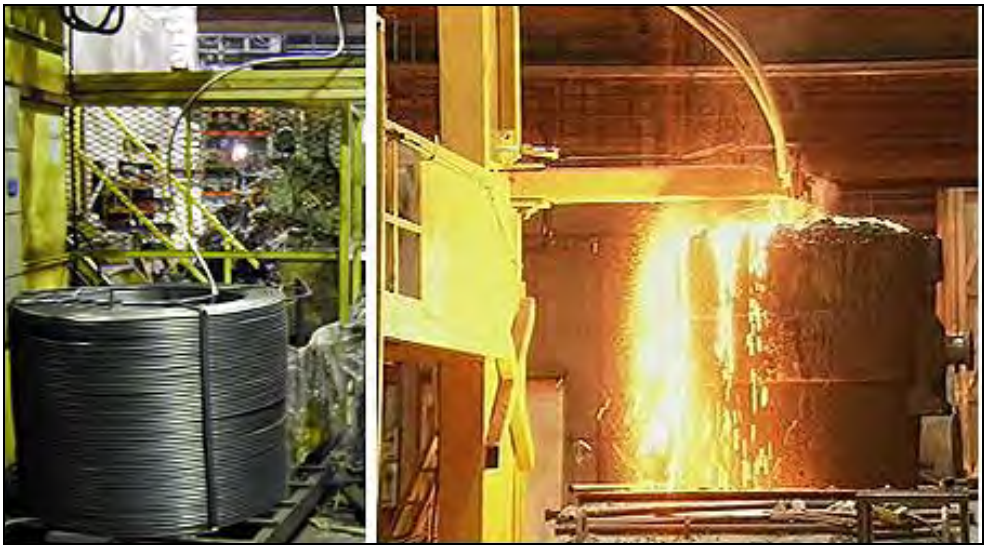

Figure 2.22: Deoxidation, using an aluminium wire
[237, HUT, 2003]

- *Sulphide formation*: As the tensile strength of steel increases, the harmful effect of sulphur increases. Sulphur is soluble in liquid steel, but on solidification it precipitates as MnS. Precipitates can take various forms and have different effects. The form of the sulphides is related to the residual aluminium content after deoxidation. The residual amount of Al should allow the formation of type III sulphides.

[110, Vito, 2001], [174, Brown, 2000]

2.4.12 Cast iron treatment

2.4.12.1 Alloying

During melting, some elements in the melt oxidise and are lost to the slag. At the end of the melting period a correction of the composition needs to be performed, in order to guarantee the appropriate final quality. For unalloyed cast iron, this is needed for: C, Si, Mn, S and P. If special properties are desired, specific alloying elements can be added, ranging from aluminium to zirconium, in concentrations of less than 1 % to more than 30 %. In general these are added as ferrous alloy blocks or grains. The additions are made to the liquid iron, since this reduces the risk of oxidation losses.

The addition is performed in the furnace, in the molten metal flow during pouring, or by putting the additives in the transport ladle before pouring the molten metal into it.
[110, Vito, 2001]

2.4.12.2 Homogenisation

The addition of alloying elements can introduce impurities such as oxides, sulphides or carbides into the iron. In order to reduce the negative effects from these compounds, the metal is overheated at 1480 ºC to 1500 ºC. Nevertheless overheating can affect graphite precipitation during solidification. Homogenisation has the following positive effects:

- reduction of oxides (FeO, SiO_2, MnO) by C, generating CO-bubbles. On their way through the melt these bubbles remove H_2 and N_2 from the melt
- at high temperature and under intense bath movements, impurities coagulate and rise to the melt surface more quickly, where they are then taken up by the slag.

[110, Vito, 2001]

2.4.12.3 Desulphurisation and recarburisation of cupola melted iron

Due to the intimate contact of the liquid metal with the coke, cupola melted iron shows a relatively high sulphur content. Sulphur pick-up in the cupola gives rise to a lower viscosity of the liquid metal, which is an advantage in some cases, e.g. for thin walled grey iron castings.

However, if the cast iron is to be treated with Mg (as described in the next section) to produce a nodular cast iron quality then the sulphur should be neutralised, to prevent excessive Mg consumption. This is performed by using one of a number of methods. In the porous plug method, nitrogen or argon gas is used to agitate the metal and CaC_2 powder is added to the metal. Upon contact with the liquid metal CaS is formed and removed as slag. The treated metal then flows to a holding ladle from which it is tapped for further treatment.

2.4.12.4 Nodularisation treatment of the melt

Nodular cast iron is obtained by the addition of Mg, either pure or as a FeSiMg or NiMg alloy, to the molten metal. Prior to this, a desulphurisation treatment may be necessary to guarantee successful nodularisation. The presence of Mg in the melt provokes a solidification of the graphite phase in the shape of microscopic spheres. This gives rise to higher mechanical properties, such as strength and ductility.

There are several techniques that can be applied to introduce Mg into the liquid metal:

- *The pour over technique*: This is the simplest method, whereby the liquid metal is poured over the Mg alloy in the bottom of the ladle
- *The sandwich method*: Here Mg alloy is placed at the bottom of a specially designed ladle and covered with steel sheets or FeSi, as shown in Figure 2.23. The metal is poured into the ladle and after melting of the cover the Mg reaction takes place
- *The Tundish Cover*: This is an improved sandwich technique, whereby the ladle is covered by a lid after the Mg alloy has been placed at the bottom of the ladle. The metal is poured in the concave lid and flows through a hole in the ladle, where the reaction takes place
- *The plunging method*: Using a plunger bell, the Mg alloy is submerged in the liquid metal until the reaction is finished. During the treatment the ladle lid is closed, to prevent MgO fume emissions
- *The G Fischer converter*: This process uses a special ladle that is closed tightly with a lid after the metal is poured into the converter in the horizontal position. The converter is then tilted into a vertical position, allowing the Mg alloy to react with the metal. Once the reaction is finished the converter is turned back into the horizontal position and is tapped after opening the lid
- *The core wire injection*: Here very fine powdered Mg alloy is rolled in tin steel sheet, forming a filled wire. This wire is then injected, by a controlled mechanism, into a slender shaped ladle, where the Mg is released
- *The flow through treatment*: Here the metal is poured into a special designed reaction chamber in which the Mg alloy was put earlier
- *The ductilator*: In this method the metal is poured into a reaction chamber where the flow is forced to form a vortex. The Mg alloy is injected into the vortex with an inert carrier gas. The treatment can be performed on large quantities of metal or during mould filling
- *The inmold process*: In this process the Mg alloy, shaped as a tablet, is put directly into the mould cavity (gating system). The reaction takes place during mould filling, ensuring a high yield.

Figure 2.23: The sandwich method for nodularisation
[237, HUT, 2003]

After treatment, the metal has to be poured into the mould within a specific time, as the Mg effect tends to fade quickly, necessitating a new treatment if a certain time limit (10 to 15 min) is exceeded.

2.4.12.5 Inoculation of the melt

The presence of coarse shaped graphite in a metal matrix leads to poor mechanical properties of the material. In order to get a fine crystalline metallurgical structure, inoculation of the melt is necessary prior to casting. This process introduces seeds for crystal growth into the metal melt. Usually FeSi alloys are used for this purpose. Ca, Al and rare earth materials are often included in the inoculant.

Again, several techniques can be used to inoculate the molten metal:
- *Injection during tapping*: Here the inoculant is injected directly into the metal flow during tapping
- *Injection during pouring*: Here the inoculant is injected directly into the metal flow during pouring of the mould (see Figure 2.24)
- *Filled wire injection in the melt* (see Section 2.4.12.4)
- *Inmold process* (see Section 2.4.12.4).

Figure 2.24: Inoculation during pouring
[237, HUT, 2003]

2.4.13 Non-ferrous metal treatment

There are three main metal treatment (or refining) operations carried out in **aluminium** melting processes. These are as follows:

- *Degassing*: Molten aluminium dissolves hydrogen, which is then expelled upon cooling and can thus lead to porosity in the finished casting. Hydrogen therefore needs to be removed. This is done by bubbling an inert gas through the melt. Good degassing methods provide bubbles with high residence time and high surface area. The degassing of aluminium is mostly performed using an impeller station. This treatment uses a rapid-spinning mixer and nitrogen injection into the melt. Degassing is often combined with a cleaning of the melt. Cleaning is performed to remove alkali or alkaline earth metals, such as Ca. Cleaning can be done by Cl_2-gas. The use of HCE for this purpose has been banned in the EU *(Dir. 97/16/EC)*. A mixture of nitrogen with 3 % Cl_2 is generally used, for simultaneous degassing and cleaning. Alternative degassing methods use tablets, a lance with a porous head, or a porous stone in the holding furnace
- *Modification and grain refining*: For aluminium alloys this usually involves the addition of small amounts of metal to the melt. These additions control the grain size and modify the microstructure of the solidifying metal and thus enhance the casting mechanical properties. Sodium or strontium are used for the modification, while grain refinement is achieved with titanium, titanium boride, zircon or carbon. This treatment is mostly performed in combination with degassing in a dedicated metal treatment station
- *Fluxing*: This usually involves the addition of solid fluoride based fluxes to the melt, to remove solid contaminants.

[164, UK Environment Agency, 2002], [175, Brown, 1999], [178, Wenk, 1995]

There are four main metal treatment (or refining) operations carried out in **magnesium** melting processes. These are as follows:

- *Grain modification*: Grain modifiers for magnesium alloy processes are usually in the form of zirconium or formerly hexachloroethane. The use of HCE for this purpose has been banned in the EU *(Dir. 97/16/EC)*
- *Fluxing*: This usually involves the addition of alkali, earth alkali, chloride and fluoride proprietary fluxes to the melt to remove solid contaminants
- *Degassing*: For magnesium processes, nitrogen or argon gas sparging may take place for degassing and oxide removal. The degassing of magnesium alloys may also be effected by a mixture of argon and chlorine gases, when argon is used as a carrier gas
- *Oxidation control*: The presence of beryllium within the melt grain modifies and stops oxidation. Finished magnesium alloys may contain up to 15 ppm beryllium by weight. A master alloy of aluminium/beryllium, containing up to a nominal 5 % beryllium, may be added to the molten magnesium alloy to give it this beryllium loading. Oxidation control may also be achieved by blanketing the surface of the metal with a carrier gas, such as carbon dioxide or argon, containing up to 4 % sulphur hexafluoride. To date, the only flux-free alternative to SF_6 is SO_2. SO_2 is significantly cheaper then SF_6 but its main drawback is its toxicity, and as a result operations need to be enclosed better. Up to the present, only 1/3 of the foundries in Europe have been using SO_2. Occasionally oxidation control may be achieved by sprinkling sulphur powder on the surface of the melt. This issue is discussed in Section 4.2.7.1.

There are three main metal treatment (or refining) operations carried out in **copper** melting processes. Molten copper dissolves oxygen and hydrogen, which may recombine to form water vapour. This in turn will generate porosity in the casting. Degassing and deoxidation are thus applied to remove hydrogen and oxygen, respectively. The applicable metal treatment operations are as follows:

- *Deoxidation*: Deoxidation is performed by adding a reagent which binds the oxygen and forms a fluid slag. Care must be taken to prevent the deoxidation products from being entrained in the solidified casting and the residual deoxidant from adversely affecting the alloy properties. Phosphorus is the most commonly used deoxidation reagent. Alternatives are magnesium, manganese, calcium, silicon and boron
- *Degassing*: Hydrogen is removed from the melt by bubbling an inert gas through it. Both argon and nitrogen may be used. The technique is comparable to aluminium degassing
- *Fluxing*: Aluminium in alloys can oxidise and generate oxide skins. These can cause problems upon casting. In non-aluminium alloys, traces of aluminium can cause defects. Therefore they need to be removed, using fluxing agents. Fluxes are also used to cover the surface in order to prevent oxidation, zinc loss and hydrogen pick-up during melting. Specific fluxing agents exist for each type of treatment.

[165, UK Environment Agency, 2002], [182, Closset, 2002]

2.5 Mould and core production

Moulding consists of making a mould in which the molten metal will be poured. Some moulds may need to have special properties to produce high quality castings, which, for example:

- reproduce exactly and with a high dimensional precision the shape of the casting model
- give a smooth skin to the casting in order to avoid excessive fettling
- avoid any casting defects such as cracks, worming, pinholes, etc.

Just as the mould defines the outer shape of the casting, the core defines the inner one, or at least the parts not directly attainable by moulding.

Moulds may be classified in two large families:

- **lost moulds** (single use moulds): These are specially made for each casting and are destroyed after pouring. The moulds are generally made of sand, and are chemically-bonded, clay-bonded, or even unbonded. Investment casting can also be included in this family
- **permanent moulds** (multi use moulds): These are used for gravity and low-pressure casting, pressure die-casting, and centrifugal casting. Typically the moulds are metallic.

The cores used for ferrous castings are practically always made of sand. The choice of binder technology used depends on factors such as the size of the casting, the production rate, the metal poured, the shake-out properties, etc.

For sand moulding, the mould may be produced by manual or mechanical ramming actions, such as by jolt, squeeze, air impact, vibration, etc.. When the mould has sufficient strength it is released from the model, which can then be used to produce a new mould.

Generally, cores are produced by the same techniques as moulds, but small or medium sized cores are often blown or shot into wooden, plastic or metallic core-boxes.

For non-ferrous casting, about 30 % of copper alloys are cast in sand moulds. Only about 10 % of light non-ferrous metals are cast in single use moulds.

The production of patterns and dies is generally carried out by specialised external suppliers. These activities are found in the metal and plastics treatment sectors.
[2, Hoffmeister, et al., 1997], [32, CAEF, 1997], [110, Vito, 2001]

2.5.1 Raw materials

2.5.1.1 Refractory materials

Whatever binder applied, the physical and chemical properties of the refractory material used to make the moulds or cores affects their characteristics and their behaviour during pouring. This is not surprising as these materials make up 95 to 99 % of the products used.

The purchase price of each sand type has four main components – extraction, preparation, packaging and transportation. Transportation costs will vary for different regions. The main factor however in the price is the sand type. The average purchase price for the various types varies widely. From a 1995 UK questionnaire, the tonnage price of chromite and zircon sand were respectively a factor 9 and 14 times higher than that of silica sand. In Portugal the cost of sand varies according to the amount purchased, but sand is generally cheaper in Portugal than in Spain, France or Italy. Portuguese prices (year 2003) range between EUR 20 - 25 per tonne of dry sand AFS 55, plus transport. Prices in the Czech Republic (year 2003) for silica sand range between EUR 10 and 20 for silica sand, with the price depending on the volume, packaging and treatment of the sand. The price for chromite sand is EUR 250 – 300/t, and for zircon sand EUR 250 – 400/t.
[72, ETSU, 1995], [225, TWG, 2003]

The different types of refractory sands used for foundry purposes are described in the following sections.

2.5.1.1.1 Silica sand

This type of sand is the most commonly used, mostly because of its wide availability and its relatively low cost. Silica sand is composed of the mineral "quartz" (SiO_2), which is more or less pure and clean, depending on its origin. Its dry piece specific weight fluctuates between 2.5 to 2.8 kg/dm³. The dry bulk density (or loose volume weight) of silica sand is 1.4 to 1.6 kg/dm³.

The thermal expansion of silica sand generates a mould movement upon pouring and cooling. Specific additives are therefore used, especially when producing cores, in order to prevent casting errors. These may be wood fluff, iron oxide or cured foundry sand. Sand containing feldspar has a lower thermal expansion than pure quartz sand and a lower sintering point, but it is widely used in order to minimise expansion defects in castings.

Silica sand is neutral and is compatible with all binders and normal cast alloys. The respirable particulate matter (RPM) fraction of quartz is classified by IARC as carcinogenic [233, IARC, 1997]. This is a health and safety issue. Studies are ongoing to determine whether or not an air pollution issue also exists. The amount of quartz in dust is defined by the content of quartz in the input materials.

In green sand moulding technology, control of the grain size distribution is very important. Figure 2.25 shows a typical grain size distribution for silica sand. The grain size distribution is used to calculate the AFS-number (AFS = American Foundry Society). This gives the overall fineness of the sand. The higher the AFS-number, the finer the sand. An alternative classification system is the middle grain number or MK.

A finer sand grade will have more grains per gram, and thus a higher surface area. This requires more binder addition for an equal mould strength. Operators therefore try to use the coarsest sand, but one that still gives a good surface finishing aspect. Standard AFS-numbers are 50 – 60. For very smooth surfaces a fine sand is needed, typically one with an AFS of 90 – 110 is used. Fine sands are also used in some instances to replace mould coatings.
[110, Vito, 2001], [202, TWG, 2002], [225, TWG, 2003]

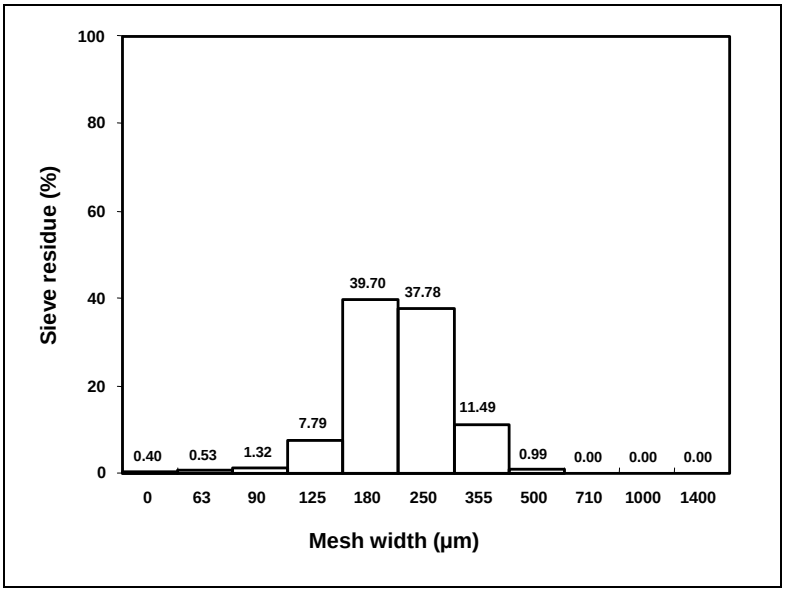

Figure 2.25: Typical grain size distribution for silica foundry sand [110, Vito, 2001]

2.5.1.1.2 Chromite sand

Chromite is a chrome ore, with the theoretical formula $FeO.Cr_2O_3$, which contains other components such as magnesium and aluminium oxides. For its use in foundries, its silica content must be lower than 2 % in order to prevent sintering at low temperatures. Its characteristics are as follows:

- density: 4.3 to 4.6, cf. 2.65 for silica sand
- theoretical melting point: 2180 ºC, but the presence of impurities can lower this to 1800 ºC
- thermal diffusivity: more than 25 % higher than that of silica sand
- thermal expansion: regular, without a transition point, and lower than that of silica sand
- pH: rather basic, from 7 to 10.

Chromite sand is more refractory than silica. It is more thermally stable and has a greater chilling power. Chromite sand provides a better surface finish on large castings. It is therefore used for the production of large castings and in areas of the mould where chilling is required.
[32, CAEF, 1997]

2.5.1.1.3 Zircon sand

Zircon is a zirconium silicate, $ZrSiO_4$. Zircon is the most widespread zirconium ore. Its characteristics are as follows.

- density: 4.4 to 4.7, cf. 2.65 for silica sand
- melting point: higher than 2000 ºC
- thermal diffusivity: more than 30 % higher than that of silica sand
- thermal expansion: regular, without a transition point, and lower than that of silica sand.

The general characteristics of zircon sand are similar to that of chromite, but zircon sand produces a better finish as a finer grade is used. These physical and thermal properties account for its use for moulding or core-making in difficult cases, in spite of its very high price.
[32, CAEF, 1997], [72, ETSU, 1995]

2.5.1.1.4 Olivine sand

Olivine sands are a mineral group which includes forsterite, fayalite and others. The characteristics of olivine sands are as follows:

- melting point: forsterite: 1890 ºC, fayalite: 1205 ºC
- density: 3.2 to 3.6
- pH: around 9.

The basic pH makes this type of sand not suitable for use with acid catalysed binder systems.

Olivine sand is produced by crushing natural rocks, which explains its diverse characteristics. It is usually used for moulding and core-making in manganese steel casting. The presence of manganese prohibits the presence of silica as these two components react to give a very fusible compound. The reported purchase price in Spain is EUR 130/tonne (2002).
[32, CAEF, 1997], [210, Martínez de Morentin Ronda, 2002]

2.5.1.2 Binders and other chemicals

2.5.1.2.1 Bentonite

Bentonite is a smectite clay, which has a lamellar structure. By adding water, the clay structure swells due to the adsorption of water molecules. The clay then becomes workable and can be spread to coat the sand grains during mixing.

Natural calcium bentonites do not swell or gel when mixed with water. They are rarely used at present, being used only for very special castings. Alternatively, these materials may be "activated" by treatment with soda ash to give "soda activated bentonites". These are used extensively in ferrous foundries throughout Europe; their properties approach those of natural sodium bentonites.

Natural sodium bentonites greatly swell when mixed with water. The main features in green sand are their high dry strength, good tolerance to water content variation, high resistance to burn-out and their improved high temperature durability. As they are imported from the US, where they are in common use, their price generally limits their use to high value steel casting or in blends with activated calcium bentonites.

Pouring molten metal into a green sand mould subjects the moulding-sand to considerable heat. This heat removes moisture from the sand and destroys the clay-bonded structure (and additives). If during pouring and cooling bentonite stays below the deactivation temperature, the lamellar structure is maintained as well its ability to swell and develop cohesion. The deactivition temperature varies with the bentonite type.

Prices for bentonite range between EUR 70 – 250/t, depending on the packaging and product type (Czech Republic, 2003).
[32, CAEF, 1997], [73, ETSU, 1995], [202, TWG, 2002], [225, TWG, 2003]

2.5.1.2.2 Resins

Over the past few decades a range of chemical binders have been developed. These are single- or multi-component systems which are mixed with the foundry sand until all the grains are coated with a thin film. After mixing, a hardening reaction starts, binding the sand grains together and developing mould strength. Resins can be classified according to the hardening method:

- cold-setting resins
- gas-hardened resins
- hot-curing resins.

The various resin types will be discussed under Section 2.5.6. In Table 2.7 a survey of the applicability of the various resins is given.

Hardening	Resin type ("commercial name")	Mould production	Core production	Curing temperature	Hardening time (*)	Metal types	Size of series
Cold-setting	Furan	Medium to large	Some	10 – 30 ºC	10 – 120 min	Ferrous + non-ferrous	Small to large
	Phenolic	Large	No	10 – 30 ºC	10 – 180 min	Ferrous	Small to large
	Polyurethane (“Pepset/Pentex")	Small to medium	Some	10 – 30 ºC	5 – 60 min	Ferrous + non-ferrous	Small to large
	Resol - ester ("Alfaset")	Small to Large	Some	10 – 30 ºC	5 – 400 min	Ferrous + non-ferrous	Small to large
	Alkyd oil	Large	Some	10 – 30 ºC	50 min	steel	Small
	Silicate - Water glass	Medium to large	No	10 – 30 ºC	1 – 60 min	Ferrous + non-ferrous	Small to medium
Gas-hardening	Phenolic/Furan[1] ("Hardox")	Small	Yes	10 – 30 ºC	<60 s	Ferrous + non-ferrous	All
	Polyurethane ("Cold-box")	Small	Yes	10 – 30 ºC	<60 s	Ferrous + non-ferrous	All
	Resol ("Betaset")	Small	Yes	10 – 30 ºC	<60 s	Ferrous + non-ferrous	All
	Acryl/Epoxy ("Isoset")	No	Yes	10 – 30 ºC	<60 s	Ferrous + non-ferrous	All
	Silicate	Small	Yes	10 – 30 ºC	<60 s	Ferrous + non-ferrous	All
Thermosetting	Oil	Small	Yes	180 – 240 ºC	10 – 60 min	Ferrous	Small
	"Warm-box"	Seldom	Yes	150 – 220 ºC	20 – 60 s	Ferrous	Medium to large
	"Hot-box"	Seldom	Yes	220 – 250 ºC	20 – 60 s	Ferrous + non-ferrous	Medium to large
	"Croning"	Yes	Yes	250 – 270 ºC	120 – 180 s	Ferrous + non-ferrous	Large

(*) i.e. the release time - the time in which the mould/core has gained sufficient strength to be released from the pattern
[1] Not applied for capacities <20 tonnes/day

Table 2.7: Survey of various resin types and their applicability [110, Vito, 2001]

2.5.1.2.3 Coal dust

Coal dust is usually added to green sand for cast iron moulding. It is used to a limited extent in some non-ferrous foundries. Coal dust may be mixed with small amounts of resins and oil products. During casting, the thermal degradation produces ‘lustrous carbon’, which improves the casting surface finish and shake-out properties. Coal dust is added for three reasons:

- to create an inert atmosphere in the mould cavity during pouring, through the combustion of organic compounds, which in turn slows down the oxidation of metal (slag formation)
- to reduce the penetration of metal in-between the quartz grains, through deposition of a graphite film, which also creates a flat casting surface
- to reduce the amount of sand remaining on the casting surface upon shake-out.

In addition to the black and sticky dust caused by handling, coal dust may contain or generate polycyclic aromatic hydrocarbons (PAH) during pouring.

For steel castings, coal dust is not used because of carbon pick-up. In this case, it is usually replaced by cereal binders such as starch or dextrin.

Various types of coal dust replacements exist. These consist of blends of high volatile, high lustrous carbon materials blended with clays. They are generally more environmentally acceptable than coal dust, i.e. producing less fume during casting, although some coal dust replacements will generate more PAH in the sand.
[174, Brown, 2000], [225, TWG, 2003]

2.5.1.2.4 Cereal binders

Cereal binders are used mainly in steel foundries to increase the strength and toughness of the green sand. There are two main types of cereal binder: starch and dextrin. Starch is the basic material and is produced from a number of plant materials, with maize starch being the most commonly used for foundry purposes. Dextrin is a repolymerised form of starch, produced through a subsequent acid and thermal treatment of starch.

Starches can help to reduce expansion defects, since as they burn out, they allow the sand grains to deform without deforming the mould. Cereals increase the green strength, dry strength and toughness but can reduce the flowability. Dextrines improve the flowability and moisture retention, preventing moulds from drying out and edges becoming friable.

Cereal additions do not improve the erosion resistance of the sand nor its resistance to metal penetration.
[174, Brown, 2000], [175, Brown, 1999]

2.5.1.2.5 Iron oxide

Iron oxide reacts with quartz at high temperature and forms a low melting compound, fayalite. This glassy plastic product sinters the grains together. It is mainly used in the production of core sand, in order to reduce the formation of veins.
[110, Vito, 2001]

2.5.1.3 Running, gating, feeding and filtration

The different parts of the running and gating system are shown in Figure 2.26. The system carries out the following functions:

- controls the flow of the metal into the mould cavity at the rate needed to avoid cold metal defects in the casting
- avoids turbulence of metal entering the mould
- prevents slag and dross present in the melt from entering into the mould
- avoids high velocity impingement of the metal stream onto cores or mould surfaces
- encourages thermal gradients within the casting, which help to produce sound castings
- enables the casting to be separated from the running/gating system easily.

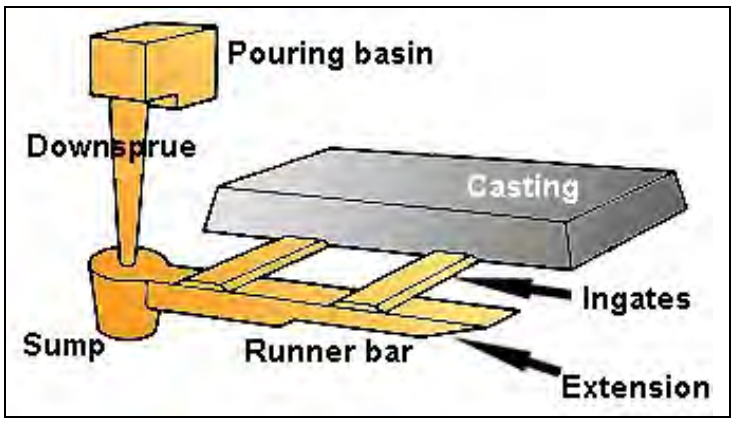

Figure 2.26: Components of the running and gating system
[237, HUT, 2003]

The design of the running system needs to take account of the varying slag and dross forming properties of the metal to be poured, e.g.:

- in lamellar iron, some furnace slag may be present but the melt is not subject to inclusions due to oxidation
- nodular iron contains magnesium silicate and sulphide dross, arising from the nodularisation treatment
- steel is susceptible to oxidation and slag formation
- aluminium alloys (and aluminium bronzes) are all subject to dross formation, whereby a film of oxide forms immediately on any metal surface exposed to air.

Inclusions in steel can arise from slag entrapment, the erosion of furnace or ladle linings or refractories, or from deoxidation. Filtration is now widely used to reduce the presence of inclusions. The introduction of ceramic filters has even enabled simplifications to be made in the design of running and gating systems. Various types of filters are shown in Figure 2.27.

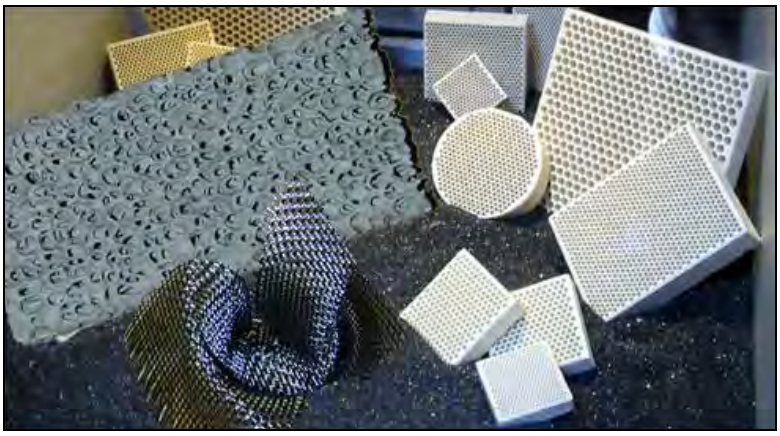

Figure 2.27: Various types of filters
[237, HUT, 2003]

2.5.2 Sand preparation (transport, sieving, cooling, mixing)

2.5.2.1 Sand conditioning for green sand moulding

One of the major advantages in using green sand moulding is that the sand from the moulds can be reconditioned for multiple re-use. The layout of a typical green sand plant is depicted in Figure 2.28, and some examples of sand mixers are shown in Figure 2.29.

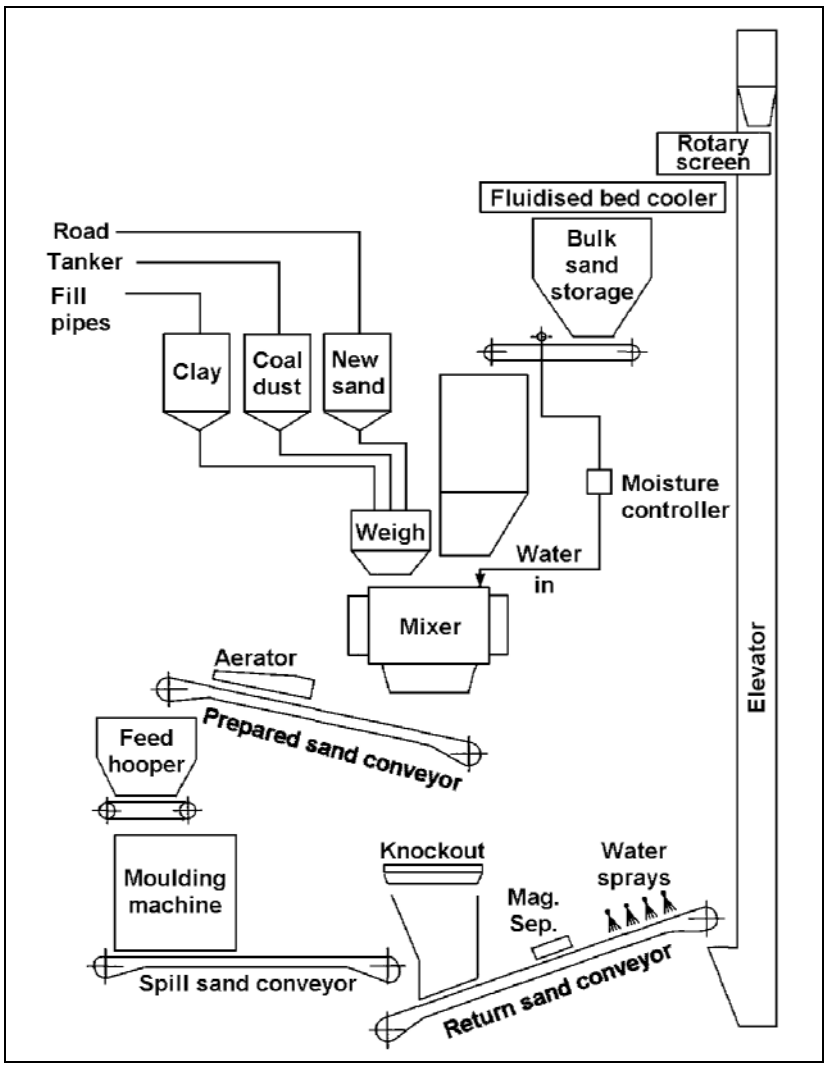

Figure 2.28: Flow diagram for a typical green sand plant [174, Brown, 2000]

Figure 2.29: Various types of sand mixers [237, HUT, 2003]

As the sand usually contains metallic elements such as flashes, pouring drops, pieces of sprue or even small parts of casting, all these have to be removed, at first by means of magnetic iron separators. If separation of the magnetic iron castings is not achieved or not possible, separation may be carried out by Eddy current separators. The residual sand lumps are then broken up. It is important not to crush the sand, in order to prevent the demixing of the sand and bentonite.

Usually, the sand has to be cooled in order to keep the moisture level of the prepared sand as constant as possible and to avoid any loss by evaporation. Cooling is often performed in a fluidised bed, which also allows the sand to be dedusted by removing excessive amounts of fines.

The sand is then screened to remove the remaining lumps and stored before mixing with the required amounts of additives, say clay, water, etc. to prepare the green sand for re-use.
[32, CAEF, 1997], [174, Brown, 2000]

2.5.3 Moulding with natural sand

Some foundries use naturally bonded sand. This is sand which contains a natural percentage of clay. Only water needs to be added in order to activate the binding capacity. If needed, some additives may be mixed as well. The approximate composition of natural sand is given in Table 2.8.

Compounds	Approximate %
Quartz sand	80
Clay	15
Water	5

Table 2.8: Composition of natural sand
[126, Teknologisk, 2000]

Natural sand, which is found ready-mixed in nature, does not have the same high demands for mixing equipment as synthetic sand. It is mainly used in small-sized non-ferrous (e.g. copper) foundries and is not used in foundries casting iron and steel.

2.5.4 Moulding with clay-bonded sand (green sand moulding)

Green sand moulding is the most common moulding process. Green sand is generally not used to make cores. Cores are formed using a chemical binding system. Green sand is the only process that uses a moist sand mix. The mixture is made up of about 85 to 95 % silica (or olivine or zircon) sand; 5 to 10 % bentonite clay; 3 to 9 % carbonaceous materials such as powdered (sea) coal, petroleum products, corn starch or wood flour; and 2 to 5 per cent water. The clay and water act as the binder, holding the sand grains together. The carbonaceous materials burn off when the molten metal is poured into the mould, creating a reducing atmosphere which prevents the metal from oxidising as it solidifies. Table 2.9 gives a survey of the additives used for various types of metal castings.

Metal	Additives for green sand preparation
Nodular cast iron casting Lamellar iron casting Malleable iron casting	Bentonite Cereal binder* Coal dust
Steel casting	Bentonite Cereal binder*
Light metal and aluminium casting	Bentonite Cereal binder*
Magnesium-alloyed-aluminium casting	Bentonite Boric acid
Magnesium casting	Bentonite Powdered sulphur Boric acid
Heavy metal casting (copper alloys)	Bentonite Cereal binder* coal dust
* Optional additive	

Table 2.9: Composition of additive mix for green sand preparation (excl. water) [36, Winterhalter, et al., 1992]

Green sand, as demonstrated by its widespread use, has a number of advantages over other casting methods. The process can be used for both ferrous and non-ferrous metal casting and it can handle a more diverse range of products than any other casting method. For example, green sand is used to produce the total range of castings, from small precision castings up to large castings of up to a tonne. If uniform sand compaction and accurate control of sand properties are maintained, very close tolerances can be obtained. The process also has the advantage of requiring only a relatively short time to produce a mould compared to many other processes. In addition, the relative simplicity of the process makes it ideally suited to a mechanised process.

Although manual moulding is still in use, machine moulding is currently the most widespread. Two sequential operations must be performed by a moulding machine: the first is ramming the sand, followed by separating the pattern from the compacted sand. The most commonly used processes proceed from the working principles described hereafter.

Squeeze moulding machines use pressure to pack the sand, which is applied through a squeeze head or by a multiple-piston squeeze head. Moulding by squeezing alone becomes less effective as the depth of the half mould increases. In these cases, jolting the work table greatly increases the compaction of the sand.

In impact moulding, sand is fed under gravity into the flask and compacted by the instantaneous release of compressed air through a rapid acting valve. This process gives a high and uniform densification, particularly in the sand surrounding the pattern.

Flaskless moulding, with both vertical and horizontal parting, achieves impressive production efficiencies. High mould accuracies can be achieved, but this process requires an effective set-up and high quality patterns to achieve the desired objective.
[32, CAEF, 1997], [42, US EPA, 1998]

2.5.5 Moulding with unbonded sand (V-process)

This process uses dry sand, rammed by vibration without any binder addition, with the sand held between two polyethylene sheets by partial vacuum.

The production of a half mould is illustrated in Figure 2.30. The successive steps of the process are as follows:

- the pattern is fixed to an airtight chamber which is connected to a vacuum pump. The pattern is vented by small diameter holes connecting through the airtight chamber
- a thin film of polyethylene vinyl acetate (PEVA), 75 to 100 microns thick, is heated up to 85 ºC
- this film, which is expanded under heat, is applied on the pattern and fixed by vacuum applied through the airtight chamber
- a moulding box, in which a vacuum can be created, is placed on the pattern, and filled with dry sand
- this sand is compacted by vibration, made even, and then a second film of PEVA is applied to the sand
- air is extracted from the moulding box and at the same time, the vacuum is released in the airtight chamber; the vacuum stiffens the sand and the half mould can then be stripped off
- the second half mould is made in the same way and both are assembled and closed, with the vacuum still being applied
- the metal can now be poured, the two moulding boxes remaining under vacuum until the casting is cool enough to be shaken out
- shake-out occurs simply by shutting off the vacuum: the sand flows out from the box through the grid and may be recycled after dedusting and separation of the unburned plastic sheets.

[174, Brown, 2000]

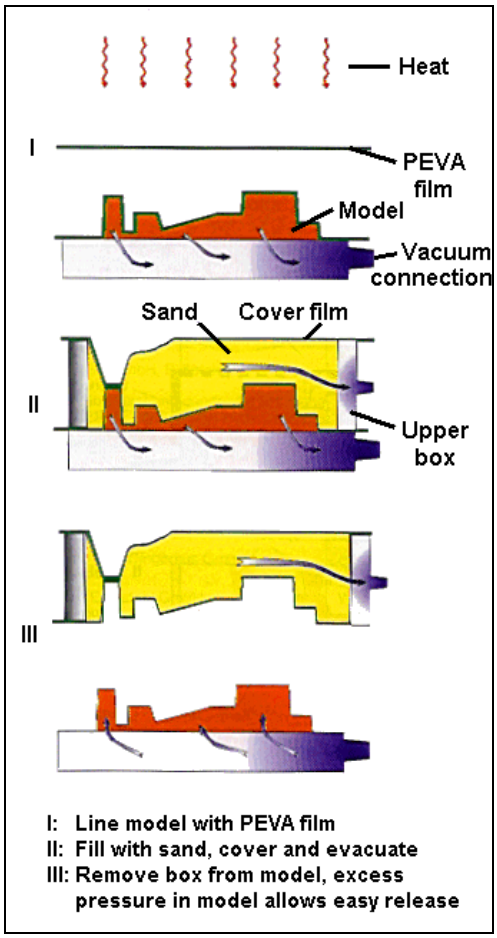

Figure 2.30: Vacuum moulding
[179, Hoppenstedt, 2002]

2.5.6 Moulding and core-making with chemically-bonded sand

For core-making, chemical binding systems are primarily used. Cores require different physical characteristics than moulds; therefore, the binding systems used to make cores may be different from those used for moulds. Cores must be able to withstand the strong forces which can occur when molten metal fills the mould, and often must be later removed from small passages in the solidified casting. This means that the binding system used must produce strong, hard cores that will collapse to allow removal after the casting has hardened. Therefore, cores are typically formed from silica sand (and occasionally olivine, zircon or chromite sand), and strong chemical binders. The sand and binder mix is placed in a core-box where it hardens into the desired shape and is removed. Hardening, or curing, is accomplished with a chemical or catalytic reaction or by heat.

Table 2.10 gives the relative share of the various core-making processes in German automobile foundries in 1991. This shows that the amine cold-box and hot-box systems dominate the market. Over 90 % of the automobile foundries use the amine cold-box system. The other processes (croning, CO_2-silicate) are mainly used for supplementary use, i.e. making cores with specific requirements (size, thickness,…).
[42, US EPA, 1998], [174, Brown, 2000]

System	Number
Amine cold-box	44
Hot-box	10
Shell/croning	9
CO_2 – silicate	3

Table 2.10: Core-making processes used in 48 automobile foundries in Germany, 1991 [174, Brown, 2000]

2.5.6.1 Cold-setting processes

The curing of cold-setting sands is effective at ambient temperature. The process begins when the last component of the formulation has been introduced into the mix. It then continues for a few minutes to several hours, depending on the process, the amount of binder and the hardening agent strength.

These processes are more often used to make moulds than cores, especially for medium or large sized castings.

2.5.6.1.1 Phenolic, acid catalysed

This process has been in use since 1958. As the components are relatively cheap, it is mainly used for the production of large parts. It is applicable for all alloy types. The hardening of these resins is more difficult and less regular compared to the furan resins.

The resins are either phenol-formaldehyde (PF), or urea-formaldehyde/phenol-formaldehyde copolymers (UF/PF), both being "resols", with a formaldehyde/phenol ratio higher than one.
The catalysts are strong sulphonic acids, such as paratoluene, xylene or benzene-sulphonic, with sometimes an addition of sulphuric acid, usually used in a diluted form.

2.5.6.1.2 Furan, acid catalysed

These binders, firstly introduced in foundries in 1958, are commonly used for the moulding and core-making of medium and large sized parts, for small and medium batch production and for all alloy types. Only certain types are used for steel casting, as cracks, fins or pinholes may occur. The process allows good flexibility in application and properties. Furfuryl alcohol (FA) has the disadvantage of being a (strategic) basic product, which leaves it subject to market price variations. Furan binders are comparable to phenolic binders in that their setting mechanism and the acid catalysts used are the same for both processes. Some examples of furan cores are shown in Figure 2.31.

Figure 2.31: Furan cores
[237, HUT, 2003]

The addition of an acid catalyst to a furan resin causes an exothermic polycondensation, which hardens the binder. Furan resins are available with different formulations, all of which are based on furfuryl alcohol:

- furan resin	FA
- urea - formaldehyde - furfuryl alcohol	UF - FA
- phenol - formaldehyde - furfuryl alcohol	PF - FA
- urea - formaldehyde - phenol - furfuryl alcohol	UF - PF - FA
- resorcinol - furfuryl alcohol	R - FA.

A silane is nearly always added to enhance the resin-sand bond. The catalysts are strong sulphonic acids, such as paratoluene, xylene or benzene-sulphonic, sometimes with an addition of sulphuric or phosphoric acid, usually used in a diluted form.
[110, Vito, 2001]

2.5.6.1.3 Polyurethane (phenolic isocyanate)

This process is used to a minor extent for moulding and core-making, with restrictions for steel casting, as cracks or pinholes may occur. These can be prevented however, by the addition of iron oxide and by drying the moulds and cores. In some countries (e.g. Sweden) this type of binder has not been used for 25 years, mainly because of its effect on the working environment.

This process is based on a polyaddition reaction between a phenolic resin and an isocyanate (mostly MDI), catalysed by a pyridine derivative; with the result being a polyurethane structure. All the components are in solution in aromatic and/or polar solvent (i.e. aliphatic solvent) with a high boiling point. Contamination by water must be strictly avoided since water reacts strongly with the isocyanate.

2.5.6.1.4 Resol – ester (alkaline phenolic ester hardened)

This process is used for small or medium batch production. It may be used for all alloy types but is of special interest for lighter alloys, because of the ease of shake-out. The absence of nitrogen in the compounding reagents is a benefit for steel casting.

The resin is an alkaline phenolic resol solution, which reacts with a liquid ester. The resin and the ester produce an unstable complex, causing gelification. The complex disintegrates and causes cross-polymerisation of the resin, producing a salt and an alcohol.

In this process, the curing speed is not adjusted by the addition rate of the hardener, but by using different grades. The hardening time may vary from a few minutes to more than one hour. Mechanical properties immediately after hardening are rather poor, but improve upon storage.

2.5.6.1.5 Alkyd oil, unbaked

This process is mostly used for single castings or for small batch production in steel foundries. It provides the benefit of a good surface finish and good stripping properties. However, it is expensive.

An oil modified polyester resin is mixed with isocyanate, producing a polyurethane resin, which hardens slowly. The curing of the mould is accelerated by a catalyst and completed by heating to 150 ºC.

2.5.6.1.6 Ester silicate

This process is used mostly in steel foundries, for medium and large sized castings in medium and small series. It is similar to the unbaked alkyd oil process. However, it has poor shake-out properties and lower mechanical resistance than organic resin-bonded systems.

The hardening of a silicate - ester sand proceeds through an intermediate step, which consists of the hydrolysis of the ester by the alkaline silicate solution. This hydrolysis produces glycerol and acetic acid, which precipitates a silicate gel to form the initial bond. Further strength develops as the residual silicate dries.

2.5.6.1.7 Cement

This process is only used for very large sized castings. Its application is relevant for public works applications. It does not generate any emission problems during moulding or core-making.

2.5.6.2 Gas-hardened processes

In these processes, curing takes place by injecting a catalyst or a hardener in a gaseous form. The curing speed can be very high, which allows high production rates to be achieved. They are suitable for moulds and cores of limited size, in medium batch or mass production. Their use has been constantly expanding over the last few years.

The chemistry behind many of these gas-hardened processes is similar to the cold-setting processes. Because of the gaseous form of the catalysts, it is sometimes necessary to collect and treat their emissions.

2.5.6.2.1 Cold-box (amine hardened phenolic urethane)

This process is commonly used to make cores of up to 100 kg and more, and small moulds. It provides a very smooth surface finish, and the dimensional accuracy is very high. The core removal properties are excellent and the sand can easily be reclaimed. This process is the most commonly used in core-making. An example cold-box core is shown in Figure 2.32.

Figure 2.32: Cold-box core
[237, HUT, 2003]

The chemistry of this polyurethane based process is very similar to the polyurethane cold-setting one, e.g.: it involves a phenolic resin and an isocyanate (MDI). Only the catalyst is different; here a tertiary amine is used, such as triethylamine (TEA), dimethylethylamine (DMEA), dimethylisopropylamine (DMIA) or dimethylpropylamine (DMPA). The amine is applied as a vapour, using compressed air, nitrogen or CO_2 as a carrier gas. Both resin and isocyanate are in solution in aromatic and/or polar solvents that have high boiling points. Contamination by water must be strictly avoided as it reacts strongly with isocyanate and weakens the binder.

The amine is delivered either by a generator, in which a supporting gas, preferably inert, is saturated with amine vapours, or by an injector, which measures out just the right amount of amine required for the operation, this latter being carried to the sand by compressed air or gaseous nitrogen. The addition rate for the binder varies from 1.0 to 2.0 % based on the sand weight, with resin and isocyanate in a 50:50 ratio.

The amine is just a catalyst and is not consumed in the reaction. After curing, it remains in the sand of the mould or core and has to be purged. The purging period currently lasts 10 to 15 times longer than the injection of the amine. The amount of amine required for curing is about 0.05 % based on the sand weight, but typically 0.10 to 0.15 % is used.

In a variant of the process called the ‘Cold-box Plus’ process the corebox is heated to 40 – 80 ºC using circulating hot water. This yields cores with even better mechanical properties, but results in higher interval times.
[110, Vito, 2001]

2.5.6.2.2 Resol – ester (alkaline phenolics methyl formate hardened)

This process is relatively new. Its advantages and disadvantages are similar to those of the cold-setting process from which it is derived. As its price is relatively high, the process is mostly used for core-making. Even though difficulties in recycling used sand have been reported, this process is widely used, mainly because of its shake-out properties; the ability to prevent cracking, veining and pinholes; and because of its low odour emissions. The process can be used for all types of series and alloys but is mainly used for light and super light alloys (easy shake-out) and steel (low crack risk).

The resin is an alkaline phenolic resol, which reacts with methyl formate to produce methanol and an alkaline formate. The phenolic resin is precipitated as a gel that binds all compounds together. Further cross-linking leads to even higher strength on storage.

Methyl formate is liquid at ambient temperature, the boiling point being 32 ºC, but it is gasified by air typically heated up to 80 ºC; which also acts as the carrier in the process. The gassing period is always followed by an air purge, the purpose of which is to evenly distribute the methyl formate throughout the mass of sand.

2.5.6.2.3 SO_2 hardened furan resins

This process is no longer in widespread use, although it is suitable for a large range of applications in the manufacturing of small to medium sized moulds and cores in any alloy. The sulphur catalyst may cause some metallurgical problems on the surface of ductile iron castings. The major advantages it provides are long lifetime of the prepared sand, good mechanical properties and shake-out performance, and the prevention of cracks. Nevertheless its effective implementation is limited due to the adhesive character of the resin and due to concerns in using sulphur dioxide as a hardener.

This process uses furan resins, which contain about 80 % furfuryl alcohol. Both resins polymerise under acid conditions. These resins need to be mixed with the sand and with oxidising agents, such as organic peroxides or hydrogen peroxide. The reaction between these peroxides and the injected sulphur dioxide then generates sulphuric acid, which causes a rapid polymerisation. The gassing period is always followed by a purging period, the purpose of which is to remove the excess unreacted sulphur dioxide from the mass of sand.
[32, CAEF, 1997], [174, Brown, 2000]

2.5.6.2.4 SO_2 hardened epoxy/acrylic (free radical curing)

This process offers many advantages: good compaction ability; long bench lifetime of the prepared sand (the mixers or shooting heads do not need to be cleaned); good mechanical properties; no nitrogen, phenol or formaldehyde; good shake-out performance; and no crack formation. However, the higher cost of binder constituents is one major disadvantage though.

This process is characterised not by the type of resin, but by the principle of its cross-linking, which occurs through free radicals. The resin must contain carbon double bonds: polyester - acrylic, polyester - urethane or polyester - epoxy resins may be used. These resins generally have a low molecular weight and are diluted with organic solvents at nearly 50 % by weight, though solvent free types are also available. They are mixed with an organic peroxide, which acts as a reaction initiator. For curing, sulphur dioxide is carried by an inert gas, such as carbon dioxide or nitrogen, through the sand.
The gassing period is always followed by purging with the same inert gas that was used for curing, the purpose of which is to remove the unreacted excess sulphuric dioxide from the sand mass.

2.5.6.2.5 CO_2 hardened sodium silicate (water glass)

This process presents real advantages: it is cheap, easy to handle and environmentally clean. Also for workers health and for reliability of operation, this technique has advantages over organic binders. Its use however, has declined in popularity due to technical reasons, such as poor compaction ability and problems with collapsibility, poor mechanical strength, sensitivity to crumbling, moisture pick-up and poor reclaimability. Furthermore, the use of water glass can lead to increased cleaning costs. The cores reach their full strength only after a drying period. This reduces their applicability in automated processes. The technique therefore finds its main application in small scale foundries.

The silicate generally used is sodium silicate, defined by its concentration (dry solid content) and modulus (silica soda ratio SiO_2/Na_2O). This modulus ranges from 2.0 to 2.8, the most common being 2.0 to 2.3. This silicate is mixed with the sand at a concentration of between 2 to 4 %. Shake-out and de-coring additives are commonly used and are usually pre-mixed with the silicate.

Curing occurs by gassing with carbon dioxide, due to its slightly acidic character. The CO_2-ratio should not exceed 1 to 2 % of the mass of sand, with a gassing time in the range of 10 to 60 seconds. The cured moulds and cores do not require purging.
[126, Teknologisk, 2000], [152, Notzon and Heil, 1998]

2.5.6.2.6 CO_2 hardened alkaline phenolic

This process was introduced for the first time in 1989 and has been undergoing improvements ever since. It is now commercially available and is in use in a few locations, but its use is not yet widespread.

The resin is an alkaline phenolic one, containing a linking substance stabilised at a high pH, approximately 14. Curing occurs by gassing with carbon dioxide, which dissolves in the water solvent of the resin, so lowering its pH and activating the linking substance.

2.5.6.3 Hot curing processes

In these processes, curing takes place by heating the sand-resin mix or, more often, by allowing it to come into contact with the heated pattern equipment. They all provide a high dimensional accuracy, which can only be achieved by means of using high quality (metal) patterns, which can be very expensive. For this reason, hot curing processes are used for the production of cores of limited size, mostly in mass production processes. Their use, very widespread for years, is now on the decline, as they are being replaced by gas cured processes.

Hot curing processes are characterised by major emission problems: when heated, the resins and catalysts emit noxious chemicals including ammonia and formaldehyde that can be the source of odour nuisance. A number of abatement techniques have been tried to solve these problems, such as scrubbing, combustion or biological abatement, but none of these has proven to be effective.

2.5.6.3.1 Hot-box, phenolic and/or furan based

This process can produce cores of a high dimensional accuracy and good mechanical strength, but to achieve these, the operators need a very good knowledge and control of the production process. The limits of the process are set by its cost, principally for the resin, energy and pattern equipment, and by the poor internal working conditions caused. It is currently used in the manufacturing of small or medium sized cores in mass production.

A resin binder and a heat activated catalyst are pre-mixed with sand and the mixture is blown into a heated corebox or pattern, where it is cured for approximately 5 to 60 seconds.

A wide range of resins may be employed, such as:

- urea - formaldehyde	UF
- urea - formaldehyde - furfuryl alcohol	UF - FA
- phenol - formaldehyde	PF
- phenol - formaldehyde - furfuryl alcohol	PF - FA
- urea - formaldehyde - phenol - formaldehyde	UF - PF
- urea - formaldehyde - phenol - formaldehyde - furfuryl alcohol	UF - PF – FA.

The catalysts are ammonium salts of mineral acids, sometimes with urea additions to reduce free formaldehyde. Additionally, other additives are used, such as silanes, iron oxides, preservatives and silicon oil.

The addition ratio for the resin varies from 1.2 to 3.0 % based on sand weight, with an average of about 1.8 %. The addition ratio for the catalyst varies from 10 to 25 % based on resin weight, with most formulations being optimised at 20 %. The temperature mostly used for the pattern ranges from 230 ºC to 290 ºC, with the optimum range being 220 ºC to 250 ºC. If excessive heat is used in an attempt to accelerate the curing time, the core surface can be burnt, producing brittleness during pouring.

2.5.6.3.2 Warm-box

This process is very similar to the hot-box process and uses the same production techniques. Only the type of resin differs, allowing curing at a lower temperature. However, this kind of resin is significantly more expensive than those in use in the hot-box process. Therefore the warm-box process, in spite of some real advantages, is not generally find widespread use.

The binder is furfuryl alcohol-based, with a typical composition containing around 70 % furfuryl alcohol or a low polymer of furfuryl alcohol. The catalysts are copper salts derived from aromatic sulphonic acids, in water or an alcohol solution. The distinctive feature of these catalysts is their excellent stability at ambient temperature and their relatively low dissociation temperature, which is 150 - 170 ºC. Accordingly, the tool temperature can be held at around 180 ºC, which leads to major energy savings of about 15 to 25 % compared to the hot-box.

2.5.6.3.3 Shell (Croning)

This process is the only one among all moulding and core-making processes that can use pre-coated sand, directly available from suppliers and ready for use, although pre-coating of the sand may also be performed at the foundry.

The sand is cured by heating it in a metallic pattern, producing a hardened surface layer. The unheated or uncured sand may be discarded by turning the pattern upside down and then re-used. The cured sand forms a "shell", which has given its name to the process.

This process gives high dimensional accuracy and a good surface finish to the castings, good shake-out and de-coring properties and allows a nearly unlimited storage time for the pre-coated sand. The process limits are the price of the pre-coated sand and the pattern equipment costs. Its use is restricted to the production of small or medium sized moulds and cores in mass production. Example cores and mould are shown in Figure 2.33.

Figure 2.33: Croning cores (top) and moulds (bottom)
[237, HUT, 2003]

The resin used for pre-coating is a phenolic "novolac", with a formaldehyde/phenol ratio lower than 1. Hexamethylenetetramine is added to the resin as a hardener. 'Hexa' decomposes at 160 ºC into its 2 basic components: formaldehyde and ammonia. When pre-coated sand contacts the heated pattern, the hexamethylenetetramine decomposes and the formaldehyde cross-links the resin binder to form the characteristic strong bond.

2.5.6.3.4 Linseed oil

This ancient process is probably the oldest one processing chemically-bonded sands. It is very easy to use, does not need sophisticated patterns and has a good resistance to veining and cracking. It is still in widespread use for specialised small cores.

These sands are bonded with a mixture of drying oils, these usually being to a great extent linseed oil, often with an addition of dextrin and a few per cent water. The addition rate of oil varies from 0.8 to 4 %, based on sand weight. Drying agents may also be added. Curing occurs by cross-linking of the unsaturated fatty acids contained in the drying oils, induced by atmospheric oxygen and accelerated by heating in a drying-oven at a temperature between of 190 and 260 ºC for 1 to 2 hours.

2.5.6.3.5 Alkyd oil, baked

This process is similar to the previously described unbaked alkyd oil process, the only difference being in this case heat treatment of the parts in order to accelerate the curing.

2.5.6.4 Coating of chemically-bonded sand moulds and cores

The skill of the founder is to produce high quality castings, without defects, and requiring only minimal finishing and repair. To achieve this, the ideal is to minimise all the interactions that may occur between mould, core and metal during pouring. These effects may be generated by different causes, such as sand expansion, ramming defects, abrasion of sand, metal penetration, chemical decomposition or by interaction between the binders, etc.

For these reasons, it is often beneficial to coat the mould or the core with a refractory lining, in order to give a smooth surface finish to the casting and to reduce fettling cost.

2.5.6.4.1 Composition of coatings

Coatings are available as ready-to-use products or as a mass to dilute with water or alcohol. They usually contain the following components:

- one or more refractory fillings, such as talc, pyrophyllite, mica, zircon, magnesite, quartz, etc., or blacking
- a make-up liquid, which may be an alcohol (e.g. isopropanol, ethanol) or water
- high temperature bonding agents, such as bentonites, resins, boric acid
- rheological agents, such as bentonites or synthetic polymers
- additives, such as surfactants, foam breakers, fungicides, etc.

2.5.6.4.2 Coating process

The coating may be applied on the mould or on the core by different means:

- by brushing, for small cores or for localised application
- by dipping, for complex shaped cores; this process often being automated
- by spraying, usually airless
- by flow-coating, for large or medium sized moulds or cores.

If alcohol-based coatings are applied, the working area needs to be ventilated in order to prevent the danger of fire or explosion. The coated moulds and cores are mostly burnt out, which limits the emissions. If they are not burnt out then drying is carried out under exhaust with the VOC emissions maintained under control. Flow coating with alcohol-based coatings and subsequent firing or drying is presented in Figure 2.34.

Figure 2.34: Flow coating with alcohol-based coating, followed by firing or drying [237, HUT, 2003]

The drying of water-based coatings occurs by heating in a drying furnace using hot air, infrared or microwaves. The dip-coating of cores and subsequent hot air drying is presented in Figure 2.35. Water-based coatings do not generate emission problems, neither during coating nor during drying. For these reasons, water coatings are now increasingly replacing alcohol-based

ones. However, their application faces technical constraints in terms of the coating quality continuity and drying constraints. A full discussion of water-based versus alcohol-based coatings is provided in Section 4.3.3.5.
[143, Inasmet and CTIF, 2002]

Figure 2.35: Dip-coating with water-based coatings, followed by drying in a hot-air furnace [237, HUT, 2003]

2.5.7 Expendable pattern casting

In expendable pattern casting, the pattern is not removed from the mould before pouring. The pattern, which is made of expanded material, is a single-use one, which is destroyed when poured. These expandable patterns may be embedded either in chemically-bonded sands or in binderless sand, hardened by vibration.

This process, commonly called "Lost Foam casting", was developed 30 years ago and its commercial growth was initially rather slow. However, during the last 10 to 15 years, it is has become used more often, primarily for the mass production of automotive parts or similar products, in spite of significant set-up difficulties.

2.5.7.1 Unbonded sand – Lost Foam process

The Lost Foam process (Figure 2.36) starts with the 3D-CAD design and production of a precision moulded foam pattern, made from expanded polystyrene (EPS) or PMMA, produced by automated injection moulding machines. These patterns can be made from one piece or by assembling a number of parts by adhesives. Here usually, a number of patterns, dependent on size, are fixed to a runner-down gating system, made from the same material as the pattern, thereby generating a cluster.

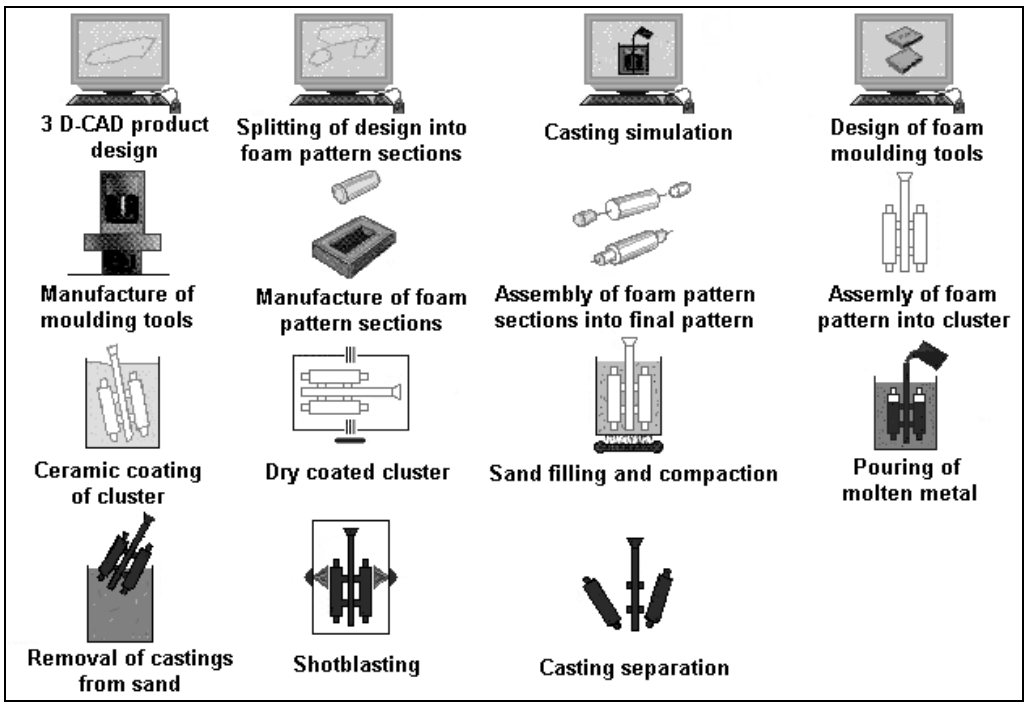

Figure 2.36: The Lost Foam process
[110, Vito, 2001]

The clusters are dipped in a water-based refractory type coating, which creates a barrier between the molten metal and the sand during pouring. After drying, the cluster is positioned in a moulding flask, which is filled with unbonded sand. A low-viscosity resin may be added to the sand, in order to prevent deformation during compaction. The sand is compacted by triaxial vibration around the patterns, penetrating the holes and reproducing exactly all the details, thus making the core and core-making equipment unnecessary. Upon pouring, the molten metal causes a pyrolysis of the polystyrene and fills the emptied space.

The sand, mostly quartz, needs to be very permeable, in order to ensure the evacuation of the pyrolysis gases. Sand with an AFS-number of 35 – 50 is used. Interruption of the pouring may cause a collapse of the sand mould. Therefore an automatic casting system is often used.

The cast pieces are characterised by a very good dimensional precision, as shown in Figure 2.37. The technique can be used for any type of alloy and is used for medium to large sized series production. The process is environmentally friendly during the moulding but produces gaseous emissions during pouring and shake-out, due to the vaporisation of the expendable patterns. Lost Foam casting enables metal casters to produce complex parts which would often not be possible using other methods. The process allows designers to develop more complex shapes, to reduce machining need and to minimise assembly operations. Proper controls must be exercised in each step of the process to ensure consistent high quality castings. A lack of in-depth industry-wide knowledge on how to set up proper control measures has slowed adoption of the Lost Foam casting process.
[32, CAEF, 1997], [110, Vito, 2001], [144, US Dept. of Energy, 1998]

Figure 2.37: Expendable polystyrene pattern (r.) for the Lost Foam process and an example of a casting produced by the Lost Foam method (l.)
[237, HUT, 2003]

2.5.7.2 Chemically-bonded sand – Full mould process

The Lost Foam process can also be used to produce single-piece prototypes, thereby permitting a shortening of the delivery time. Furthermore the technique can be applied for the production of very big pieces, such as bases for metal processing machines, or presses, etc. in cast iron, steel or non-ferrous alloys. The wall thickness may range from 5 mm up to 1000 mm. Pieces of up to 50 tonnes have been cast using this technique. For the production of these bigger pieces, the application of a (furan) binder is needed in order to attain the necessary mould strength.

The Lost Foam process with chemically-bonded sand, in this case also called the ‘full mould process’, is mostly used for producing middle or large sized castings, in single production or in small batch series.

The patterns are made from low density expanded materials, such as:
- white, foamed polystyrene, with a density of 16 to 20 g/dm^3
- blue, foamed polystyrene, also called "poresta-blue", with a density of 18 to 22 g/dm^3
- foamed polymethylmetacrylate, also called PMMA, with a density of 25 g/dm^3.

These materials are cut out as various parts, which are then assembled and stuck together with hot melt glue, thus creating the final shape of the casting, also taking into consideration any possible shrinkage of the metal.

The assembled pattern, with its gating and feeding system, has to be coated, mostly with a water-based coating system, and thoroughly dried before being embedded in the sand. The binding process of the sand has to be specially selected in order to avoid any moisture pick-up by the pattern before pouring.

This process, as far as moulding is concerned, is very environmentally friendly, but produces gaseous emissions during pouring and shake-out, due to the vaporisation of the expandable patterns and destruction of the sand binder.

As with the unbounded process, uninterrupted casting is very important in order to prevent the mould form collapsing. For the casting of big pieces, pouring is performed using two (or more) pouring ladles and two (or more) entry holes simultaneously.

The full mould process has the following advantages:
- high size precision
- production of complex geometries, especially internal cavities
- integration of several parts into one casted piece
- reduction or exclusion of release edges
- possibility of thermal sand regeneration.

Despite the fact that the Lost Foam and full mould techniques have been known for a long time, they are not widely applied in Europe. This is primarily because their optimisation requires a lot of research and development. The main difficulties are:

- definition of the product range: determining which pieces can be made more easily as compared to traditional methods
- selection of the compaction technique: application of the sand in order to perfectly fill all cavities
- choice of coating and sand type: these should have a sufficient gas permeability to allow the combustion gases to escape.

[110, Vito, 2001]

2.5.8 Permanent (metal) moulds preparation

Permanent moulds are made from metallic elements adapted to the shape of the casting, whose assembly allows the moulding, pouring and stripping of the casting. These metal moulds are used for gravitational casting, high pressure die-casting, centrifugal casting, continuous casting and for low pressure casting. Unlike sand moulds, they can be re-used many times and for this reason, they are called permanent moulds.

If the shape of the casting cannot be easily made by the use of metallic core pins, sand cores may be used. For instance, sand cores are used to form the widening-out of centrifugal cast pipes.

Permanent moulds are generally coated with a "white or black wash"; these water-based release agents are refractory based in the case of the white one and graphite based for the black one. Their function is to provide protection of the die, to regulate die cooling by water evaporation, and to provide lubrication. They also act as parting compounds.

In a few cases, blackening is provided by burning acetylene in the absence of air, producing acetylene black that partially sticks to the die. The non-adhesive black then has to be collected and filtered before emission.

Permanent moulds (or dies) are generally not made in the foundry, although die-casting foundries do have a workshop for die assembly, maintenance and repair. This type of operation, however, does not generate any environmental effects.

2.5.9 Investment casting and ceramic shell

This process is used to produce intricate, thin section parts with high dimensional accuracy, fine details, and very smooth surfaces.

The process steps are depicted in Figure 2.38. They begin with the manufacture of expendable wax patterns, by injecting molten wax into an aluminium or epoxy die to form a pattern that is virtually an exact replica of the desired casting. The wax may contain fillers. For smaller castings, several wax patterns are attached to a wax gating system. Water soluble die release agents are used to facilitate the wax model take-out.

The wax patterns are cleaned with water or organic solvent and coated with a wetting agent, which helps the ceramic slurry to adhere to the wax. The cluster is then dipped in a liquid ceramic slurry, stuccoed with granular silica, zircon or alumina/silica refractories and then dried before the application of the next coat. The coating process is continued until a sufficiently thick shell is established.

The dried mould is then de-waxed by inserting it into a steam autoclave in which the wax patterns are melted out, or into a "flash-furnace", in which the wax may be partially burnt out.

After this, the shell is fired in a furnace at a high temperature. This burns out the residual wax and hardens the ceramic, leaving a one piece ceramic shell mould, into which the molten metal is poured to form the casting.

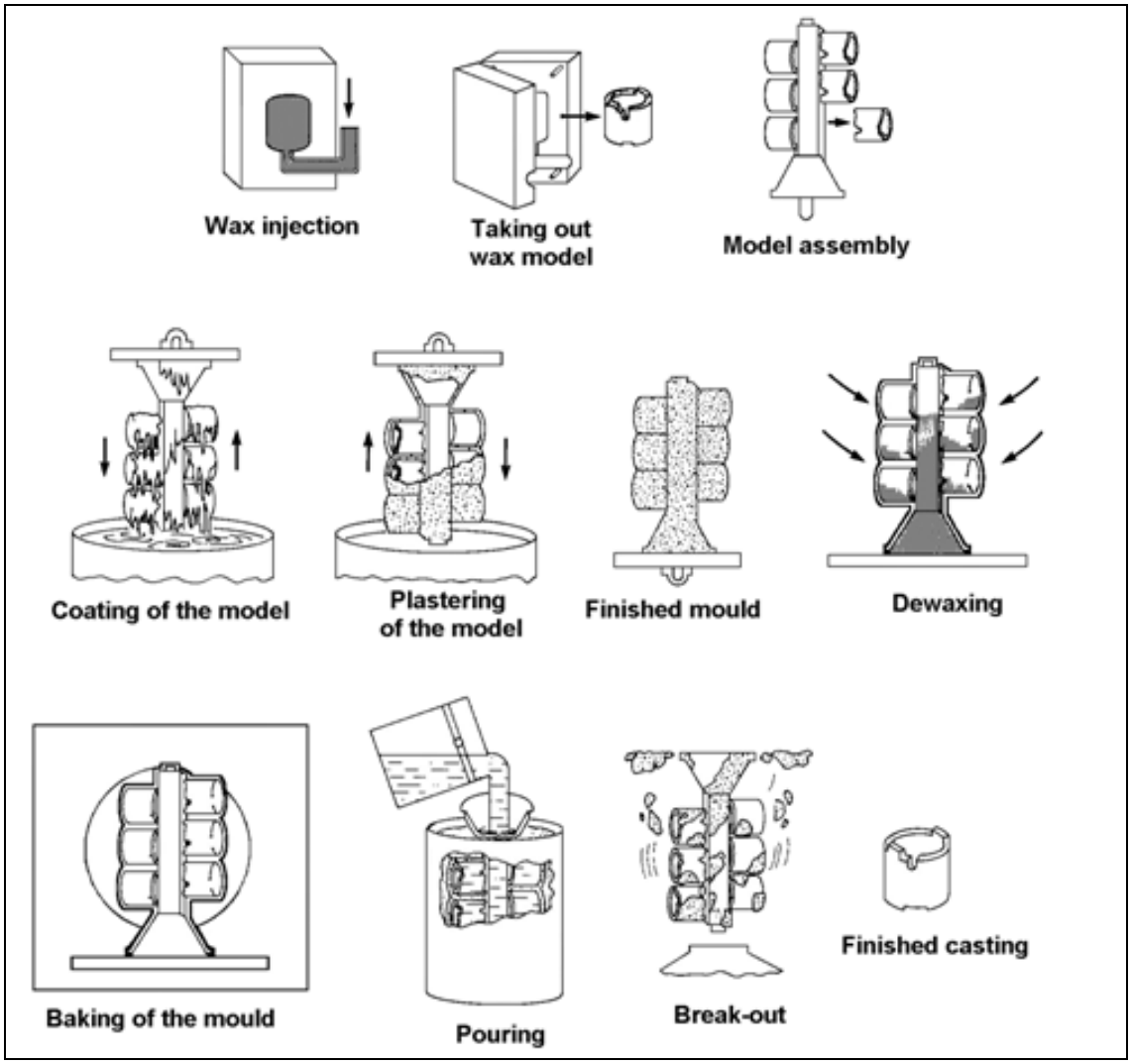

Figure 2.38: Investment casting process
[110, Vito, 2001]

In this process, air pollution may occur during two operations: investing and de-waxing.

Investing:
The liquid ceramic slurry consists of a binder and a very fine refractory powder, reduced to slime by permanent mixing. The binder may be colloidal silica, hydrolysed ethyl silicate or hydrolysed sodium silicate, the choice of the technology applied being determined by technical reasons. When using ethyl silicate, drying is faster, which allows a higher cycle rate, but ethyl alcohol vapours are emitted. These vapours, if present in too large an amount, have to be collected and treated before emission.

De-waxing and firing:
De-waxing by means of a steam autoclave does not produce any significant impact on air. However, this is not the case if the de-waxing is conducted in a firing oven, and during the firing of the shell, where wax residues are burned.

This burning occurs often in a lack of air, which results in the formation of carbon black particles. These particles have to be collected and either destroyed by afterburning or removed. Ceramic filters have been successfully used for this purpose, as they suit the high temperature of the exhaust gases, but this very recent technology has not yet become widespread.

This technique is used e.g. for precision casting and art casting. It is generally not applied in large-scale foundries (>20 tonnes/day capacity), and therefore is mentioned here only for informative reasons.

The ceramic shell process (patented as Replicast®) extends the quality and precision of investment casting to larger components, using a combination of Lost Foam and investment casting principles. The technique uses an inert, fired ceramic mould. To create the mould, an expanded polystyrene replica of the required component is produced, which is dimensionally precise and of a high surface finish. No parting lines or cores are required, nor draft angles, and polystyrene replicas can be glued together to create complex geometries. The polystyrene is burnt out before casting, allowing a wide range of alloys to be cast in the mould - from ultra low carbon stainless steel to nickel based alloys. This is in contrast to the Lost Foam process where liquid metal consumes and replaces the polystyrene pattern, making it unsuitable for the vast majority of steel components (polystyrene is 92 % by weight carbon).
[219, Castings Technology International, 2003]

2.6 Casting

Pouring is the central activity in casting production. The finished mould is filled with the liquid metal under the effects of gravitational or centrifugal forces or pressure. After pouring the casting is cooled to allow solidification and is then removed from the mould for further cooling and treatment.
[32, CAEF, 1997]

2.6.1 Casting in lost moulds

2.6.1.1 Pouring

There are two types of ladle generally used in pouring liquid metal: lip and teapot ladles. A third type (i.e. the bottom ladle) is more specific to steel.

- *Lip pour*: In this type of ladle (Figure 2.39) the metal is charged over the lip, with the flow controlled by tilting the ladle using a geared handwheel. Since the metal flows from the top of the ladle, the metal surface must be slag-free or a skimmer must be used to prevent slag entering the mould. Lip pour ladles are used for pouring small steel castings

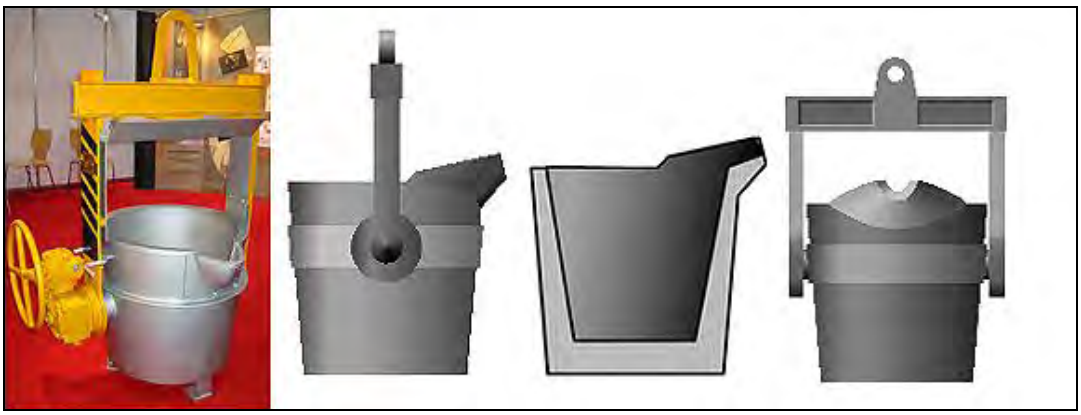

Figure 2.39: Lip pour ladle for molten metal pouring
[237, HUT, 2003]

- *Teapot ladles*: As depicted in Figure 2.40, a refractory dam before the ladle lip ensures that the metal is drawn from the bottom of the ladle, so that the stream is slag free. The molten metal is generally cleaner than from a lip pour ladle. One disadvantage is that the narrow spout may occasionally permit the liquid steel to freeze if the heat is tapped cold or if pouring is prolonged

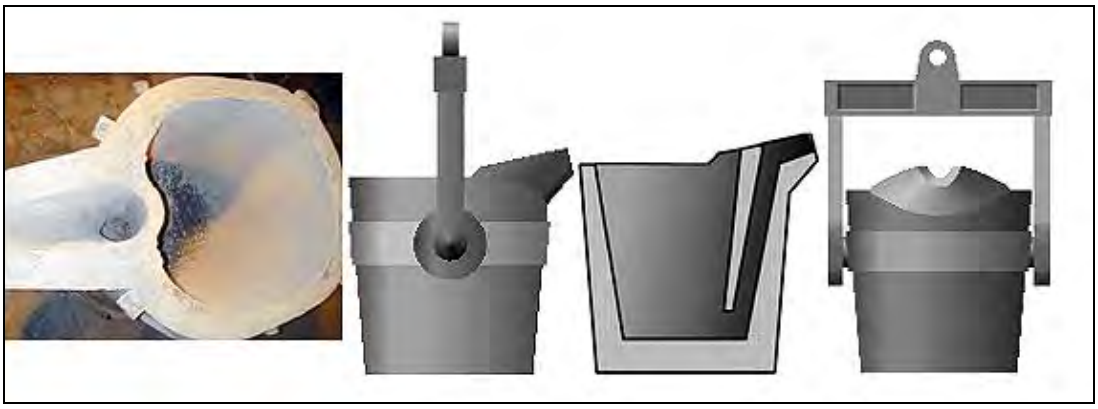

Figure 2.40: Teapot ladle for molten metal pouring
[237, HUT, 2003]

- *Bottom pour ladles*: The ladle is fitted with a pouring nozzle in its base, closed by a refractory stopper rod. The metal is drawn from the bottom and is therefore slag-free and non-metallics, such as deoxidation products, are able to float out of the melt. The metal stream flows downwards, so that there is no movement of the stream during pouring. The disadvantage is that the velocity and the rate of flow change during pouring as the ferrostatic head changes.

Figure 2.41: Bottom pour ladle for molten metal pouring
[237, HUT, 2003]

Automatic casting lines are often equipped with a pouring furnace. The working principle behind one example furnace is depicted in Figure 2.42. The casting line halts when a mould is in the correct position, i.e. under the pouring exit. Metal is poured during a fixed period by elevating a stopper. Because the metal level in the casting recipient is held constant, a fixed volume of molten metal is poured into the mould. The metal level in the furnace is controlled by a floating device, which controls the gas pressure inside the furnace. The casting furnace is refilled with metal from the melting furnace at fixed time intervals.
[110, Vito, 2001], [174, Brown, 2000]

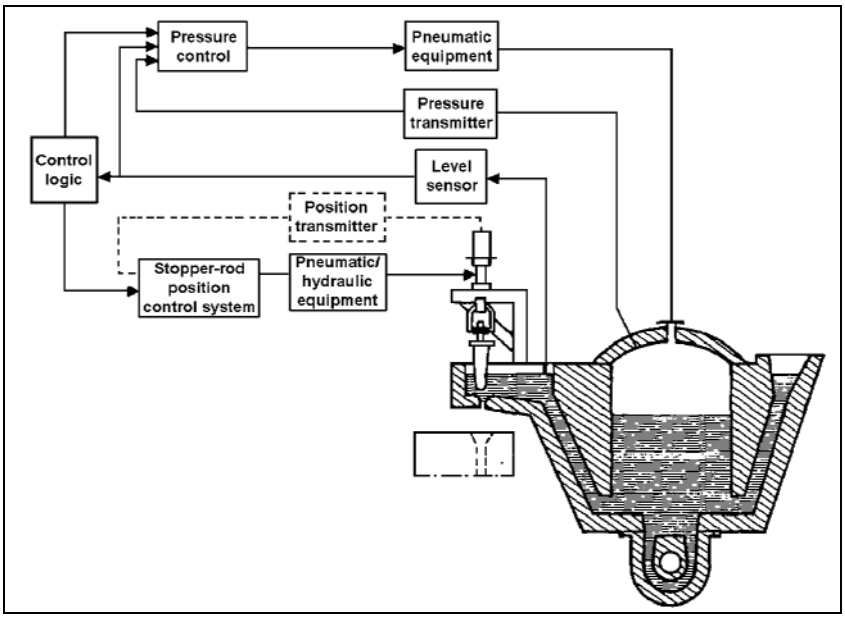

Figure 2.42: Pouring furnace
[110, Vito, 2001]

2.6.1.2 Solidification (1st cooling)

The poured moulds are transported along the moulding line onto the cooling lines. The length of the cooling line determines the final temperature of the casting at the point of shake-out. This temperature must be low enough to provide the casting with sufficient strength during shake-out and further manipulation.

Big moulds are not moved during cooling. The cooling time can be up to several days.
[110, Vito, 2001]

2.6.1.3 Shake-out

In the case of individual moulding, clay or chemically bonded moulds can usually be destroyed by vibration. In most cases this is accomplished by placing the moulding box on a vibrating grate, using a crane to do this. As a result of the vibration, the sand is separated from the casting and the moulding box. The casting and moulding box remain on the grate rods, whereas the sand falls through and is subsequently reprocessed. The casting is usually transported to a cooling area for further cooling in ambient air (second cooling).

A similar shake-out procedure is often carried out in mechanised systems and older low-capacity automated systems (Figure 2.43). Here the moulding boxes are removed from conveyor belts, by means of hoists or other transfer equipment, and placed on vibrators. Finally, the castings are left to cool down or placed in a casting cooling device. In many systems, the sand casting is pressed out of the moulding box and a subsequent controlled cooling of the castings and sand is achieved in combined or separate cooling devices, such as in cooling drums, swing pipes, chain conveyors, fluidised bed coolers, etc.

Figure 2.43: Shake-out at the end of an automated moulding line
[237, HUT, 2003]

Vacuum bonded sand moulds are destroyed by releasing the vacuum. The casting bucket or moulding box, containing the loose sand and the casting, is emptied and then the casting is cooled by one of the described methods.
[32, CAEF, 1997]

2.6.1.4 Casting cooling (2nd cooling)

The controlled cooling of castings and sand is carried out in rotary drums, swing drums or on oscillating conveyor troughs. The casting is cooled in oscillating conveyors or in cable-car baskets. In many cases an airflow, which is often directed in the opposite direction to that of the casting, is used for cooling. In some cases, fine water jets are used in order to increase the cooling effect.

2.6.2 Casting in permanent moulds

2.6.2.1 Gravity and low-pressure die-casting

Gravity and low-pressure die-casting make use of a permanent steel die into which the melt is poured under the influence of gravity or a low-pressure gas. Sand cores can be used to form undercuts and complex interior shapes in the casting. Due to the rapid solidification process, permanent mould castings have a dense fine-grained structure with good strength characteristics.

The principle of low-pressure die-casting is shown in Figure 2.44. A metal die is mounted above a sealed furnace containing molten metal. A refractory-lined riser tube extends from the bottom of the die into the molten metal. When air is introduced into the furnace under low pressure (15 – 100 kPa) the molten metal rises up the tube to flow into a die cavity with low turbulence, the air in the die escaping through vents and the parting lines of the die. When the metal has solidified, the air pressure is released, allowing the still-molten metal in the riser tube to fall back into the furnace. After a further cooling time, the die is opened and the casting extracted. Due to the absence of feeders and risers, the casting yield is exceptionally high, generally over 90 %. A good dimensional accuracy and surface finish are possible and complex castings can be made using sand cores. This technique is typically used for aluminium castings, e.g. automotive parts such as wheels, cylinder heads, and electric motor housings, and for domestic kitchenware. The die must be coated to optimise the casting release and cooling. In general, a die coating is applied once per shift. The die life is normally around 30000 – 50000 shots. An example of a low-presure die-casting machine is given in Figure 2.45.

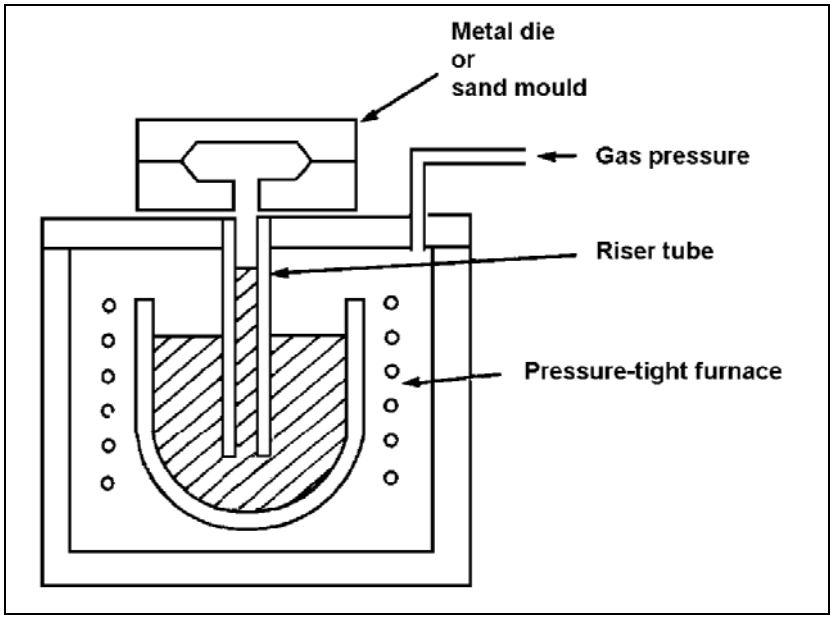

Figure 2.44: The principle of a low-pressure die-casting machine
[175, Brown, 1999]

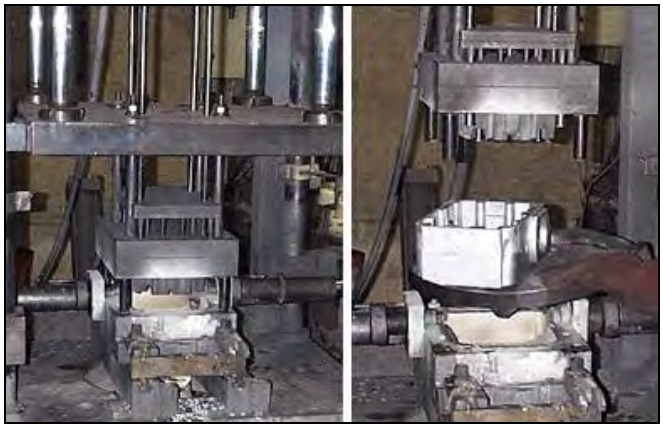

Figure 2.45: Low-pressure die-casting machine
[237, HUT, 2003]

In gravity die-casting, the molten metal is poured under gravity into a permanent mould or die. Gravity die-casting machines range from simple, hand operated rack and pinion die sets, manually poured, to carousel machines, which usually have a tilting mechanism for filling the

die and which are often operated using a pouring robot. The dies are coated with a refractory-based coating, controll the cooling rate. The time before the casting can be extracted from the die varies from 4 to 10 minutes depending on the type of casting. The process is therefore relatively slow, compared to pressure die-casting. To achieve reasonable output rates, a manual operator will operate 2 – 4 die sets in sequence, allowing an output of 30 – 60 castings an hour. Automatic carousel machines may have 4 – 6 stations with multiple die sets, allowing production rates of around 1 casting per minute to be achieved. The process is most widely used in aluminium casting for series' of 1000 to more than 100000 pieces per year for e.g. manifolds, cylinder heads, water pumps.

Permanent mould coatings are typically formulated using water as a carrier, a high temperature binder (normally sodium silicate) and a refractory filler or blend of fillers. There are two categories of coatings:

- insulating: containing blends of insulating minerals such as talc, mica, kieselguhr, titanium dioxide, alumina, etc.
- lubricating: based on colloidal graphite or boron nitride to aid release of the casting.

Coatings are generally sprayed onto the die. Careful attention to die preparation, coating preparation and application and the type of coating equipment utilised can yield significant quality and productivity benefits.
[175, Brown, 1999]

2.6.2.2 High-pressure die-casting

The term "die-casting" often implies "high-pressure die-casting". The process utilises a permanent die (metal mould) into which molten metal is forced under high pressure. The application of high pressure causes a high and turbulent metal flow, which allows the production of castings with high surface areas and low wall thicknesses. Dies are usually made from two blocks of steel, each containing part of the cavity, which are locked together while the casting is made. Due to the high metal pressure, the maximum size of the casting is limited by the maximum locking force of the casting halves. Retractable and removable cores are used to form internal surfaces. Due to the high metal pressures, only metal cores can be used. This limits the complexity of the casted piece. The metal is held under pressure until it cools and solidifies. The die halves are then opened and the casting is removed, usually by means of an automatic ejection system. Dies are preheated and lubricated before being used, and are either air- or water-cooled to maintain the desired operating temperature. Two basic types of high-pressure die-casting (HPDC) machines are used: hot-chamber or cold-chamber (see Figure 2.46).

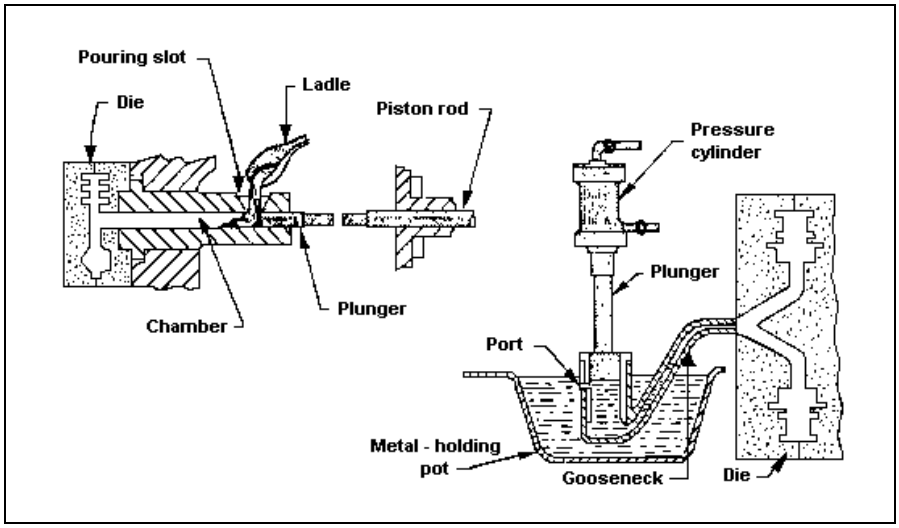

Figure 2.46: Cold-chamber and hot-chamber high-pressure die-casting devices [42, US EPA, 1998]

Hot-chamber HPDC machines comprise a molten metal reservoir, the die, and a metal-transferring device, which automatically withdraws molten metal from the reservoir and forces it under pressure into the die. A steel piston and a cylinder system with a gooseneck is used to create the necessary pressure within the die. A gooseneck machine utilises a cast iron channel to transfer the molten metal from the reservoir to the die. Pressures can range from a few bar to over 350 bar. Hot-chamber techniques are mainly used for zinc alloys and magnesium alloys.

Cold-chamber HPDC machines have molten metal reservoirs separate from the casting machine. Just enough metal for one casting is ladled by hand, or mechanically, into a small chamber, from which it is forced into the die under high pressure. Pressure is produced through a hydraulic system connected to a piston, and is typically in the range of a few hundred bar to 700 bar. In cold chamber machines, the metal is just above the melting point and is in a slush-like state. Since the metal is in contact with the piston and cylinder for only a short period of time, the process is mainly applicable to aluminium alloys, and to a lesser extent magnesium alloys, zinc alloys, and even high melting point alloys such as brasses and bronzes.

Proper lubrication of the dies and plungers is essential for successful high-pressure die-casting. The die lubrication affects the casting quality, density, and surface finish, the ease of cavity fill, and the ease of casting ejection. Proper lubrication can also speed up the casting rate, reduce maintenance requirements, and reduce the build up of material on the die face. Although specific formulations are proprietary, in general, lubricants (also called release agents) are a mixture of a lubricant and a carrier material. Formulations may also include additives to inhibit corrosion, to increase stability during storage, and to resist bacterial degradation. Lubricating materials are typically mineral oils and waxes in water emulsions. Silicone oils and synthetic waxes are finding increased use. Both water-based lubricants and solvent-based lubricants are in use today. Water-based lubricants however dominate the market (95 %). The lubricant is applied to the open die by spraying, between each shot. Dilute solutions of lubricant are used (1:20 – 1:200 release agent:water ratio). Alternative electrostatic powder coatings are currently being developed.

High-pressure die-casting is not applicable to steel and high melting point alloys. The technique finds widespread application for aluminium castings. Dies are expensive but can have a life of 150000 shots. The process is therefore most suitable for long runs of castings. One major advantage of HPDC over other casting methods is that the castings produced can have very complex shapes. The ability to cast complex shapes often makes it possible to manufacture a product from a single casting instead of from an assembly of cast components. This can greatly reduce casting costs, as well as the costs associated with fabrication and machining. Furthermore, HPDC produces castings which have a high degree of dimensional accuracy and surface definition compared to other casting methods, which may help to reduce or eliminate costly machining steps. Finally, castings with relatively thin wall sections can be produced using the HPDC method. This can result in substantial savings in material costs and reductions in component weight.

Relatively little waste is generated in the actual HPDC process compared to other metal casting processes. However, some gaseous and fume emissions occur during metal injection. Metal oxide fumes are generated as some of the metal vaporises and condenses. Gaseous emissions can originate from: the molten metal itself; the evolution of chemicals from the lubricant as it is sprayed onto the hot metal die and as it contacts the molten metal. Emissions to water may occur from any leakage or spillage of hydraulic oil or heating oil and from cooling water.
[42, US EPA, 1998], [128, IHOBE, 1998], [175, Brown, 1999], [225, TWG, 2003]

2.6.2.3 Centrifugal casting

In centrifugal casting, a permanent mould rotates at high speed around its axis as the metal is poured. The speed of rotation and the metal pouring rate vary with the alloy and the size and shape being cast. The rotating axis is generally horizontal or under a small angle (Figure 2.47). Some specific devices apply rotation around a vertical axis. The resulting material has a very dense structure and properties that cannot be obtained with sand casting.

This technique is used to produce cylindrical products in cast iron, steel, and in alloys of aluminium, copper and nickel. Typical parts made by this process are pipes, boilers, pressure vessels, flywheels, cylinder liners and other parts that are axisymmetric.
[179, Hoppenstedt, 2002]

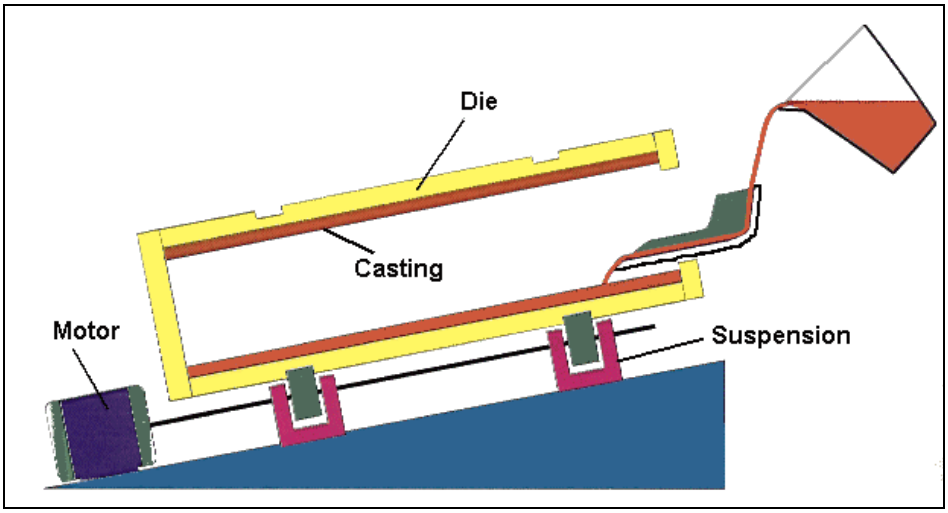

Figure 2.47: Schematic representation of a centrifugal casting machine [179, Hoppenstedt, 2002]

2.6.2.4 Continuous casting

Continuous casting is a high productivity device for the production of bars, tubes and profiles, where through rapid cooling, a fine-grained material with good mechanical properties is obtained. In continuous casting, the molten metal is cast into a water-cooled die, which is open at the bottom or at the side (Figure 2.48). The die gives the desired form to the product. Through intensive cooling, the outside of the metal product solidifies, while it is slowly pulled out of the mould. Through continuous pouring and extraction as the product is pulled out of the mould, the product gets longer. A burner cuts the product whenever the desired product length is reached. This technique is used for both ferrous and non-ferrous casting. The technique is used for the casting of bars, slabs and sheets as a final step in iron, steel and non-ferrous metals production. Its use in this context is described in the BREF for non-ferrous metal industries [155, European IPPC Bureau, 2001] and the BREF on iron and steel production [211, European IPPC Bureau, 2000].

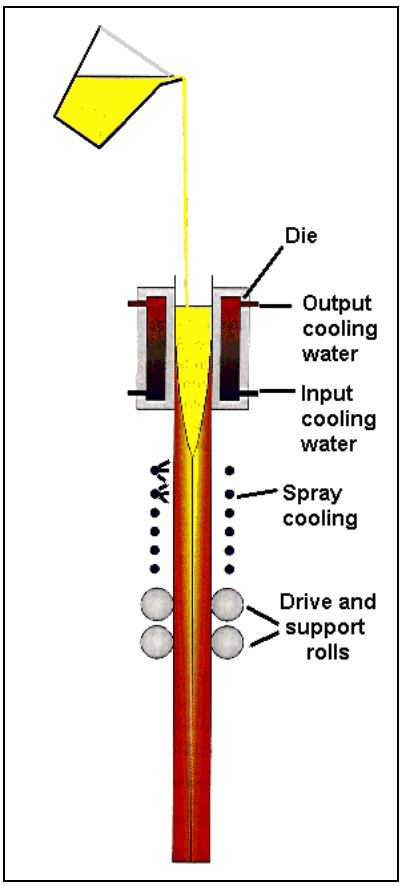

Figure 2.48: Schematic representation of a thread casting machine used for continuous casting [179, Hoppenstedt, 2002]

2.7 Finishing and post casting operations

Finishing of the raw castings encompasses all necessary treatments to yield a finished product. According to the process, various steps may be required, such as:

- removal of the running system
- removal of residual moulding-sand from the surface and core remains in the casting cavities
- removal of pouring burrs
- repair of casting errors
- preparation of the casting for mechanical post-treatment, assembly, thermal treatment, coating, …

In some cases, foundries also perform assembly, surface finishing and coating of the castings. However, these activities are not discussed in this document. Surface finishing and coating techniques are discussed in the BREF documents on Surface Treatment of Metals (STM BREF) and on Surface Treatment Using Solvents (STS BREF).
[110, Vito, 2001], [225, TWG, 2003]

2.7.1 Removal of the running system

In the finishing of the raw castings and to remove the running system (see Figure 2.49), the following operations take place:

- *Beating, pressing*: In the case of brittle materials such as grey cast iron castings and white malleable cast iron, chamfers and feeders can generally be knocked off. Hydraulic equipment is increasingly being used for this task
- *Grinding with grinding wheels:* These can be handheld, semi-automatic or automatic
- *Cutting*: For the removal of massive pieces in carbon steel or low alloy steel, an oxygen-acetylene cutter is used. For cast iron or high alloy steel, oxygen-acetylene-powder or oxygen-LPG-powder cutters are used
- *Sawing*: Materials which are sensitive to heat, such as aluminium alloys, are usually sawed.

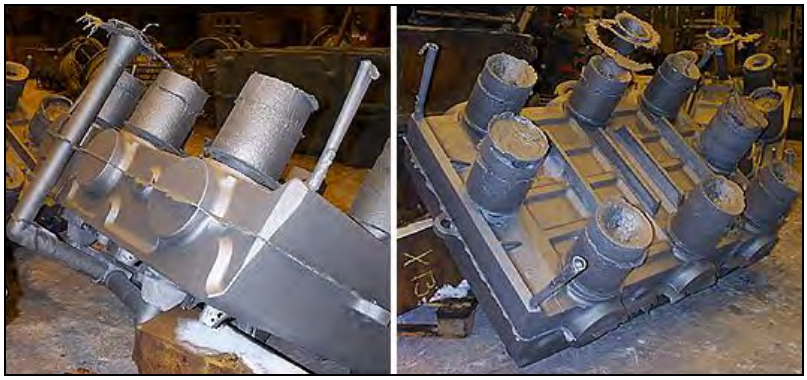

Figure 2.49: Casting with running and gating system
[237, HUT, 2003]

Through good design of the connection points, the feeding system may even get broken–off during shake-out. This is mainly possible for grey iron.
[32, CAEF, 1997], [202, TWG, 2002]

2.7.2 Sand removal

Removal of the sand is performed in blasting cabins. The blasting medium is adapted to the material to be treated and varies from blasting grit to glass beads. The cleaning of model plates and permanent moulds is done with glass beads, aluminium beads or CO_2 ice grains. An example of castings before and after blasting is shown in Figure 2.50.

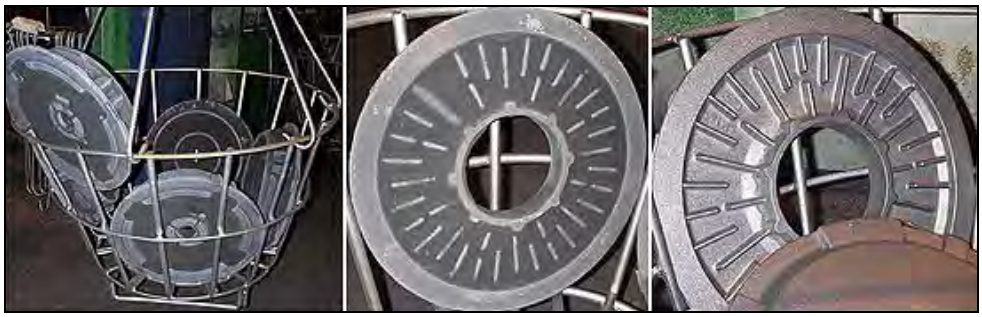

Figure 2.50: Castings before (l., m.) and after (r.) sand removal by blasting
[237, HUT, 2003]

Various blasting techniques exist. The acceleration of the grit is done with compressed air or turbine blades. The treatment is carried out in a closed room, with rubber-sealed doors.

The castings are suspended on a monorail and move batch wise through the blasting cabin. For smaller pieces, a specific moving belt is used. Big pieces are blasted manually, using a lance in an enclosed cabin. In this case, personal safety measures are very important. A helmet with a dust mask and respiratory equipment are required.

The coarse dust (sand and metal flakes) that is generated by blasting of the workpiece, is collected together with the grit. It is dedusted, magnetically separated and sieved. The fine fraction is removed from the exhaust air together with the coarse fraction, using a bag filter. Cleaning of the grit before internal re-use is of major importance as the presence of sand could cause a quick wearing of the throwing shovels.

2.7.3 Removal of burrs

Burrs, which occur at the point where mould and core pieces join, at veins and at other surface irregularities, are removed using grinding wheels and grinding stones. Grinding wheels are handheld, whilst with grinding stones the casting is pressed against a rotating stone.

Other applied techniques include:

- *Slide grinding*: Grinding burrs and small amounts of other excess material on the casting surface can be removed without hand grinding. The parts are revolved in drums or vibrating containers together with abrasive shapes, causing them to be rubbed against each other and against the abrasive wheels. In a typical unit the castings are ground using a bed of pyramidal grinding stones, together with the addition of a water-soap emulsion. The roughness and the size of the grinding stones vary depending on the size of the castings
- *Tumbling*: This technique, also called blast removal, is used to remove thin burrs or small amounts of casting residue. During this process the burrs remove themselves in an airless blast cleaning process as a result of the parts being impacted together in a rotating drum. At the same time the edges are rounded-off. Sometimes the process is assisted by a liquid.

Figure 2.51: Burrs (l.) and their removal using a grinding stone (m.) and slide grinding (r.) [237, HUT, 2003]

Automation of these operations is difficult due to the variability in shape of the burrs and the need to fix the casting easily and quickly. Nevertheless, automatic grinding machines are increasingly being used in serial production. Raw casting parts are inserted into such machines to produce suitably worked parts which do not need any retooling or further manual grinding work.

Furthermore the following techniques are applied in automated lines:

- *Punching*: Due to the use of cutting and forming techniques, serial casting parts are often designed in such a way that the unavoidable burr occurs in predetermined amounts which are easily accessible as far as processing is concerned. If the series is large enough, dedicated punching tools can be designed to quickly remove the burr and to provide the casting with a uniform contour

- *Milling*: With the development of electronic controls for processing machines it has become increasingly easier to compile programs with which to process individual workpieces. Thus it is possible to use milling machines for smaller series instead of the punching machines with their single purpose tools. During such a process, the workpieces are taken up by the device and passed across a number of different milling machines.

Finally, welding may be carried out in order to join castings, as well as to manufacture and repair casting flaws. In most of these cases, arc welding is used. Depending on the requirements and equipment, the work is carried out either with hand operated stick electrodes or with welding wire and with or without inert gas. Scarfing is used on steel castings, which consists in applying grooves for stress relieve. This uses a cutting torch with a copper-coated carbon electrode.
[32, CAEF, 1997], [110, Vito, 2001], [202, TWG, 2002]

2.8 Heat treatment

2.8.1 Introduction

For ferrous castings, there are basically two types of thermal treatments which can be applied: annealing and hardening. In the case of annealing, the tension caused in the workpiece as a result of pouring, and the subsequent cooling down of the casting, is reduced and the structure is evened out. In the case of hardening, the level of heat is raised above the transformation temperature and the workpiece is subsequently rapidly cooled, in a process known as quenching. This causes the material properties to change. Different results may be obtained by the use of water, oil or air quenching. ‘Quench and temper’ is the name of the procedure in which the workpiece is reheated to the tempering temperature following quenching, and the quenching procedure is repeated.

The malleableising of iron is a thermal treatment which differs from annealing and hardening. Here, the malleable unfinished casting is either transformed to a white or black temperature casting depending on the procedure.

Many non-ferrous castings are used in an ‘as-cast’ condition, but certain applications require higher mechanical properties than ‘as-cast’ material. Possible treatments are annealing, controlled cooling, solution heat treatment, artificial ageing and precipitation treatment.
[32, CAEF, 1997], [175, Brown, 1999]

2.8.2 Heat treatment furnaces

2.8.2.1 Chamber furnaces

Chamber furnaces are the most common furnace construction. Their actual design has been adapted in many sub-forms in order to meet the needs of the differing thermal treatments of various types of casting and production. Some examples of chamber furnaces are bogie hearth furnaces, top hat furnaces, hub open-hearth furnaces, etc. Chamber furnaces with continually running conveyance means are called tunnel furnaces. Heating is provided either electrically, or with gas or fuel oil.

For non-ferrous materials, some heat treatments are carried out close to the melting point of the casting, so accurate temperature control is needed. Forced air circulation is used to ensure that the temperature at all parts of the furnace is constant and equal.
[32, CAEF, 1997], [175, Brown, 1999]

2.8.2.2 Shaft furnaces

Pipes, long waves and similar parts are often treated while suspended in a vertical position in shaft furnaces. In shaft furnaces, the heating is provided by electricity, gas or fuel oil.

2.8.2.3 Annealing furnaces

Chamber, top hat or tunnel furnaces are used to temper unfinished castings. The heating of such furnaces is carried out via electricity, gas or fuel oil.

2.8.3 Quenching

In thermal treatment processes, chilling is the cooling down of a workpiece at a greater speed than in calm air. This can be achieved by means of a rapid submersion in water or oil (see Figure 2.52), as well as by forced air-cooling. Care should be taken that the workpieces are cooled at a uniform rate. When submersing in fluids, either the parts must be moved or the fluid must be continually circulated to ensure a full and even cooling of all parts of the workpiece. In a similar principle, in air quenching the blowing procedure must be arranged so that the air covers the entire surface.

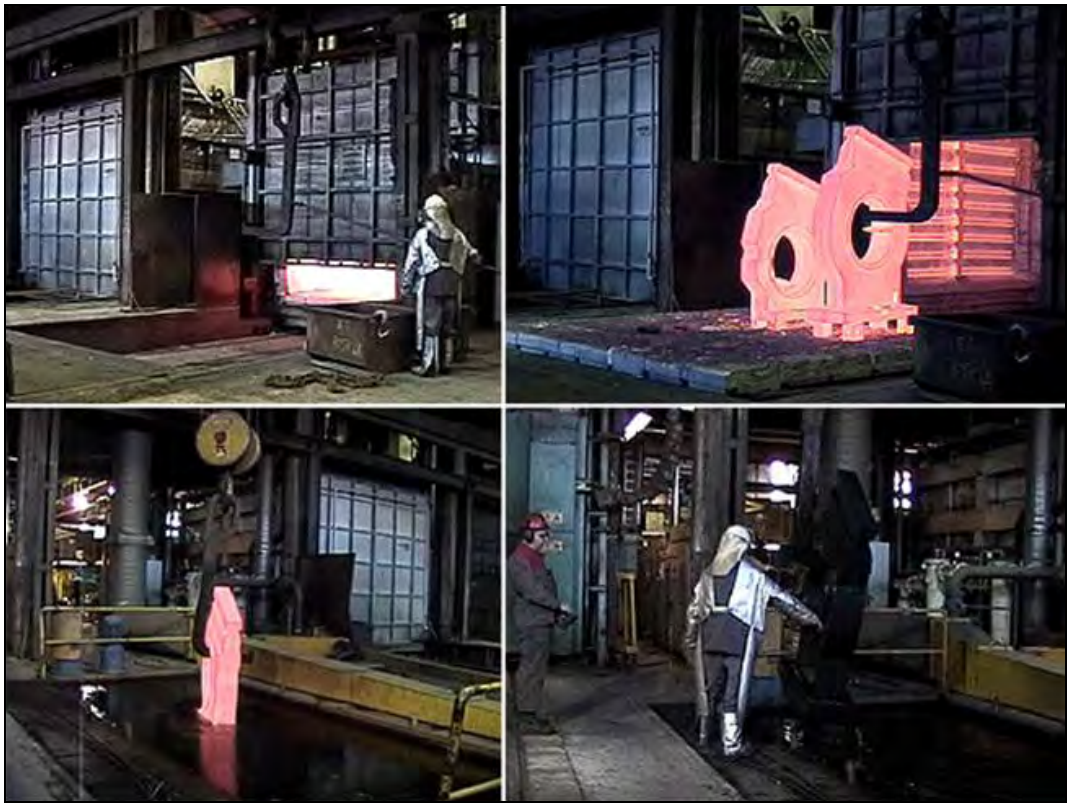

Figure 2.52: Quenching of a hot casting shortly after heat treatment [237, HUT, 2003]

2.8.4 Heat treatment of ductile iron (SG iron)

It is obviously desirable to achieve the required metal properties in the ‘as-cast’ form to save further treatments being necessary, but this is not always possible because of variations in section thickness, etc. The heat treatment of the castings can eliminate carbides in thin sections, produce more consistent matrix structures and for a given structure, often improve its

mechanical properties, especially by normalising the grain structure. Where tempered martensite structures are needed, heat treatment is essential.
[32, CAEF, 1997], [174, Brown, 2000]

2.8.4.1 Stress relief

Stress relief consists of heating the castings at a rate of 50 – 100 ºC/h to 600 ºC (taking care not to exceed 610 ºC), followed by soaking them for a minimum of one hour, plus an extra hour for every 25 mm of section thickness in the thickest section, and then cooling them at a rate of 50 - 100 ºC/h or less. The castings must be adequately supported in the furnace so that they are not subjected to stress.

2.8.4.2 Breakdown of carbides

Thin section castings may contain carbides in the 'as-cast' structure. These can be eliminated by soaking the castings at 900 – 925 ºC for 3 to 5 hours.

2.8.4.3 Annealing to produce a ferritic matrix

Annealing involves soaking the castings at 900 – 925 ºC for 3 – 5 hours, followed by a slow cooling at around 20 – 35 ºC/h through the critical temperature range (about 800 – 710 ºC), and finally furnace cooling at, say 50 – 100 ºC/h to 200 ºC.

2.8.4.4 Normalising to produce a pearlitic matrix

For normalising, a soaking of the castings above the critical temperature followed by air cooling is necessary. Again a soaking temperature of 900 – 925 ºC is usually used, to ensure that the carbides are broken down. Forced air cooling is used to form pearlite. The type of heat treatment furnace available and the size of the load determines the process cycle that is possible. It may be necessary to adjust the metal composition with tin or copper to help the formation of fully pearlitic structures.

2.8.4.5 Producing hardened and tempered structures

Hardened structures are produced by austenitising the casting at 900 – 920 ºC, followed by oil quenching. Tempering is usually carried out at 600 – 650 ºC.

2.8.4.6 Austempered ductile iron (ADI)

Austempering is an isothermal heat treatment for producing ausferrite structures. It can double the strength of ductile iron whilst allowing it to retain good ductility and toughness. Wear resistance and fatigue properties are excellent, even to such a degree that ADI is comparable with wrought and hardened-tempered steel.

The ADI heat treatment is a two-stage process, as shown in Figure 2.53. Austenitising is carried out at 815 – 930 ºC to fully transform the matrix to austenite. This is done either in a non-oxidising atmosphere furnace or in a high temperature salt bath. Temperatures and times are determined by the chemical composition, the section size and the grade of ADI required; 1 to 1.5 hours is usually adequate. Slow initial heating of the casting is desirable to avoid the risk of cracking the complex shapes. The castings are then quenched to the required isothermal heat treatment temperature, usually between 210 and 400 ºC. This is usually done in a salt bath. The

castings are held at this temperature for 1 – 2 hours to complete the transformation of austenite to ausferrite. Lower temperatures give high hardness, strength and wear resistance, while higher heat temperatures result in higher ductility and toughness. After the isothermal treatment, the castings are cooled to ambient temperature.

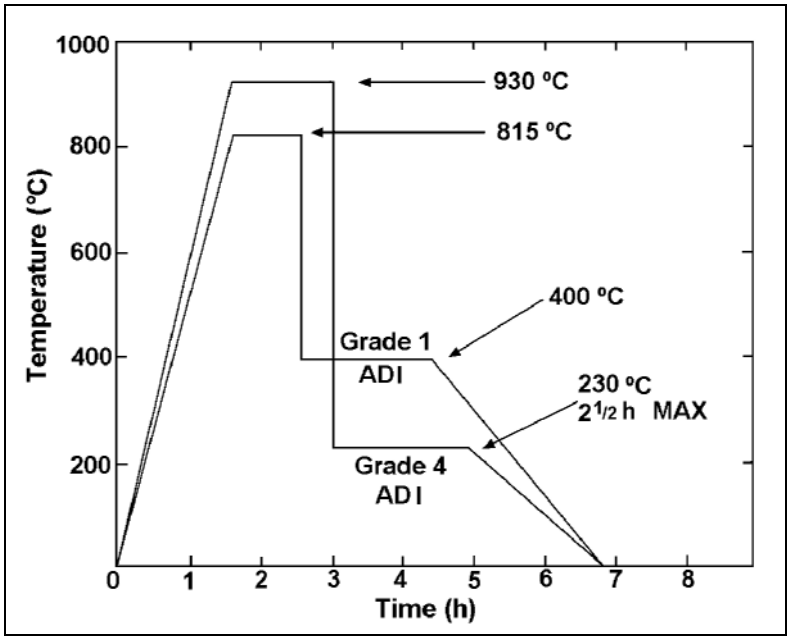

Figure 2.53: Typical austempering heat treatment stages
[174, Brown, 2000]

Unalloyed ductile irons may be austempered in sections of up to about 8 mm thickness. Thicker section castings require the addition of Mo or Ni to increase the hardenability.

Austempered ductile iron is used as a replacement for forged steel components in the agricultural, railway, automotive and general engineering industries; for example, for plough tips, digger teeth, spring brackets, rear axle brackets, gears, etc. ADI production is growing but its use is limited to some extent by the lack of suitable heat-treatment facilities.
[32, CAEF, 1997], [174, Brown, 2000]

2.8.5 Heat treatment of steel

Steel castings are normally subject to a heat treatment before delivery, e.g. normalising, with this heat treatment leading to a structural change. Additionally, potential casting stresses have to be reduced (stress relief annealing). Many steel casting qualities have to be additionally tempered after stress relief anneal (hardening and tempering).

Most steel castings are subjected to a heat treatment to attain the desired mechanical properties and to a stress relief, to obtain the right corrosion resistance and to avoid the difficulties during the finishing operations. The heat treatment is defined according to the steel grade. To remove the chemical and structural segregations, annealing at high temperature is generaly performed. Carbon and low alloy steels undergo:
- normalising and air cooling, or
- austenitising, quenching and tempering.

Austenitic or duplex stanless steels undergo a solution annealing and water quenching heat-treatment. Additionnal heat-treatments such as for stress relief or post weld treatment are also used to eliminate the internal stresses of the material.
[32, CAEF, 1997], [202, TWG, 2002], [225, TWG, 2003]

2.8.6 Heat treatment of aluminium

Aluminium castings are heat treated for: homogenisation, stress relief, improved dimensional stability and machinability, optimised strength, ductility, toughness and corrosion resistance. Most often the heat treatment is a compromise between varying effects, maximising the important properties of one often at the expense of others. The heat treatment of aluminium may involve: annealing, solution heat treatment, quenching, artificial ageing and precipitation treatment. The type of treatment applied is indicated by a suffix to the alloy designation. This is called the temper designation. For sand, gravity and low-pressure die-castings all treatments are possible, though not all are standardised. Pressure die-castings are not solution treated and quenched in the same way as sand, gravity and low-pressure die-castings. Entrapped gas bubbles can expand and cause casting defects. Heat treatment is not a common step for high-pressure die-castings; only about 1 % of this type of castings are subjected to heat treatment. All die-castings may be quenched from the die, precipitation treated and stress relieved without suffering any harmful effects. In the low pressure die casting production of aluminium wheels 90 % of the castings are subjected to heat treatment
[225, TWG, 2003].

2.8.6.1 Stress relieving and annealing

Castings with changes of section, or of a complex shape are likely to develop internal stresses. These can then cause dimensional changes upon machining. To stabilise the casting and to remove internal stresses, castings are heated to a temperature of 200 ºC for 5 hours, followed by slow cooling in the furnace.

2.8.6.2 Solution treatment and quenching

Castings are heated at temperatures just below the melting temperature and held there for a long time to take the alloying constituents into a homogeneous solid solution. The castings are then rapidly cooled by quenching to room temperature to retain the elements in solution. Water or special quenchants are used. The quench tanks are placed close to the furnace to ensure that rapid cooling is possible. Although sensitivity to the quench interval differs between alloys, good practice should limit the interval to 5 – 10 s.

2.8.6.3 Precipitation treatment

The controlled precipitation of alloying constituents is promoted by heating the casting to a temperature of between 150 ºC and 200 ºC. The casting strength and hardness are increased. The process is therefore also referred to as structural hardening. Each alloy has an optimal heat treatment cycle.

2.8.6.4 Artificial ageing

Some casting alloys increase in strength and hardness while left standing at room temperature. The process can take several weeks but can be speeded up by heating above room temperature and then sustaining this heat over time.
[175, Brown, 1999], [202, TWG, 2002], [213, CTIF and CQRDA, 2002], [212, Zalensas, 1993]

2.9 Quality control

During quality control the finished casting is checked for compliance with the product requirements concerning e.g. dimensions, metal structure defects, surface structure. Depending on the type of casting and the size of the series, quality control can be achieved by visual inspection, with the use of measurement tools, or automatically.

In the production of aluminium wheels the castings are controlled via X-ray analysis. A standard image of a good casting is used for verification by a computer program. If there are any differences, the image is studied and assessed by a human operator. Random tests of the alloy are analysed with spectral analysis.

The quality control procedure informs the final decision to reject a casting or to allow its further shipment to the market. Rejected castings are brought back to the raw material input to be remelted.
[225, TWG, 2003]

3 CURRENT EMISSION AND CONSUMPTION LEVELS IN FOUNDRIES

3.1 Mass stream overview

3.1.1 Introduction

The general mass stream overview for the foundry process is given in Figure 3.1. This scheme generally applies for ferrous and non-ferrous foundries. Specific aspects of the various process steps and types will be worked out below.

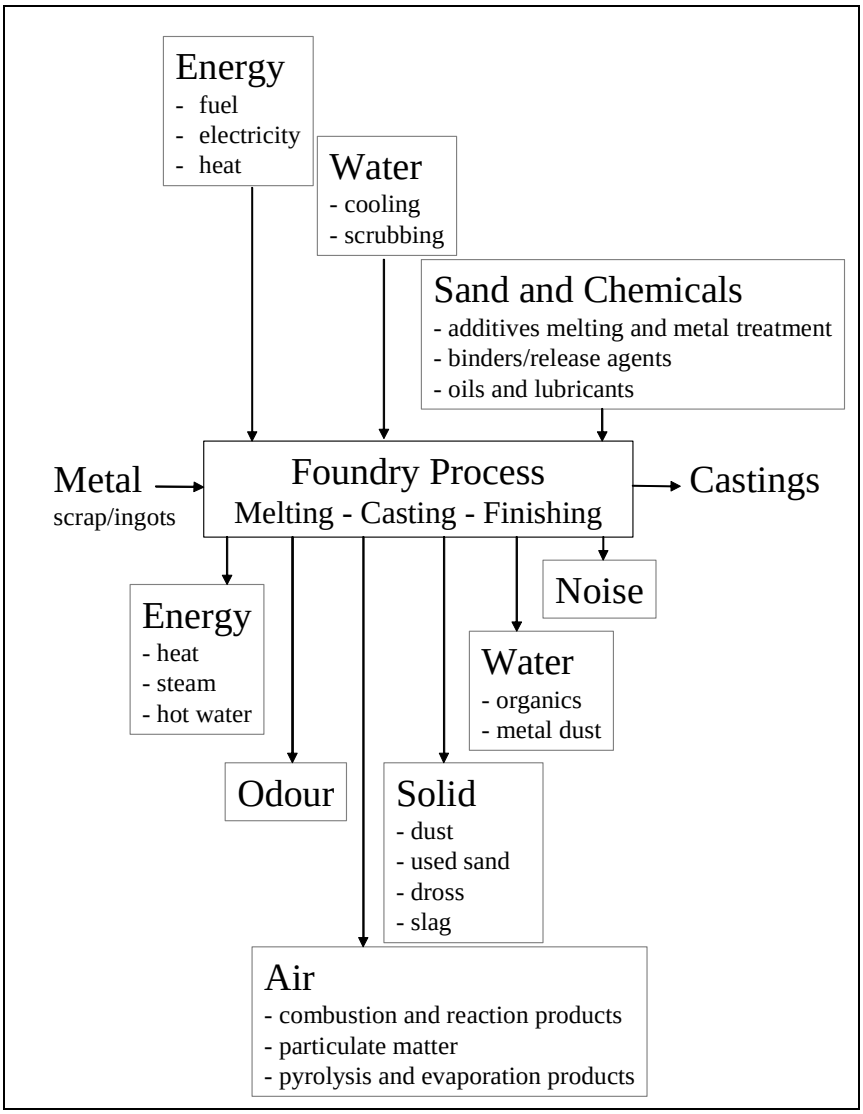

Figure 3.1: Mass stream overview for the foundry process

3.2 Melting and the metal treatment of ferrous metals

3.2.1 Properties of melting furnaces for steel and cast iron

Table 3.1 presents an overview of the typical properties of melting furnaces used for steel and cast iron. The data is then discussed in the sections below.

Process	Steel			Cast Iron					
Type	ELECTRIC ARC FURNACE		INDUCTION F.	INDUCTION F.	CUPOLA FURNACE				ROTARY F.
Subtype	Acid lined	Basic lined	Coreless	Coreless	Cold blast	Hot blast	Hot blast – long campaign	Cokeless - duplex	
Energy source	Electricity	Electricity	Electricity	Electricity	Coke	Coke	Coke	Gas/fuel	Gas/fuel
Thermal efficiency[1](%)	60 – 70	60 – 70	50 – 60	50 – 60	30 – 40	40 – 45	35 – 45	50 – 60	50 – 60
Primary thermal efficiency[2](%)	21 – 25	21 – 25	15 – 20	15 – 20	30 – 40	40 – 45	35 – 45	45 – 50	35 – 45[3]
kWh/tonne metal charge	500 – 700	500 – 700	520 – 800	520 – 800	950 – 1200	800 – 900	810 – 1100	700 – 800	600 – 800
Batch/continuous	Batch	Batch	Batch	Batch	Continuous	Continuous	Continuous	Continuous	Batch
Production rate[4] (tonnes/h)					2 - 10	8 - 70	8 - 70	>5	
Furnace capacity[5] (tonnes)	2 – 50	2 – 50	0.01 – 30	0.01 – 30					1 – 20
Meltdown time (h)	1 – 4	1 – 4	1 – 2	1 – 2					2 – 4
Refining ability	Possible	Possible	No	No	Yes	Yes	Yes	No	No
Capital cost	High	High	High	High	Medium	High	High	Medium	Low
Slag production (kg/tonne metal charge)	10 – 40	20 – 80	10 – 20		40 – 80	40 – 80		40 – 80	20 – 60
Dust production[6] (kg/tonne metal charge)	5 – 8		0.06 – 1		5 – 13	4 – 12		0.8	0.3 – 2.9
Waste gas[7] emission (kg/tonne metal charge)									
CO_2[8]	Depending on power generation		Depending on power generation		400 – 500	350 – 480		100 – 120	120
CO	7.5 – 25 (decarburisation)		n.a.		Possible[9]	0.5 – 2.5		<10	1.0 – 1.5
SO_2	<1		Minor		1 – 2	<1		Fuel dependent	2.5 – 3.0
NO_x	n.a.		n.a.		<1	<1		0.5	0.3 – 0.4

1 Indicated values give an order of magnitude but largely depend on exploitation conditions, such as metal temperature, furnace capacity and production rate
2 Efficiency of electrical power generation assumed to be 35 %
3 Taking into account energy consumption for oxygen production and the raw materials, such as graphite and FeSi, to substitute the oxidised elements during melting
4 For continuous processes only
5 For batch processes only
6 Indicated values are general values found in literature
7 Indicated values are general values found in literature
8 Assuming complete combustion
9 Depending on local exploitation conditions and construction.

Table 3.1: Typical melting furnace properties and emission data
[32, CAEF, 1997], [110, Vito, 2001], [202, TWG, 2002], [225, TWG, 2003] and comments from CTIF

3.2.2 Cupola furnaces

Input	Output
– ferrous material (iron pigs, sponge iron, steel scrap, foundry returns …)	– metal alloy (cast iron)
– alloying metal (ferro-alloys …)	– dust (metal content)
– flux (limestone…)	– CO/CO_2, SO_2, NO_x
– energy (coke, gas, oil, electricity)	– HF
– oxygen	– Dioxins, furans
– cooling water	– organic pollutants
– water	– slag
	– waste refractory

3.2.2.1 Coke and energy consumption

In cold blast operation, the coke consumption between the charges is generally 90 - 120 kg/tonne metal charge, but can be less than 70 kg/tonne metal charge, e.g. in the case of counterweights. Accounting for the amount of coke in the bed gives a total coke consumption of 110 – 140 kg/tonne metal charge. As the calorific value of European cokes is 8.5 kWh/kg, this corresponds to a calorific input of 950 – 1200 kWh/tonne metal charge.

The total coke ratio in a hot blast cupola is generally 110 – 145 kg/tonne metal charge. However, as the average steel percentage is 50 %, and the recarburisation consumes about 1.5 %, the real burned coke ratio is 95 – 130 kg/tonne metal charge, which is 810 to 1100 kWh/tonne metal charge. This corresponds to a thermal efficiency of 35 to 45 %.

Depending on the plant layout, the energy consumed by the fume treatment equipment and the holding furnace, as given in Table 3.2, must be added. German data indicate a specific electricity use for the flue-gas cleaning equipment of c. 20 kWh per tonne of good casting. [202, TWG, 2002]

Energy carrier type	**Average consumption kWh/tonne metal charge**
Gas for the combustion chamber	40
Electricity for the flue-gas cleaning equipment (fans, etc.)	40
Electricity for the holding furnace	60

Table 3.2: Average energy consumption for off-gas treatment and holding

3.2.2.2 Particulate matter

The emission range of particulate matter is very wide. Particulate emissions depend primarily on the cupola type used, as shown in Table 3.3:

Cupola type	**Dust emission** (kg/tonne metal charge)	**Coke proportion** (kg/tonne metal charge)
Cold blast	5 – 13	110 – 140
Hot blast	4 – 10	95 – 130
Liningless hot blast	5 – 12	115 – 135
Cokeless	0.8	0

Table 3.3: Dust emission levels (raw cupola off-gas) from various cupola types [32, CAEF, 1997]

Dust emission levels measured at the stack for three German furnaces are given in Table 3.4.

Flue-gas cleaning	Volume (m^3/h)	Total dust (mg/m^3)	PM_{10} (%)	$PM_{2.5}$ (%)
Above charge hole off-take; bag filter	28500	7	88	47
Cyclone, Venturi, recuperator	16000	68 – 94	96	88
n.d	6000 (Nm^3/h dry)	75	100	45 – 85

Table 3.4: Cupola dust emission levels and PM size distribution [202, TWG, 2002]

In general, particle sizes range from less than 1 µm up to 10 mm, with 50 % less than 100µm. However, 5 to 20 % are smaller than 2 µm, which makes the dust collection more difficult. Cupola dust is primarily made up of coke, silica, rust and limestone, as shown in Table 3.5.

Substance	Composition (%)	
	[32, CAEF, 1997]	[158, Charbonnier, et al., 1998]
Iron oxide	30 – 60	15 – 25
SiO_2	± 25	15 – 30
Coke dust	3 – 15	n.d
MnO	3 – 10	2 – 5
Al_2O_3	1 – 3	2 – 5
MgO	1 – 3	0 – 2
CaO	<1	5 – 10
S	<2	n.d
ZnO, depending on the charge	<3	0 – 30 Zn*
PbO, depending on the charge	<1	0 – 5 Pb*
* In the form of oxides and silicates; applicable for Zn-enriched dusts		

Table 3.5: Typical composition of cupola dust, data in weight per cent [32, CAEF, 1997] and [158, Charbonnier, et al., 1998]

3.2.2.3 Waste gases

Coke fired cupola gas is composed primarily of N_2, CO_2, H_2O, and CO, with smaller amounts of SO_2. On conventional cupolas, where the off-gas is collected above the charging door, a distinction has to be made between the condition of the flue-gases below and above the charging door, since ambient air is entrained through the open charge door. This input significantly changes the total airflow.

If the cupola gases are hot enough, and if there is enough CO present, the gases may burn spontaneously together with drawn-in air ($CO + O_2 \rightarrow 2CO_2$) and temperatures may rise to 900 ºC. Little or no CO will then be left in the exhaust. If no combustion takes place, the air intake will result in a cooling effect, of between 100 and 300 ºC, and the CO/CO_2 balance will remain unchanged. The temperature of the gases just below the charging door is primarily dependent on the charge height; the input of ambient air is determined by the fan capacity or the natural draught available.

The flow of the undiluted cupola top gases is proportional to the coke consumption. Increasing the coke proportion in the charge will decrease the production rate (tonne molten metal/h) if the same blast airflow is maintained. It may then be necessary to increase the blast to maintain the production. The metal temperature will also increase. With reference to the combustion rate ($C + O_2 \rightarrow CO_2$), more coke and blast air will result in an increased flow of exhaust gases.

For a given furnace, the coke and blast air consumption depend on the targeted melting rate and the metal temperature, which can vary on an hourly basis. Typical flowrates reported in literature vary from 600 to 800 Nm^3/tonne metal charge for cold blast cupolas and 500 to 700 Nm^3/tonne metal charge for hot blast cupolas. The composition of the unburned top gases may be as follows (Table 3.6):

Substance	Volume %
CO_2	10 – 18
CO	5 – 15
H_2	<1
SO_2	<0.05
N_2	Remainder

Table 3.6: Unburned top gas composition for cupola furnace [32, CAEF, 1997]

Above the charging door, the flowrates of the exhaust gases may be two to five times higher, depending on the target temperature (which depends on the kind of dust arrestment system applied) of the diluted gases and, in the case of a recuperative hot blast cupola, the presence of a post combustion chamber. Typical flowrate values are 3000 to 4000 Nm^3/tonne metal charge melted for cold blast cupolas and 900 to 1400 Nm^3/tonne metal charge when post-combustion is performed. The composition of the gases is determined by the rate of dilution (natural draught or fan power), the degree of spontaneous combustion of the CO, or the post combustion itself, which can be executed on the complete or partial flow.[32, CAEF, 1997]

Emission data for the main combustion gas components are given in Table 3.7. Hot blast and cold blast cupolas with varying melting capacities are listed. The table also indicates whether the off-gas is collected under or above the charging door. The hot blast systems show reduced SO_2 emission levels. The disintegrator shows a better dedusting performance than the venturi scrubber. The application of post combustion clearly affects both the CO and NO_x levels, under optimal working conditions. Analysis of the full measurement campaign data shows that sub-optimal operation of a hot blast cupola results in increased CO-emissions: 2000 mg/Nm³, compared to 5 – 20 mg/Nm³ in optimised conditions. VOC and PAH emissions rise accordingly. [110, Vito, 2001]

The use of dry dedusting (i.e. using a bag filter) results in dust emission levels ≤20 mg/Nm³. Inventory data from Italian foundries showed a dust level below 30 mg/Nm³ (ranging from 0.1 to 32 mg/Nm³) when a bag filter was applied. Wet scrubbing gives dust emissions up to 80 mg/Nm³ (ranging from 5.4 to 78 mg/Nm³) [180, Assofond, 2002]. A value of 68 – 94 mg/m³ was reported for a German cupola with wet scrubbing (see Table 3.4).

Cupola type	Capa-city tonne/h	Exhaust type	Flow m³/h	FGC equipment	Dust mg/Nm³	SO_2 mg/Nm³	CO mg/Nm³	NO_x mg/Nm³	HF mg/Nm³	O_2 vol %
Hot blast[1)]	19	UC	29000	Venturi[1)]	41	21	17798	21	n.d	11
Hot blast	20	UC	40000	Disintegrator	5	57	712	11	n.d	11
Hot blast	24	UC	46445	Bag filter	1.1 – 1.4	20	14 – 17	70 – 75	7	11
Hot blast	25	UC	35000	Venturi	36	28	21	16	n.d	11
Hot blast	60	UC	75000	Disintegrator	5	58	9	7	n.d	11
Cold blast	3.2	AC	12000	Bag filter	10	401	5084	16	1	11
Cold blast	5	AC	23000	Bag filter	6	434	28558	63	n.d	11
Cold blast	8	AC	20000	Bag filter	20	401	936	36	n.d	11
Cold blast	9	UC	22000	Bag filter	4	105	17286	60	n.d	11

1) Working with an old recuperator
UC: Under charge gas collection; AC: above charge gas collection
All data are continuous monitored daily average values

Table 3.7: Emission data for hot blast and cold blast cupolas working with different set-ups [29, Batz, 1986], [202, TWG, 2002], data recalculated to 11 % O_2

3.2.2.4 Cupola slag

Slags contain oxides that float upon the melt and which arise from impurities in the feed material, wearing of the furnace refractory and from the ash of coke and from the melting loss of the metal charge [225, TWG, 2003]. Slags are bonded through the addition of binders, such as vermiculite. The typical composition of cupola slag is given in Table 3.8. A cupola furnace typically produces 40 – 80 kg slag per tonne of liquid iron.

Compound	%
SiO_2	45 – 55
CaO	25 – 40
Al_2O_3	8 – 20
MgO	1 – 3
MnO	1 – 4
FeO	1 – 6
Sulphides	<1
TiO_2	<1
ZnO	<0.1

Table 3.8: Typical cupola slag composition [172, Neumann, 1994], [156, Godinot, 2001]

Cupola slag consists of 30 % refractory material, 10 % sand (from internal scrap), 40 % CaO (flux), 10 % cokes ashes, and 10 % burn-off material.

An important aspect of cupola slag is its high SiO_2-content. After quenching, the slag has a vitrified structure. This generates an inert non-leaching material.

3.2.2.5 Waste refractory

The cupola furnace has the specific feature that the lining material (quartz-clay mixture) of the furnace at the melting zone only lasts for one melting campaign. The main part of the refractory is converted into slag. The amount to be taken out and disposed of as waste is much smaller than the applied amount.

3.2.3 Electric arc furnace

Input	Output
– ferrous material (steel scrap, foundry returns swarf, pig iron …)	– metal alloy (cast steel)
– alloying metal (ferro-alloys …)	– dust (metal content, refractory)
– flux (limestone …)	– NO_x, CO_2, CO
– energy (electricity, gas, oil)	– organic air pollutants, HC
– oxygen	– metal oxide fumes
– electrodes	– slag (CaO, SiO_2, MgO)
	– waste refractories

3.2.3.1 Input

500 – 600 kWh of electricity is used to melt and raise one tonne of steel to its casting temperature. Furnaces are normally rated at 500 kVA per tonne, giving a melting time of about 1.5 hours.

The electrodes are made of graphite and are consumed during operation through oxidation, volatilisation and breakage, so they must be replaced as necessary. A three tonne furnace typically uses electrodes of 200 mm diameter. Electrode consumption is a significant factor in the cost of arc melting and figures vary from 3 to 10 kg/tonne of steel melted depending on the type of steel produced and the practice used. [174, Brown, 2000]

3.2.3.2 Particulate matter

Particulate emission rates reported in literature vary from 2 to 20 kg per tonne of iron charged with an average of 5 to 8 kg per tonne. The highest emission rates are recorded at the beginning of the melting cycle, during the decarburisation treatment and during back charging [173, Huelsen, 1985]. Particle sizes range from less than 1 µm up to 100 µm, with 50 % being less than 3 to 5 µm. During oxygen treatment, one analysis showed almost 90 % of the particles were smaller than 5 µm.

In terms of the chemical composition of the particulate matter, an even bigger range of measured data can be observed. Table 3.9 gives an overview of the reported figures in the literature.

Substance	Weight per cent (%)
$FeO + Fe_2O_3$	30 – 60
SiO_2	5 – 35
CaO	1 – 15
MgO	0 – 15
ZnO	0 – 16
Cr_2O_3	0 – 8
MnO	2 – 10
Al_2O_3	0 – 5
MoO_3	<1
NiO	<1
Pb	<1
Cd	<0.01
TiO_2	<0.05
V_2O_5	<0.05
Ignition loss	0 – 4

Table 3.9: Chemical composition of EAF dust from steel foundries [32, CAEF, 1997]

The composition of the furnace dust primarily depends on the steel grade being produced. For instance, low alloy steels will not generate emissions containing chromium or nickel, whereas stainless steel will. Another important factor is scrap quality. Melting galvanised steel scrap leads to significant emissions of zinc oxide.

The application of an appropriate hooding of the furnace allows the capture of up to 98 % of the furnace dust. The captured exhaust gas is then cleaned, usually using a bag filter. This reduces dust emission levels to below 10 mg/Nm³.
[29, Batz, 1986]

3.2.3.3 Visible fumes

Visible fumes are emitted during charging of the hot furnace and at the beginning of the melting cycle. The available literature does not report the quantities and the composition of these secondary emissions. Again, the nature of the fumes depends on the cleanliness of the charged material with respect to its oil, grease, paint or other organic matter content.

3.2.3.4 Waste gases

Electric arc furnaces are mainly used for steel melting. They primarily generate dust emissions and gaseous compounds, such as nitrogen oxides, carbon monoxide and organic compounds. The organic compounds depend on the type and amount of impurities in the feed metal. The raw materials used as charge materials in the foundry are selected so that they don't usually contain materials that can produce dioxins. Organic compounds are decomposed into harmless products, so long as no scrap preheating without post-combustion is applied. [29, Batz, 1986]

Emission data for the main combustion gas components are given in Table 3.10. Inventory data from Italian foundries showed a dust level below 10 mg/Nm³ (ranging from 1.2 – 8.3 mg/Nm³) when a bag filter is applied. Wet scrubbing gives dust emissions below 25 mg/Nm³ (ranging from 12 – 24.5 mg/Nm³). [180, Assofond, 2002]

	Capacity tonne/ charge	**Off-gas** collection	**Flow** m³/h	**FGC** equipment	**Dust** mg/Nm³	**SO_2** mg/Nm³	**CO** mg/Nm³	**NO_x** mg/Nm³	**HF** mg/Nm³	**O_2** vol %
EAF	50	FH	265000	Bag filter	2	n.d	n.d	50	n.d	20
EAF	2 x 50	FH	380000	Bag filter	4	n.d	n.d	n.d	n.d	20
EAF	10	PH	160000	Bag filter	1	1	200	5	0.1	20
FH: Full hooding; PH: Partial hooding										

Table 3.10: Typical emission values for EAF furnaces
[29, Batz, 1986]

During melting and refining, CO is generated from the oxidation of the graphite electrodes and the carbon from the metal bath. Estimated quantities are 6 to 20 Nm^3 CO/tonne (or 7.5 to 25 kg CO/tonne) depending on the initial carbon content of the charged material and the required carbon level after treatment. The oxygen injection causes quantities of iron oxide (red smoke) to be emitted from the metal bath. No other significant emissions have been reported. [32, CAEF, 1997]

3.2.3.5 Slags

The chemical composition of EAF slags are given in Table 3.11. The reported values were based on the analyses of 3 samples.

Compound	Average (%)	Range (%)
SiO_2	36.2	28.6 – 41.8
CaO	12.4	7.2 – 17.7
MgO	22.1	18.3 – 27.0
Al_2O_3	8.4	7.4 – 0.1
FeO	0.7	0.5 – 1.0
MnO	14.8	4.0 – 29.6
TiO_2	1.2	0.39 – 2.7
Na_2O	0.3	0.11 – 0.57
K_2O	0.1	0.1 – 0.23

Table 3.11: Chemical composition of EAF slag
[171, The Castings Development Centre, 1999]

3.2.4 Induction furnace

Input	Output
– ferrous material (iron pigs, steel scrap, swarf, foundry returns …)	– metal alloy (cast iron, cast steel)
– alloying metal (ferro-alloys …)	– dust
– carburising agents, flux	– organic and metallic fumes
– energy (electric)	– CO
– cooling water	– slag
	– refractory waste

3.2.4.1 Coreless induction furnace

3.2.4.1.1 Energy input

A coreless induction furnace can melt a tonne of iron and raise the temperature of the liquid metal to 1450 ºC using under 600 kWh of electricity. However, in practice, only a few foundries can achieve this level of specific consumption on a week-by-week basis. The actual energy consumption varies according to the size and working regime of the furnace. Large furnaces, working 24 h a day and using a molten heel can achieve a 600 kWh/tonne value. Surveys of foundries show that consumptions of 520 – 800 kWh/tonne metal charge are common, the variation being due to individual melting practice, such as the rate at which the pouring line will accept the molten metal and whether furnace lids are used effectively. Attention to energy saving measures should allow figures of 550 – 650 kWh/tonne metal charge to be achieved. The typical heat losses from a coreless induction furnace are shown in Figure 3.2.
[47, ETSU, 1992], [174, Brown, 2000], [202, TWG, 2002]

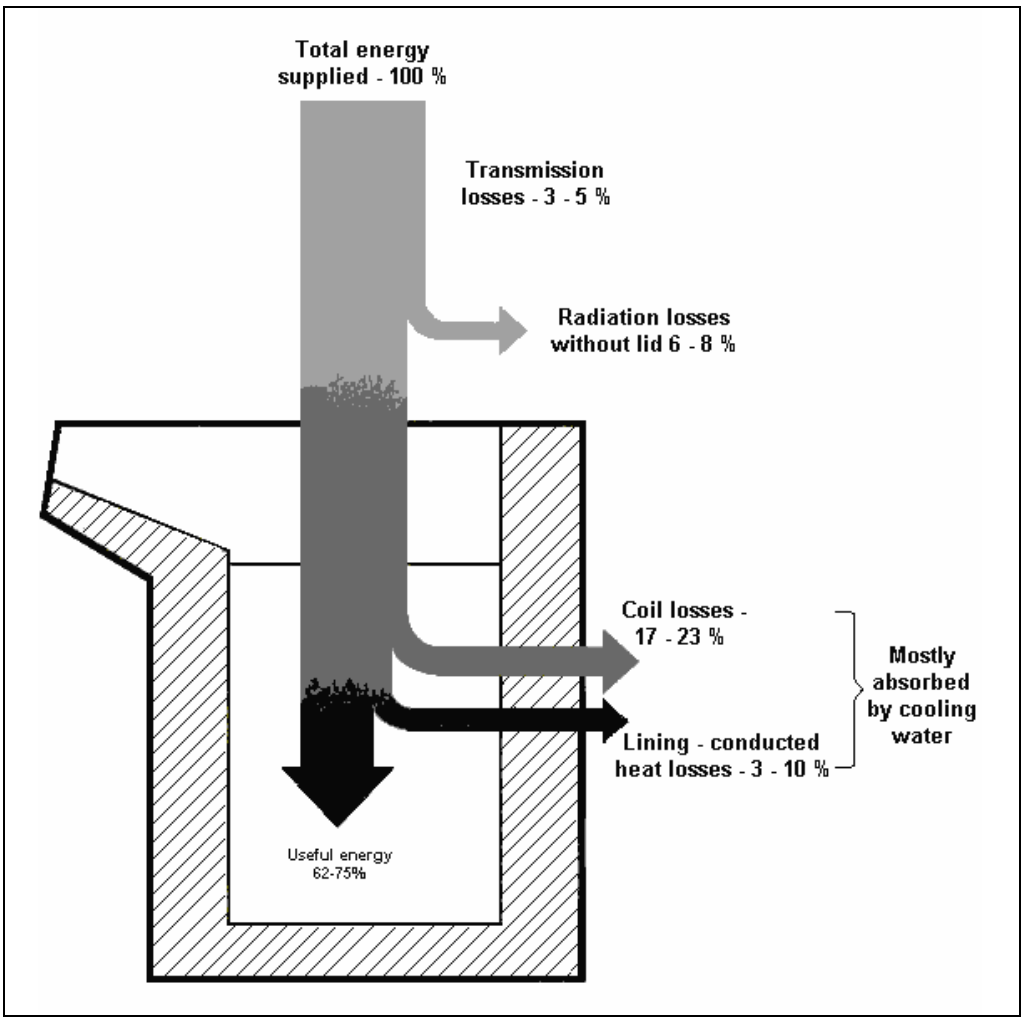

Figure 3.2: Typical energy losses from a mains frequency coreless induction furnace [47, ETSU, 1992]

3.2.4.1.2 Particulate matter

Emission rates of 0.06 to 1 kg/tonne metal charge have been reported in literature, but at present, emission rates of 0.04 to 3 kg/tonne are normal. The highest emission rates occur during charging and at the beginning of the melting cycle. Particle sizes range from 1 – 100 µm, with more than 50 % being smaller than 10 – 20 µm. [32, CAEF, 1997], [202, TWG, 2002]

Dust emission levels and PM distribution from a German IF foundry are given in Table 3.12.

Flue-gas cleaning	Volume (m^3/h)	Total dust (mg/m^3)	PM_{10} (%)	$PM_{2.5}$ (%)
Hood and bag filter	10400	c. 0.4	78	50

Table 3.12: IF dust emission level and PM size distribution [202, TWG, 2002]

As for the chemical composition of the particulate matter, there is no published data regarding the melting of steel, but there is reason to believe that it is close to that of the composition of the dust emitted during the melting of cast iron as shown in Table 3.13. The presence of Zn, Pb or Cd will lead to metallic fumes during the meltdown of the charge.

Substance	Weight per cent (%)
$FeO + Fe_2O_3$	30 – 70
SiO_2 (depending on the lining material)	5 – 25
MnO	<5
Al_2O_3 (depending on the lining material)	3 – 10
CaO	<1
ZnO (depending on the charge material)	<5
Metallic oxides (depending on the charge material)	<0.1
Loss on ignition	0 – 10

Table 3.13: Chemical composition of induction furnace dust in cast iron foundries [32, CAEF, 1997]

3.2.4.1.3 Waste gases

The melting of iron and steel in induction furnaces results in low emissions compared to the cupola furnace. Emissions due to the combustion of fossil fuel are especially prevented. An exhaust capture efficiency of up to 95 % is possible using special capture systems, such as side-draughts, movable hoods and partial covering of the furnace. Filtration of the off-gases is mainly performed using dry systems. Dust emission levels below 5 mg/Nm³ can be obtained [225, TWG, 2003]. Typical emission data are given in Table 3.14.

	Capacity No of furnaces x tonne/charge	**Off-gas collection**	**Flow** m³/h	**FGC equipment**	**Dust** mg/m³	**SO_2** mg/m³	**CO** mg/m³	**NO_x** mg/m³	**HF** mg/m³	**O_2** vol %
IF	(2 x 10) + (3 x 3)	Side-draught	54000	Bag filter	5	n.d	n.d	n.d	n.d	21

Table 3.14: Typical emission data for induction furnace melting in a ferrous foundry [29, Batz, 1986]

Charging oily scrap or borings in a cold furnace will lead to the presence of organic vapours in the exhaust gases, which will not be burned since they are created at the beginning of the melting cycle. Adding this kind of scrap to a molten bath (i.e. the molten heel practice) can be very dangerous since small explosions in the metal bath may occur, which can then lead to splashing metal drops and sparks out of the furnace.

Since the scope of the work is limited to the foundry boundaries, no emission data for the generation of electrical energy have been taken into account.

3.2.4.1.4 Slags

The typical properties of induction furnace slags are given in Table 3.15. Induction furnaces produce 10 – 20 kg slag per tonne metal charge. The amount of slag produced depends on the quality of charge material. The lower limit of the given range applies if internal scrap is cleaned (blasted) before re-melting.

Compound	%
SiO_2	40 – 70
FeO	10 – 30
Al_2O_3	2 – 15
MnO	2 – 10
CaO	0 – 3
MgO	0 – 3

Table 3.15: Typical composition of induction furnace slag
[172, Neumann, 1994]

3.2.4.2 Channel induction furnace

In ferrous metal foundries, the channel induction furnace is mainly used as a holding furnace. It is the furnace of choice for duplex operation with the hot blast cupola. In this case, its function is either to hold or to homogenise the chemical composition of the metal, or to serve as a reservoir of the melted metal for the casting. The furnace's role is not to increase the metal temperature, but rather to prevent unwanted cooling.

Figure 3.3 presents the energy consumptions of some representative channel induction furnaces. The consumption depends on process related parameters, such as the holding time. The graph shows that the consumption decreases with increasing annual tonnage. The extreme values are 80 and 20 kWh per tonne transferred.

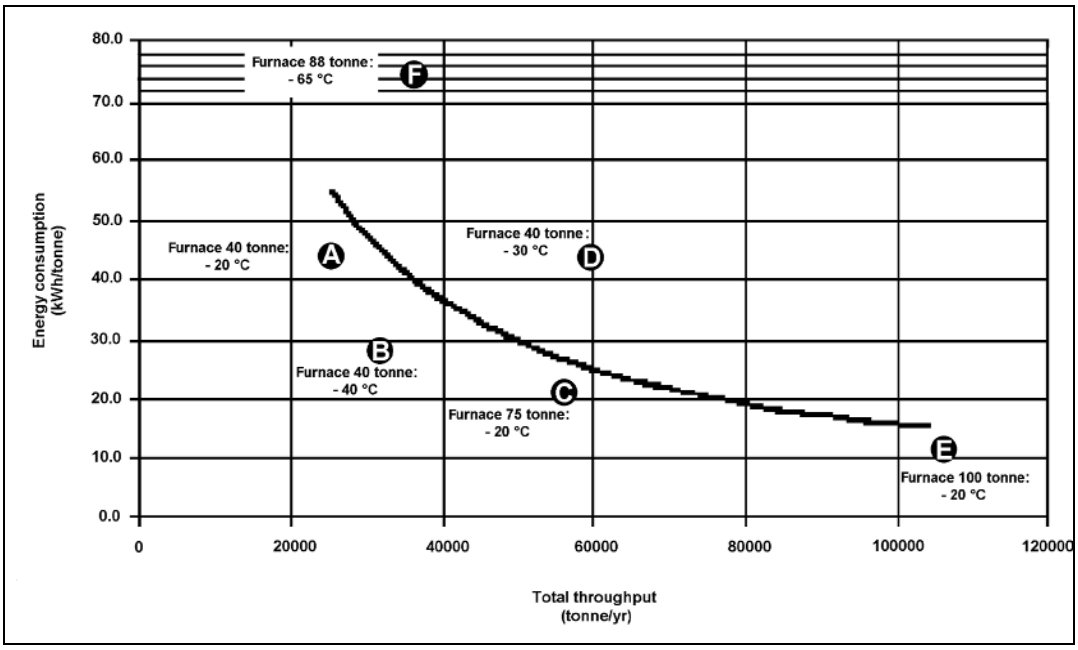

Figure 3.3: Energy consumption (kWh/tonne) as a function of transferred tonnage and loss of temperature for channel induction furnaces
[140, EU Thematic Network Foundry Wastes, 2001]

3.2.5 Rotary furnace

Input	Output
– ferrous material (iron pigs, steel scrap, swarf, foundry returns …)	– metal alloy (cast iron)
– alloying metal (ferro-alloys …)	– dust
– carburising agents, flux	– organic and metallic fumes
– energy (electric, oil, gas)	– slag
– cooling water	– refractory waste

3.2.5.1 Input

As is the case with electric melting, the energy source used in the rotary furnace allows a clean process, especially if natural gas or propane is used. The degree of contamination of the charged scrap is again very important to the nature and the quantities of the emissions that arise. This fact explains why no uniform emission pattern exists, and why the measurement data show wide variations.

3.2.5.2 Particulate Matter

Particulate matter originates from dirt adhering to the charged material, lining wear during charging and melting, and from the burn out of alloying elements and the different additions to the charge. The reported data show overall emission rates of 0.3 to 2.9 kg/tonne metal charge. The grain size is relatively small, from less than 1 µm to 100 µm, with 20 % <1µm, 60 % less than 10 µm and 95 % smaller than 50 µm. [32, CAEF, 1997], [204, Carnicer Alfonso, 2001]

The chemical composition of rotary furnace dust is given in Table 3.16.

Compound	%
Iron oxides	50 – 75
MnO	<1
SiO_2	<1
MgO	1 - 2
Cr_2O_3	<0.5
ZnO	<1
Pb	<0.5
Sn	0.2
Loss on ignition	5 – 10

Table 3.16: Chemical composition of rotary furnace dust in ferrous melting [204, Carnicer Alfonso, 2001]

3.2.5.3 Waste gases

CO_2 production is estimated to be 120 kg/tonne metal charge. The thermal efficiency of the furnace is very high at 50 to 65 % [4], depending on the capacity. This high yield is achieved by using pure oxygen instead of air as a combustion medium. During the reducing flame conditions the combustion of the fuel or gas may be incomplete. CO may be produced under these conditions. However, at this point the exhaust gases leave the furnace at a temperature of 1500 ºC and CO burns spontaneously when in contact with the ambient air, which is used to cool the gases.

If sulphur bearing fuel is used, SO_2 emissions can be significant. However, natural gas or propane does not show any significant SO_2 emission.

NO_x emissions of 50 to 250 ppm in the off-gases have been measured in a 5 tonne furnace. The NO_x originates from the oxidation of atmospheric nitrogen at high flame temperatures (2800 ºC) if ambient air is leaking into the furnace through the burner door. The production of NO_x is significant during the oxidising flame regime but only low during the reducing regime. No reports have been made concerning carbonaceous emissions, probably due to the high flame temperature in the furnace and the relatively high cleanliness of the charged material. [32, CAEF, 1997]

[4] This is if the energy for oxygen production is not taken into account. With oxygen production, the efficiency should be 10 to 15 % less. Furthermore if the energy for the replacement of the burnt out charge elements (C, Si) is discounted the resulting primary efficiency is only about 30 to 35 %.

For ferrous rotary furnaces operating with simple air/fuel burners and an afterburner, dust emissions peak at about 250 mg/m^3 for short periods (between 3 seconds continuously but also intermittently over a period of a minute) during the solid phases of the melt cycle. Thereafter, once the charge starts to become liquid, the dust emissions reduce to less than 30 mg/m^3 during normal running. Emissions may remain as high as 150 – 200 mg/m^3 continually during the solid phase of the melt. 40 % combustible emissions are common. Peak emissions from rotary furnaces consist of at least 80 % unburned fuel and occur during charging operations when the main furnace burner is extinguished and then re-lit. The mentioned emissions only apply if at all times, including during charging, the fumes are ducted via the afterburner, which is kept fully operational [163, UK Environment Agency, 2002]. The following raw gas dust levels have been reported for an oxygas rotary furnace without an afterburner: an average dust load of 400 – 450 mg/Nm³ over the two distinct melting phases. These phases are a solid phase with dust emission levels of 150 mg/Nm³, and a liquid metal phase with peak levels up to 1500 mg/Nm³ at the start of the rotation and 600 – 700 mg/Nm³ during normal operation. [204, Carnicer Alfonso, 2001]

Typical emission data are given in Table 3.17. These were collected from a 1.4 tonne/h cast iron melting furnace, without any flue-gas cleaning equipment. Inventory data from Italian foundries showed a dust level below 15 mg/Nm³ (ranging from 0.6 – 14.6 mg/Nm³) if a bag filter is applied [180, Assofond, 2002].

Parameter	Measured value	Parameter	Measured value
Gas flow (Nm³/h)	9000	Chlorine (mg/Nm³)	0.01
Capacity (tonnes/h)	1.4	Dioxins (ngTEQ/Nm³)	0.018
SO_2 (mg/Nm³)	70 ± 60	PAHs (ng/Nm³)	
NOx (mg/Nm³)	200 ± 200	Naphthalene	548
CO (mg/Nm³)	20 ± 10	Phenanthrene	269
Hydrocarbons (mg/Nm³)	<1	Anthracene	9
HCl (mg/Nm³)	1.64	Fluoranthene	102
HF (mg/Nm³)	0.91	Pyrene	55
Dust (mg/Nm³)	220	Benzo(a)anthracene	10
Mercury (mg/Nm³)	0.35	Chrysene	73
Cadmium (mg/Nm³)	0.001	Benzo(a)fluoranthene	3
Thallium (mg/Nm³)	<0.0015	Benzo(b)+(k)fluoranthene	39
Arsenic (mg/Nm³)	0.0002	Benzo(a)pyrene	12
Nickel (mg/Nm³)	0.015	Benzo(e)pyrene	20
Cobalt (mg/Nm³)	0.0001	Indeno(1,2,3-cd)pyrene	10
Lead (mg/Nm³)	0.38	Dibenzo(a,h)+(a,c)anthracene	3
Chromium (mg/Nm³)	0.022	Benzo(g,h,i)perylene	11
Copper (mg/Nm³)	0.196	Perylene	4
Manganese (mg/Nm³)	0.38	Anthanthrene	3
Antimony (mg/Nm³)	<0.0001		
Vanadium (mg/Nm³)	0.011		
Tin (mg/Nm³)	0.0187		
Selenium (mg/Nm³)	<0.0001		
Platinum (mg/Nm³)	<0.0006		
Palladium (mg/Nm³)	<0.0029		
Rhodium (mg/Nm³)	<0.0016		
Zinc (mg/Nm³)	1.768		
Iron (mg/Nm³)	64.63		

- Data for installation without flue-gas cleaning
- Average values for 3 measurements, when the standard deviation is >30 % the value is given

Table 3.17: Measured emissions for rotary furnace, melting cast iron, without flue-gas cleaning equipment
[110, Vito, 2001]

3.2.6 Argon Oxygen Decarburisation (AOD) converter

Input	Output
- molten steel	- decarburised steel
- alloying metals (ferro-alloys)	- metal oxide dust and fumes (Fe,Mn,Cr,Ni)
- Al, FeSi, lime	- gases (CO_2, CO, inert gases)
- O_2, N_2, Ar	- slag (CaO,SiO_2, AlO_3)

3.2.6.1 Input

The AOD converter is used mainly in the production of low carbon stainless steels and, in special cases, carbon and low alloy steels: to remove impurities such as carbon, sulphur and oxides and also to decarburise high chromium stainless steels. The processed material is liquid steel that has been melted in EAF furnaces or in induction furnaces and afterwards poured off into the vessel through ladles. The technique is most common in the steel industry, but it is also applied in foundries, although to only a limited extent. For decarburisation, oxygen is injected in the converter and oxidises carbon into CO gas, which escapes from the liquid metal. No energy source is used except for the energy from the combustion reaction between oxygen and carbon during oxidation and, afterwards, between oxygen and aluminium (and/or silicon) during reduction.

The consumption of carbon ranges from 0.4 to 1 %, being about 50 – 120 m³ of CO per tonne of steel and 25 – 60 m³ oxygen. To eliminate sulphur it is necessary to use a high basicity slag in a completely reduced liquid steel. Reduction materials, such as aluminium or silicon and lime are charged in the AOD converter. The consumption levels depend on the quality of the steel grade and are given in Table 3.18.

Compound	Consumption (per tonne of steel)
CO	50 – 120 m³
O_2	25 – 60 m³
Al	1 – 2.5 kg
Lime	10 – 20 kg
Si	1 – 2 kg
Ar	1 – 5 m³

Table 3.18: Consumption levels for the AOD treatment of steel [202, TWG, 2002]

3.2.6.2 Output

Dust emissions are comparable to EAF furnaces' dusts, both in quantity and quality. AOD dust emissions have lower levels of residuals (organic) from the scrap charge, but on the other hand have a higher level of metal oxide (Cr, Ni), as it is mainly stainless steel which is processed in AOD vessels.

3.2.6.3 Waste gases

The effluent from the mouth of an AOD consists of carbon monoxide and inert gas. The rate of carbon monoxide evolution depends on the tuyères oxygen injection rate and the oxygen efficiency, or per cent of oxygen which reacts with carbon. This oxygen efficiency, or "carbon removal efficiency", as it is traditionally labelled in AOD operation, varies during the course of an AOD blow, in response to combined variables of the bath carbon level, temperature, bath chemistry, and the mixture of injected gases.

The CO and inert gas mixture leaves the vessel approximately at the bath temperature. The CO mixture exiting the vessel is mixed with excess air in order to fully burn the CO to CO_2 very early in the exhaust duct. This is done to prevent the presence of combustible or explosive mixtures persisting downstream into the duct to the filter equipment.

3.2.6.4 Slags

Slag is particularly "clean" from metal oxides, since, due to the peculiarity of the process, they are usually consumed. The slag composition is given in Table 3.19.

Compound	%
CaO	50 – 70
Al_2O_3	5 – 25
SiO_2	10 – 25
MgO	5 – 15

Table 3.19: AOD slag composition
[202, TWG, 2002]

3.2.7 Vacuum Oxygen Decarburisation Converter (VODC)

The VODC process involves decarburisation under reduced pressure. It is much less used than the AOD process. Vacuum processes (EAF/vacuum) accounted for 5.8 % of the Western World's stainless steel production in 1991. The technique consumes 1 Nm^3 Ar per tonne of steel, shows low chromium oxidation and has a silicon consumption of 3 – 5 kg/tonne. The VODC allows the production of ultra-low-carbon and nitrogen grades. [202, TWG, 2002]

3.2.8 Steel refining and treatment

For deoxidation, aluminium is commonly used in the form of a stick. Additions vary from 0.1 % for medium carbon steel to 0.2 % for low carbon steel. Recovery is between 35 % and 80 %. Mechanical feeding of aluminium wire is also used. [174, Brown, 2000].

3.2.9 Cast iron treatment

3.2.9.1 Nodularisation

The efficiency, the qualitative assessment of flue-gas production and the complexity of the various nodularisation methods are compared in Table 3.20.

	Sandwich	Tundish cover	Plunging	Flow through	Wire injection	Inmold	Ductilator
Mg- take-up efficiency (%)	35 – 50	45 – 60	40 – 60	40 – 50	20 – 50	70 – 90	60 – 75
Flue-gas production	High	Low	Low	Low	Low	No	High
Comment	Easy operation	Optimised sandwich but more maintenance	High maintenance	High maintenance	Expensive installation	Different design of pouring system	High maintenance

Table 3.20: Comparison of various nodularisation procedures
[110, Vito, 2001], [225, TWG, 2003]

3.3 Melting and the metal treatment of aluminium

3.3.1 Survey of melting furnaces for aluminium

Table 3.21 shows typical furnace properties, consumption and emission data for various types of aluminium melting furnaces. Due to the wide range of furnace capacities and set-ups, the literature data does not always provide consistent consumption ranges. Consumption levels are highly dependent on the furnace capacity and exploitation conditions, such as metal temperature and charge density.

The use of a pure starting material and mainly electric and gas-fired heating, results in relatively low emission levels from the melting. Due to the limited concern about off-gas quality, information on the flue-gas composition is limited.

In an aluminium melting operation there is no generation of metal fume and the metal is only lost when dross forms. This type of loss is often calle the loss by burning and is an oxidation of the molten metal. It depends on the amount of covering slag and whether combustion occurs. It is brought about by a leakage of air into the furnace or by the malfunction of the burner. The costs for this loss can be high, sometimes even being higher than the energy costs. [148, Eurofine, 2002]

Data for each of the specific furnace types will be discussed and detailed in the subsequent sections.

	Units	Rotary furnace	Hearth type furnace	Shaft furnace	Crucible furnace		
Subtype			One chamber		Fuel heated	Resistance heated	Induction
Energy sources		Fuels (liquid, gaseous)	Fuels (liquid, gaseous)	Fuels (liquid, gaseous)	Fuels (liquid, gaseous)	Electricity	Electricity
Thermal efficiency[1]	%	15 – 40	<30 – 57	35 – 60	15 – 40	65	65 – 70
Primary thermal efficiency[2]	%	15 – 40	<30 – 57	35 – 60	15 – 40	22	22 – 25
Spec. Energy demand[3]	kWh/t Al[4]	600 – 1250	975 – 1150	580 – 900 *610 – 720*	900 – 1200 *610 – 680*	750 *470 – 590*	475 – 640 *440 – 470*
Batch/continuous		Batch	Batch	Continuous	Batch	Batch	Batch
Melting capacity	t	3 – 10	0.5 – 30	0.5 – 4 (-15)	0.1 – 1.2	0.1 – 0.4	0.2 – 25
Holding capacity	t	n.a	n.a	1.5 – 10	0.1 – 1.5	0.1 – 1.5	0.15 – 6
Meltdown time		2 – 4	3 – 4	0.5 – 1	0.5 – 1	4 – 5	0.2 – 0.5
Refining ability		Low	Low	Low	Good	Very good	Low
Loss by burning	%	n.d	n.d	1 – 3	1 – 2	1 – 2	1 – 2
Dust generation	kg/t Al[4]	n.d	<1	<1	<1	Minor	Minor
NO_x [5]	kg/t Al[4]	n.d	<1 – 6	<1 – 6	<1 – 6	n.a	n.a
Investment costs[6]	EUR '000	n.d	n.d	190 – 370	20 – 50	12 – 100	190 – 500
Running costs	EUR '000	n.d	n.d	20 – 100	3 – 20	15 – 45	35 – 150
Abatement techniques		Bag house filter for bigger installations	Bag house filter for bigger installations	Bag house filter for bigger installations	Typically not necessary due to small furnace size	Not necessary	Not necessary

[1] Definition: the relationship between the heat of the molten bath and the fuel heat supplied; indicated values give an order of magnitude but largely depend on the exploitation conditions, such as the metal temperature
[2] Efficiency of electrical power generation (fuels) assumed to be 35 %
[3] Depends on heat recovery measures; only valid for melting; values given by [148, Eurofine, 2002] *in italics*
[4] Units 'per tonne Al' refer to tonne of molten aluminium alloy
[5] Depends on burner design and operational performance
[6] Depends on heat recovery measures; only valid for melting
Sources of information: VDG internal survey; Aluminium Taschenbuch, Band 2, 15. Auflage, Aluminium Verlag GmbH, Düsseldorf, 1996; Aluminium recycling, Aluminium Verlag GmbH, Düsseldorf, 2000; [148, Eurofine, 2002]; comments CTIF

Table 3.21: Typical furnace properties and emission data for aluminium melting [148, Eurofine, 2002] and comments from CTIF and VDG

3.3.2 Shaft furnace

Input	Output
– aluminium ingots, foundry returns	– molten aluminium
– energy	– dust
– deoxidation and gas removal products	– NO_x, CO
	– used refractory

Emission factors have been provided for emissions per tonne of good casting, based on the following assumptions:

- average molten metal yield: 70 % (casting/molten metal)
- average scrap value: 5 % (scrap from finishing/casting)
- global metal yield: 0.7 x 0.95 = 66.5 % (good casting/molten metal)

Consumption and emission data per tonne of good casting for a 3 t/h shaft furnace, melting aluminium are given in Table 3.22. This also gives the flue-gas emission levels of the raw off-gas without cleaning.

Input	**Value per tonne**	**Value per Nm³**
Aluminium ingots	1503 kg/t	
Natural gas	717 kWh/t	
Electric energy	172 kWh/t	
Total energy use	889 kWh/t	
Output		
Slag (with 35 – 40 % Al)	40.3 kg/t	
Used refractories	0.3 kg/t	
Emissions (without flue-gas cleaning)		
Particles	0.12 kg/t	112 mg/Nm³
NO_x	0.18 kg/t	113 mg/Nm³
VOC	0.12 kg/t	
SO_2	0.04 kg/t	
CO		150 mg/Nm³
Pb + Cr + Cu		0.98 mg/Nm³
Cd + Hg		0.01 mg/Nm³
As + Ni		0.03 mg/Nm³
Data are calculated values per tonne of good casting		

Table 3.22: Input and output for aluminium melting in a shaft furnace [177, Silva Ribeiro, 2002]

Table 3.23 gives the consumption levels for a two tonne melting capacity shaft furnace melting aluminium.

	Total measured consumption	**Specific consumption per tonne of charged metal**
Metal charges	115332 kg (54 % ingot, 46 % scrap)	1 tonne
Metal tapped	113983 kg	0.988 kg/tonne
Metal loss	1349 kg	0.012 kg/tonne – 1.2 %
Dross removed	1412 kg	0.012 kg/tonne – 1.2 %
Gas consumption	92786 kWh	804 kWh/tonne

Table 3.23: Results from a 6-day trial melt in a 2 tonne melting capacity shaft furnace for Al [48, ETSU, 1994]

3.3.3 Induction furnace

Input	Output
– aluminium ingots, foundry returns	– molten aluminium
– electrical energy	– dust
– cooling water	– used refractory

Aluminium induction furnaces usually range from 500 kg to 2 tonnes capacity and operate at frequencies of 250 – 1000 Hz.

For example, in one installation, two 1.5 tonne aluminium capacity steel shell tilters are powered by a 1250 kW, 250 Hz power supply with a change-over switch which allows alternate furnaces to be melted. With this system 1.5 tonnes can be melted in 40 minutes.

Induction furnaces are energy efficient melters. The energy consumption for melting is affected by the density of the charge and the melting practice used. Batch melting is less efficient than using a molten heel. A 50 % molten heel is the most efficient. The energy consumption varies from 540 kWh/tonne for a high bulk density charge (small scrap and ingot) to 600 kWh/tonne if a lower density scrap (such as pressure die-casting runners and ingot) is melted. While the energy consumption is low, the costs for melting may be higher than for gas-fired furnaces because of the generally higher cost of electricity as a source of heat. [175, Brown, 1999] [148, Eurofine, 2002]

The induction furnace coil needs a cooling system. Cooling water may run in a closed circuit or in an open evaporative system.

3.3.4 Radiant roof furnace (resistance heated)

These resistant heated furnaces are holding furnaces, mainly used for aluminium alloys. The emission depends on the used metal, the holding-temperature, the surface area and the "metal out" and "metal in" and especially of the holding-time. The emissions are so low that no measurements are available. [202, TWG, 2002]

3.3.5 Hearth type furnace

Hearth type (or reverberatory) furnaces exist in various sizes and shapes. Large hearth type furnaces allow rapid melting and can handle bulky charge material, but the direct contact between the flame and charge material may lead to high metal losses, gas pick-up and to considerable oxide contamination. Temperature control can also be difficult. This type of furnace is used less because of its relatively low thermal efficiency (around 1100 kWh/tonne). The hearth type furnace is also used for copper alloy melting (see Section 3.5.1). [175, Brown, 1999]

Table 3.24 gives the emission data for a 450 kg/h oil-fired hearth type furnace melting aluminium, and working without a flue-gas treatment system.

Compound	Emission level (mg/Nm³)	Mass flow (g/h)	Yearly mass flow (tonne/yr)
O_2	17.6 %		
CO_2	2.2 %		
CO	<4	<24	<0.0438
NO_x	45	270	0.4928
SO_2	13	78	0.1424
dust	1	6	0.011
TOC	5	30	0.0548
Al	0.092	0.552	0.001
Flue-gas flow: 6000 Nm³/h (dry); operational hours: 1825 h/yr			

Table 3.24: Emission data for an oil-fired hearth type furnace melting Al [183, Goovaerts, 2002]

3.3.6 Crucible furnace (fuel and resistance heated)

Input	Output
– aluminium ingots, foundry returns or liquid aluminium if used as a holding furnace – electrical energy or fuel	– molten aluminium – dust

Crucible furnaces are indirectly heated using fuel-fired burners or electrical resistors. For fuel-fired crucibles, the thermal efficiency is not as high as for other melting furnaces, since it is difficult to make use of the heat of the combustion products. They are relatively inexpensive and since the flames are not in contact with the molten metal, metal losses are low and the melt quality is high, and also alloy changes can be readily carried out. [175, Brown, 1999]

For aluminium alloys the amount of particles can roughly be assumed to be around 0.3 kg/tonne of molten metal. [126, Teknologisk, 2000]

Consumption and emission data per tonne of good casting for a 3 t/h crucible furnace, melting aluminium are given in Table 3.25.

Input	
Natural gas	538 kWh/tonne
Electricity	414 kWh/tonne
Total energy input	952 kWh/tonne
Output	
Slag	61 kg/tonne
Refractories	6.87 kg/tonne
Emissions (after bag house)	
NO_x	0.18 kg/tonne
SO_2	0.04 kg/tonne
VOC	0.12 kg/tonne
Dust	0.12 kg/tonne
All data are calculated values per tonne of good casting	

Table 3.25: Consumption and emission data for the crucible melting of aluminium [177, Silva Ribeiro, 2002]

3.3.7 Aluminium melt treatment

For the combination of degassing and cleaning in an impeller station, a mixture of argon or nitrogen with 3 % Cl_2 is generally used. For degassing alone, the gases Ar or N_2 are generally used without Cl_2. The applied flow and degassing time depend on the type of alloy used and the size of the treatment vessel.

The consumption of modification agents, grain refiners and fluxes depends on the type of alloy, but is generally in the order of 100 g – 1 kg per 50 kg of molten metal.

3.4 Melting and casting of magnesium and magnesium alloys

3.4.1 Magnesium melt protection

SF_6 and SO_2 are used as a covering gas to prevent the oxidation (or burning) of molten magnesium. Since SF_6 is more easy to handle than the toxic SO_2, it became the preferred cover gas after its introduction in the mid 1970s. SF_6 has a global warming potential (GWP) of 22200 (for a 100 years time horizon) and an atmospheric lifetime of 3200 years [194, UNEP IPCC, 2002].

The quantities of SF_6 used in various operating conditions are given in Table 3.26 (pressure die-casting) and Table 3.27 (gravity die-casting). These concentrations need to be maintained close to the melt surface [191, IMA, et al.]. The tabled values are the recommended practice for the use of SF_6 from the International Magnesium Association (IMA). In practice, higher concentrations are sometimes used (e.g. 99.4 % CO_2, 0.6 % SF_6) [202, TWG, 2002].

Melt temp. (°C)	Atmosphere over the melt (vol %)	Surface agitation	Residual flux[1)]	Melt protection
650 – 705	Air/0.04 SF_6[2)]	No	No	Excellent
650 – 705	Air/0.2 SF_6	Yes	No	Excellent
650 – 705	75 air/25 CO_2/0.2 SF_6	Yes	Yes	Excellent
705 – 760	50 air/50 CO_2/0.3 SF_6	Yes	No	Excellent
705 – 760	50 air/50 CO_2/0.3 SF_6	Yes	Yes	Very good
1) May be present from prior operations 2) Minimum concentration under controlled conditions Note: Dry air (<0.1 % H_2O) should be used in the mixing				

Table 3.26: The use of SF_6 in pressure die-casting operations under various operating conditions [191, IMA, et al.]

	Quiescent (melting/holding) low gas flowrate		Agitated (alloying/pouring) high gas flowrate	
Crucible diameter (cm)	SF_6 (ml/min)	CO_2 (l/min)	SF_6 (ml/min)	CO_2 (l/min)
30	60	3.5	200	10
50	60	3.5	550	30
75	90	5	900	50
Note: The suggested flowrates are 1.7 % – 2 % SF_6 by volume				

Table 3.27: Use of SF_6 in gravity die-casting operations [191, IMA, et al.]

To date the only flux-free alternative to SF_6 is SO_2. In an undisturbed melt, the use would be typically 1 - 2 % in air or nitrogen at a flowrate of 5 to 10 l/min. [182, Closset, 2002], [218, Harnisch and Schwarz, 2003]

In 2001, the overall EU production of magnesium parts totalled 39100 tonnes, 37 % of which were produced with SO_2 and 63 %, or 24500 tonnes, with SF_6 (see Figure 3.4). This issue is discussed further in Section 4.2.7.1.

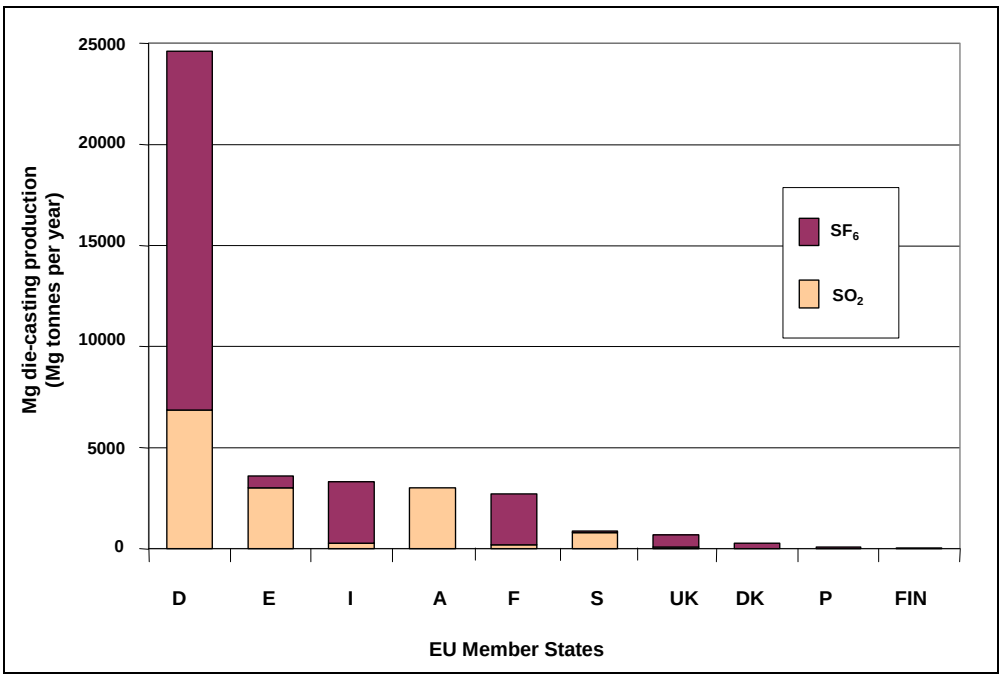

Figure 3.4: Mg die-casting production in tonnes/yr by EU states and by cover gas (SO_2 or SF_6) (data 2001)
[218, Harnisch and Schwarz, 2003]

3.4.2 Magnesium melt treatment

Magnesium alloys containing aluminium are treated with hexachloroethane (HCE) for grain refinement. This treatment applies for alloys for sand and gravity die-casting, which makes up some 10 % of the total magnesium alloys. The required amount of HCE depends on the type of component to be manufactured and existing data based on the experience of the individual foundries. An approximate value of 2 kg of HCE per tonne of aluminium containing magnesium alloy has been reported. [178, Wenk, 1995]

3.4.3 Magnesium scrap

In a Mg die-casting foundry, the amount of return materials (Mg- scrap) is nearly equivalent to the amount of good die-castings. About 80 % of the return material complies with scrap grade class 1 (see Table 3.28).

Class	Description
Class 1	Clean, compact scrap with known composition Feeders: clean Press residues: clean Bad castings: clean, uncoated
Class 2	Scrap castings, painted (partly inserts of Fe, Al, no copper and nickel contamination)
Class 3	Unclean compact metal scrap (oily, wet, contaminated with sand, copper, nickel, ferrosilicon), i.e. mostly post consumer scrap
Class 4	Turnings: clean, dry Turnings: oily, wet Scales, flashings, runners: oily, wet
Class 5	Dross (from metal surface)
Class 6	Crucible slag
Class 7	Flux containing scrap, used salt (black dross)
Class 8	Non–metallic residue
Class 9	intermetallics

Table 3.28: Magnesium scrap grade classes
[206, Ditze and Scharf, 2000]

3.5 Melting and casting of copper and copper alloys

3.5.1 Melting and casting units

Copper and copper alloys are generally melted in crucible furnaces. These furnaces generally operate within the following ranges:

- charge: 30 – 1800 kg
- capacity: 30 – 400 kg
- energy consumption (oil): 0.4 l/kg
- energy consumption (butane): 0.3 Nm^3/kg

Medium frequency induction furnaces are also used with silica or alumina linings.

Table 3.29 gives a typical mass balance for a brass foundry manufacturing taps. Data are given for combined melting and low-pressure die-casting operations (but without finishing and core-making). All data refer to tonnes of good castings sold. The data apply to melting in a gas-fired crucible furnace, with 1 tonne/h capacity.

Input	
Electric energy	1360 kWh
Propane gas	14
Compressed air	48 kWh
Water	85.7 l
Gas removal tablets	0.6 units
Deoxidant	0.9 units
Copper alloy	0.44
Cover flux	0.31
Cores	286
Graphite paint	3.4
Output	
Non-poured sand	101
Poured sand	6.7
Graphite paint	61.4 l
Zinc powder	0.075
Slag	36.3
Brass scrap	57.1
Brass swarf	18.4
Emissions (without flue-gas cleaning)	
Dust	3.9
VOC	3.3
SO_2	0.1
NO_x	0.03
Copper	0.081
Zinc	26.3
All data per tonne of casting sold, data in kg unless stated differently	

Table 3.29: Mass balance data for a brass low-pressure die-casting foundry (melting + die-casting operations)
[177, Silva Ribeiro, 2002]

For copper alloys, the amount of particles emitted greatly depends on the zinc content of the alloys. As a guide the values in Table 3.30 show the relationship between the quantity of particles emitted and the zinc content.

	Zn content (%)	Particle emissions (kg/tonne molten metal)
Bronze	0 – 7	0.3 – 1.5
Brass	20 – 40	0.5 – 16

Table 3.30: Particulate emissions from the crucible melting of copper alloys [126, Teknologisk, 2000]

The production of slags and dross is around 60 kg/tonne of molten metal. This value is similar for melting in induction or hearth type furnaces and for various copper alloys. The composition of the slag depends on the type of alloy melted. In general the copper content is in the 45 – 55 % range. A constant slag quality may be attained by specific mixing of the various slag types from the foundry. This constant quality is needed for external recycling.

The production of refractory waste is 8 – 9 kg/tonne of molten metal for induction melting and 7.5 kg/tonne of molten metal for oil-fired hearth type furnaces.
[34, Binninger, 1994]

3.5.2 Copper and copper alloy melt treatment

When the bubbling of inert gas is used for the degassing of copper, 50 – 70 litres of gas are used for each 100 kg of copper. An alternative is the use of specific tablets or briquettes. Degassing treatment usually takes 3 – 10 minutes depending on the size of the melt. The precise amount of deoxidant needed depends on the melting practice used.
[175, Brown, 1999]

3.6 Melting and casting of zinc and zinc alloys

Table 3.31 gives a typical mass balance for a zinc foundry using pressure die-casting. It applies to the casting of zamac (ZnAl4Cu1 or ZnAl4). Zinc alloy ingots are melted together with rejects and feeders in a gas-fired crucible furnace of the casting machine. A release agent is sprayed on the die before casting. The casted piece is cooled in a water bath and the feeder system is removed. The casting is subsequently degreased and ground. The melting off-gas is collected and dedusted in a dry system. Data on core production and finishing are given in Section 3.9 and 3.11.

Input	
Zinc alloy	1040
Casting rejects	50
Feeders	450
Release agent	20 l
Water	1 m³
Electrical energy	700 kWh
Natural gas	70 Nm³
Output	
Good castings	1000
Swarf	3
Dross	30
Sludge from washing and grinding	2
Off-gas	10000 Nm³
Particulates	1
All data per tonne of good casting, data in kg unless stated different	

Table 3.31: Typical mass and energy data for zinc pressure die-casting

3.7 Melting and casting of lead

Casting processes for lead may be divided into:
- pressure die-casting of lead
- casting for storage batteries
- sand casting for protective screens.

3.8 Waste gas cleaning

3.8.1 Abatement systems

Various waste and exhaust gas cleaning techniques are used in the foundry industry. Their principles are discussed in the BREF document for non-ferrous metal industries. The properties and emission levels of dust abatement systems are given in Table 3.32. A full discussion on the selection of the abatement technique, its applicability in the various foundry processes and the achievable emission levels is given as part of the techniques to be considered in the selection of BAT in Section 4.5.

Technique	Particle Size (µm)	Collection Efficiency at 1 µm (%)	Maximum Operating Temperature (°C)	Range of Achievable Emissions (mg/Nm^3)	Comments
Hot EP	<0.1	>99 Depending on design	450	5 – 15 (Pre abatement >50)	4 or 5 zones. Usual application is pre-abatement
Wet EP	0.01	<99	80	1 – 5 (Visually clear)	EP with 2 zones in series. Mainly mist precipitation
Cyclone	10	40	1100	100 – 300	Coarse particles. Used to assist other methods
Fabric Filter	0.01	>99.5	220	1 – 5	Good performance with suitable dust type
Wet Scrubber	1 – 3	>80 – 99	Inlet 1000 Outlet 80	4 – 50	Good performance with suitable dusts. Acid gas reduction
EP: Electrostatic precipitator					

Table 3.32: Example of current emisions from some dust abatement applications [155, European IPPC Bureau, 2001]

3.8.2 Dioxins

In melting processes, dioxins may be produced if the conditions that give rise to such pollutants are present at the same location and time in the process. These conditions are:
- the presence of chloride ions – these can arise from contaminated scrap, from the use of coal, coke, fuel oil or from certain fluxes
- the presence of organic carbon – this may arise from contaminated scrap and from coal, coke or oil used as a fuel
- temperature conditions between 250 ºC and 450 ºC, with a sufficient gas residence time in this temperature interval
- the presence of a catalyst such as copper
- the presence of oxygen.

In evaluating the risk of dioxin formation, a distinction can be made between non-ferrous and ferrous foundries:

- *Non-ferrous foundries*: In as far as when only ingots and internal scrap are melted, the risk of dioxin formation in the melting stage is very low. The melting of pure non-ferrous metals lacks the presence of both the chlorine and carbon required for dioxin (re)formation. However, the re-melting of external non-ferrous scrap materials for metal production may involve a risk of dioxin formation. This action, however, falls beyond the scope of this document and is considered in [155, European IPPC Bureau, 2001]
- *Ferrous foundries*: Depending on the furnace type and metal load the conditions for dioxin formation could occur. Considering the high temperatures in the melting furnace, dioxin emission (if occurring at all) will mainly generate from *de-novo* synthesis. The above-mentioned conditions can be used to evaluate the risk of dioxin formation.

Dioxin emission data have been gathered from a broad range of sources. Table 3.33 presents data for various metals and furnace types. Blank spaces indicate that the indicated number was not specified. All systems in the survey do not provide specific dioxin capture techniques. A distinction can be made between two groups of techniques where dioxin levels are very low (<0.05 ng/Nm³) or cover a wide range (<0.01 – 3 ng/Nm³). The first group covers aluminium melting, the induction melting of iron and the EAF melting of steel. The second group covers cupola melting and the rotary melting of iron. An analysis of the literature data does not provide a full contribution of the reasons for the differences within the second group. However, it can be seen that the presented HBCs with a wet scrubber system show noticeably lower PCDD/F emission values.

Product type	Furnace	Melting (tonne/h)	Flue-gas (m³/h)	Abatement	O_2 (%)	PCDD/F (ngTEQ/Nm³)
Aluminium	Hearth type	n.d	n.d		n.d	0.002
Aluminium	Hearth type	0.45	9300	None	18.8	0.002
Aluminium	Shaft	1.5	8400	None	18.4	0.01
Cast iron	CBC	3.4	15900	Bag filter	n.d	0.04
Cast iron	CBC	3.7	14300	Bag filter	16	0.09
Cast iron	CBC	4.5	14300	Bag filter	n.d	0.09
Cast iron	CBC	3.4	n.d		n.d	0.33
Cast iron	CBC	5.5	17400	Bag filter	15.9	0.51
Cast iron	CBC	6.5	17500	Bag filter	n.d	0.51
Cast iron	CBC	6	27600	Bag + PC	n.d	3.14
Cast iron	HBC	45.5	55000	Disintegrator	6	0.003
Cast iron	HBC	60	n.d	Disintegrator	n.d	0.003
Cast iron	HBC	40.6	75000	Bag filter	12.5	0.05
Cast iron	HBC	50	75000	Bag filter	n.d	0.07
Cast iron	HBC	15	36400	Bag + PC	n.d	0.05
Cast iron	HBC	13	n.d		n.d	0.10
Cast iron	HBC	18.2	29100	Bag filter	8.6	0.20
Cast iron	HBC	17.1	22500	Bag filter	7.5	0.29
Cast iron	HBC	27	n.d		n.d	1.00
Cast iron	HBC	28	37000	Bag filter	n.d	2.08
Cast iron	HBC	21	32000	Bag + PC	n.d	3.09
Cast iron	IF	19.5	208000	Bag filter	20.2	0.003
Cast iron	IF	n.d	n.d	Bag filter	n.d	0.01
Cast iron	RF	8	n.d		n.d	0.004
Cast iron	RF	1.4	9000	None	n.d	0.02
Cast iron	RF	2.1	18600	Bag filter	19.9	0.45
Cast iron	RF	3.5	n.d	Bag filter	n.d	0.61
Steel	EAF	5.4	54150	Bag filter	20.9	0.003
Steel	EAF	9	5000	Wet scrubber	n.d	0.02
CBC: Cold blast cupola; HBC: hot blast cupola; RF: rotary furnace; IF: induction furnace; EAF: electric arc furnace;						

Table 3.33: Dioxin emission data for various foundry types
[21, Strauß, 1994], [23, Brettschneider and Vennebusch, 1992], [27, Kran, et al., 1995], [43, Batz, 1996], [110, Vito, 2001], [202, TWG, 2002], [225, TWG, 2003], personal communications

The dioxin emission data for the various ferrous metal melting furnaces are discussed below.

- *Cupola furnaces*: In cupola furnaces, a massive surplus of chlorine is always present from coke. Enough carbon is present from coke too, but an additional input of carbon may be needed the event of caused by poor scrap qualities. Under specific operational conditions, the conditions for dioxin formation could occur. Since *de novo* synthesis mainly occurs during cooling of the flue-gas, this applies to both hot blast and cold blast cupolas. In Table 3.34, the result of a statistical analysis of all the measurement data from Table 3.33 for CBC and HBC is given. Whereas Table 3.33 presents average values per plant, for Table 3.34 individual measurements were used to perform an overall analysis.

	Units	Cold blast	Hot blast
Average	ngTEQ/Nm³	0.54	0.75
St. dev.	ngTEQ/Nm³	1.08	1.3
Median	ngTEQ/Nm³	0.18	0.09
Minimum	ngTEQ/Nm³	0.001	0.001
Maximum	ngTEQ/Nm³	5.1	4.4
Number of measurements		35	18
Number of furnaces		11	11

Table 3.34: Cupola furnace dioxin emissions
[21, Strauß, 1994], [23, Brettschneider and Vennebusch, 1992], [27, Kran, et al., 1995], [43, Batz, 1996], [110, Vito, 2001], [202, TWG, 2002], [225, TWG, 2003], personal communications

Data from a German survey (6 installations, 18 measurements) showed a range of 0.006 - 0.22 ng TEQ/Nm³, with an average of 0.0724 ng TEQ/Nm³ (0.0608 i-TEQ/Nm³). The data set of the survey partially overlaps with the data set presented above, but it did not give sufficient information to expand it. [224, Helber, et al., 2000]

The data show that the average, the standard deviation and the range of values are similar for both cold blast and hot blast furnaces. The median value for hot blast is lower than for cold blast furnaces. This confirms the statement from [224, Helber, et al., 2000] that there is no statistical difference between dioxin emissions for hot and cold blast cupola furnaces. The high standard deviation shows that the data should be interpreted on a plant-by-plant basis rather than on an averaged basis.

For wet dedusting with a disintegrator, the off-gas passes through the critical temperature window (250 – 450 ºC) after dedusting, i.e. with a low dust content. Additionally, chlorides have been washed out. This strongly reduces the risk of *de novo* synthesis.

- *Rotary furnaces*: Due to the limited possibility of alloying, the rotary furnace charge generally consists of clean material. Due to the high flame temperature, the hot gases leave the furnace at temperatures of between 1000 and 1300 ºC. Post combustion occurs inside the furnace volume. *De novo* synthesis is possible if flue-gases cool slowly. Reported data range from 0.004 – 0.61 ngTEQ/Nm³.

- *Induction furnaces*: Due to the limited possibility of alloying, the induction furnace charge generally consists of clean material. Furthermore the furnace does not produce a ducted high temperature flue-gas stream that cools down slowly.

- *Electric arc furnaces*: EAF furnaces allow melt treatment and alloying if operated in basic lining practice. This enables the use of dirty scrap as a raw material for melting. If scrap containing organic and/or chlorinated compounds is charged, dioxins may be formed during cooling of the flue-gas stream. This may be the case when using scrap from e.g. electronic equipment, transformers, and shredded vehicles. The EAF in acid lining practice does not allow metal treatment and therefore the possibility for feeding contaminated scrap is reduced. This also reduces the risk of dioxin formation.

[161, UK Environment Agency, 2002]

3.9 Mould and core production

3.9.1 Introduction

Mould and core production involves mixing sand with various chemicals, in some cases followed by a heating step. Gaseous or volatile reaction-products and excess reagents are emitted. Table 3.35 presents a survey of the emissions and other environmental impacts during the mixing, setting and storage of the moulds and cores. A further discussion of the emission and consumption levels for each of the binder types is given in the subsequent sections.

System name and binder constituents	Setting method and relative energy requirement	Emissions to air during mixing and setting	Other environmental impacts
GREEN SAND Clay Coal dust or substitute Water	Pressure – low	Particulate matter – no significant emission to the environment	Sand spillage around conveyors needs to be avoided to reduce the likelihood of fugitive emissions. Abatement from the mixing process is not essential (the process is usually self-contained with displaced air vented to the foundry)
SHELL SAND Phenol - formaldehyde (Novalak) Resin	Heat - high	Formaldehyde* Ammonia* Phenol* Aromatics HCN	Odour can be an issue as the shell machines are normally extracted to air
ALKALINE PHENOLIC Resol - Alkaline phenol-formaldehyde resin 1. Gas hardened (alkaline phenolic cold-box) 2. Self-setting (alkaline phenolic no bake)	Gas hardened with methyl formate vapour – low Cold-set with esters - low	Formaldehyde* Phenol* Methyl formate Formaldehyde* Phenol* Esters	
PHENOLIC URETHANE 1. Gas hardened: Cold-box 2. Self-setting (phenolic urethane no bake)	Amine vapour – low Self-set with substituted pyridine – low	Isocyanate (MDI) Amine* Formaldehyde* Phenol Isocyanates (MDI) Formaldehyde* Phenol	Odour is frequently a problem – where DMEA is used odours arise and abatement is essential. This may be incineration or gas scrubbing (using sulphuric or phosphoric acids) – the latter gives rise to liquors, which are a special waste. Where TEA is used scrubbing is only required if odour problems arise
FURAN Combination resins of: Phenol Urea Furfuryl alcohol Formaldehyde	Cold-set with acids – low	Formaldehyde* Phenol* Furfuryl alcohol* Hydrogen sulphide Acid mists	Resins and acids must be kept apart (unless sand is present) as they are vigorously exothermic when in contact
HOT-BOX Combination resins of: Phenol Urea Furfuryl alcohol Formaldehyde	Heat – high	Formaldehyde* Acids Furfuryl alcohol* Phenol* Ammonia Isocyanic acid Methyl isocyanate	Odour can be an issue as the shell machines are normally extracted to air

System name and binder constituents	Setting method and relative energy requirement	Emissions to air during mixing and setting	Other environmental impacts
OIL SAND Linseed oil and starch	Heat – high	Acrolein* Complex organics	Odour can be an issue as the core ovens are often extracted to air
CO_2 PROCESS Sodium silicate	Gas hardened with CO_2 gas – low	None	
SILICATE ESTER Sodium silicate	Cold-set with esters – low	Esters	

Note 1: All the above processes give rise to spent sand (including broken cores, spillage and mixer residues) that may go to landfill
Note 2: Substances marked with * are those most likely to give rise to odour from the process referred to
Note 3: Any resin binder component would be regarded as special waste for disposal purposes and if spilled could give rise to a risk of contamination of water systems
Note 4: Amines and methyl formates used for gas hardening are highly flammable and odorous. The avoidance of leaks in storage is essential

Table 3.35: Environmental impact from binder systems
[126, Teknologisk, 2000], [160, UK Environment Agency, 2002], [225, TWG, 2003], [229, Lilja, et al., 2000]

Quantitative data for dust emissions from moulding shops have been gathered in an Italian foundry survey. The results are given in Table 3.36. All exhaust cleaning systems attain a level <15 mg/Nm³.

	Concentration (mg/Nm³)			Emission factor (g/tonne)*		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Bag filter	3.2	0.4	12.1	24.4	0.5	108.3
Wet scrubber	5.2	3.6	6.7	6.2	4.0	8.0
Wet Venturi system	9.6	8.5	10.9	34.2	30.1	39.9

Units: g/tonne of good casting
Number of data points: bag filter: 33; wet scrubber: 4; wet venturi system: 3

Table 3.36: Emission values and emission factors for dust emissions from moulding shops after exhaust cleaning
[180, Assofond, 2002]

The emissions given in Table 3.35 refer to the stages of mixing, setting and storage of the moulds and cores. Most emissions persist during the metal pouring and casting cooling stages, but now with the addition of pyrolysis products. These will be discussed in Section 3.10.1.

Table 3.37 gives dust emission data from a German measurement campaign. The dust was analysed into PM_{10}, $PM_{2.5}$ and PM_1 fractions.

Activity	Off-gas volume (Nm³/h)	Gas cleaning equipment	Total dust (mg/m²)	PM_{10} (%)	$PM_{2.5}$ (%)	PM_1 (%)
Sand preparation	25600	Bag filter	0.3			
Green sand preparation	24400	Fume hood, bag filter	0.7	88	38	
Sand preparation	70400	ESP	22 – 28.3	79	18	
Core shop	4670 (dry)	Amine washer	0.7	98	47 – 62	
Moulding shop	52300 (dry)	Bag filter	0.7	95 – 97	50 – 60	2 – 5
Finishing	22000 (dry)	Bag filter	5.3	100	45 – 48	9

Table 3.37: Example dust emissions and particle size for mould and core-making
[202, TWG, 2002]

3.9.2 Moulding with clay-bonded sand (green sand moulding)

Input	Output
– sand – bonding clay (e.g. bentonite) – coal dust, dextrin – water (to prepare moulding mix)	– green sand moulds – dust (silica fines, partially burnt-out clay, unburned coal dust and ash)

The composition of the bentonite added to the sand depends on the specific properties of both the sand and the bentonite, as well as on the desired strength and gas permeability of the finished mould. Table 3.38 gives some parameters of clay-bonded sand, as obtained from a selection of 105 sand samples taken from iron foundries.

Parameter	Units	Average	% of samples in range of average ± 10 %		Maximum value	Minimum value
			Range	%		
Water content	%	4.1	3.4 – 4.5	48	6.9	2.4
Bentonite content	%	8.3	7.5 – 9.1	45	11.9	5.6
Density	g/cm³	0.940	1.00 – 0.85	75	1.06	0.73
Loss on ignition	%	5.0	4.5 – 5.5	20	15.0	1.0
Compressive strength	N/cm²	18.6	16.7 – 20.5	54	24.5	13.2

Table 3.38: Typical properties of green sand, measured on 105 sand samples from 105 iron foundries
[36, Winterhalter, et al., 1992]

Further additives are mixed in the green sand mixture:

- *Coal dust*: Used mainly in iron foundries, but also to a lesser degree in some non-ferrous foundries. Coal dust levels in green sand vary from 2 or 3 % for small castings, to 7 or 8 % for heavy section castings. Too much coal dust can give rise to holes in the castings or in misruns. Various coal dust replacement products exist. They are generally added in a slightly altered concentration compared to the coal dust
- *Cereal binders*: Starch and dextrin are used mainly in steel foundries to avoid defects caused by silica expansion and to control moisture excess in the sand mix. Effective additions of cereal binders to new green sand facing mixes are between 0.5 and 0.75 %. In unit type green sands, part of the cereal is destroyed during the casting process. The recommended addition on each recycle is 0.1 to 0.25 %, depending on the amount of cereal burn-out and on the dilution by cores and new sand.

[174, Brown, 2000], [225, TWG, 2003]

3.9.3 Moulding with unbonded sand (V-process)

Input	Output
– dry sand – PE sheets – energy (produce and maintain vacuum)	– moulds – dust

The thermal shock induced by the contact of the molten metal breaks up the sand grains, generating dust that is mostly emitted during shake-out. The remaining dust in the sand has to be removed in order to allow the re-use of the sand for moulding. Using this method, only a small amount of dust should occur during the filling of the moulding boxes.

This process is of interest because of its very low environmental impact. However, as its process cycle involves many steps, the moulding rate is low and the gap between starting times for each new different casting is lengthy. Moreover investment costs are very high. As a consequence, this process has found only limited application.

3.9.4 Moulding and core-making with chemically-bonded sand

Input	Output
– sand	– sand moulds and cores
– resin	– excess reagents
– catalyst, hardener, additives	– reaction products
	– dust

3.9.4.1 Chemicals consumption levels

The consumption levels of the various types of binders, hardeners, catalysts and additives are given in Table 3.39.

Hardening type	Resin type	Resin addition % on sand weight	Catalyst/ hardener type	Catalyst/ hardener addition % on resin weight	Additive type	Additive Addition % on sand weight
Cold-setting	Furan	0.8 – 1.5	Sulphonic acid	25 – 60	Silane	0.1 – 0.2
	Phenolic	1 – 2	Sulphonic acid	25 – 50	n.a	n.a
	Polyurethane	0.8 – 1.5	Pyridine derivate	2 – 6	n.a	n.a
	Resol	1.0 – 1.5	Ester	22 – 25	n.a	n.a
	Alkyd oil	1.0 – 2.0	Isocyanate	18 – 20	Catalyst	0.002 – 0.2
	Ester silicate	2.0 – 4.5	Ester	10 – 15	n.a	n.a
Hardening type	**Resin type**	**Resin addition % on sand weight**	**Catalyst type**	**Catalyst addition % on sand weight**	**Additive type**	**Additive Addition % on sand weight**
Gas hardening	Phenolic/Furan	0.8 – 1.2	SO_2	0.3 – 3	Peroxide	0.1 – 0.5
	Polyurethane Cold-box	1.0 – 1.8	Amine	0.05 – 0.15	n.a	n.a
	Resol	1.2 – 1.8	Methyl fomate	0.3 – 0.5	n.a	n.a
	Resol	2 – 2.5	CO_2	0.7 – 1.25	n.a	n.a
	Acryl/Epoxy	1.2 – 1.6	SO_2	0.02 – 0.05	Peroxide	0.05 – 0.06
	Silicate	2 – 4	CO_2	1 – 2	n.a	n.a
Hardening type	**Resin type**	**Resin addition % on sand weight**	**Catalyst type**	**Catalyst addition % on resin weight**	**Additive type**	**Additive Addition % on sand weight**
Thermosetting	Oil	0.8 – 4			n.a	n.a
	Warm-box furfuryl alcohol-based	1.0 – 1.5	Cu salts of sulphonic acids	10 – 30	n.a	n.a
	Hot-box phenolic or furan based	1.2 – 3.0	Ammonium salts	10 – 25	n.a	n.a
	Croning phenolic	1.5 – 5	Hexamethylene-tetramine	15	n.a	n.a

Table 3.39: Consumption levels of various resins, catalysts, hardeners and additives for chemically-bonded sand preparation
[174, Brown, 2000], [225, TWG, 2003]

3.9.4.2 Emission factors

The use of chemical binders results in the production of various compounds during mixing, mould- and core-making, storage, pouring and cooling, as indicated in Table 3.35. Some indicative emission factors for several processes are given in Table 3.40 and Table 3.41.

	Furan sand	Phenolic sand
Organic solvents	1.4	1.25
Phenol	0.02	0.18
Formaldehyde	0.08	0.15
All data in kg/tonne molten metal		

Table 3.40: Emission factors for mould making
[110, Vito, 2001]

	Cold-box	Hot-box	Shell
Dust	n.a	0.003	0.003
Furfuryl alcohol	0.1	n.a	n.a
Formaldehyde	0.01	n.a	0.003
Organic solvents	n.a	0.03	n.a
Aromatic solvents	0.12	n.a	n.a
Amines	0.13	n.a	n.a
All data in kg/tonne molten metal n.a: not applicabble			

Table 3.41: Emission factors for core-making
[110, Vito, 2001]

3.9.4.3 Cold-setting processes emissions

Emissions for the cold-setting processes can be described as follows:

- *Phenolic*: Vapours of formaldehyde and phenol may be emitted because of the vapour pressure of these constituents. But, as the polymerisation occurs at ambient temperature, these vapour pressures are low and given the consumption rates, the emissions are insignificant
- *Furan*: Vapours of formaldehyde, phenol, furfuryl alcohol and alcohols may be emitted because of the vapour pressure of these constituents. But, as the polymerisation occurs at ambient temperature, these vapour pressures are low and given the consumption rates, the emissions are insignificant
- *Polyurethane*: Vapours of formaldehyde, phenol, isocyanate and aromatic solvents may be emitted because of the vapour pressure of these constituents. As the polymerisation occurs at ambient temperature, the vapour pressures of the components are low and given the consumption rates, the emissions are insignificant. Obnoxious odours may be generated in the moulding area but are not likely to cause external nuisance
- *Resol-ester:* The resin contains unreacted phenol and formaldehyde, but their emissions are extremely low and environmentally insignificant
- *Alkyd-oil:* During production of the moulds and cores, there are no emission problems, unless they are cured by heat, in which case odour problems may occur
- *Ester silicate*: This process does not generate any emission problems.

[32, CAEF, 1997]

3.9.4.4 Gas-hardened processes emissions

Emissions for the gas-hardened processes can be described as follows:

- *Cold-box*: Vapours of formaldehyde, phenol, isocyanate and aromatic solvents are emitted in low quantities, in spite of their low vapour pressures. Aromatic solvent emissions are highest during purging. The most significant emission is that of amines, which have low odour detection thresholds and can create an external nuisance. Amines are hazardous, with a relatively low exposure value limit, and possess a strong characteristic smell at very low concentrations
- *Resol-ester*: The resin contains unreacted phenol and formaldehyde, but their emission levels, even during the gassing and purging periods, are very low. Methyl formate is not toxic, does not have an unpleasant smell and its exposure value limit is relatively high
- *Resol-CO_2*: The resin has low contents of unreacted phenol and formaldehyde, and their emission levels, even during the gassing and purging periods, are very low
- *SO_2 hardened phenolic and furan resin*: The resins and the prepared sands generate formaldehyde emissions. The major emission problem is caused by sulphur dioxide, which is very hazardous
- *SO_2 hardened epoxy/acrylic*: Minimal emissions are generated during the core-making process
- *CO_2 silicate*: This process does not generate any emission problems during moulding or core-making.

[32, CAEF, 1997]

3.9.4.5 Hot curing processes emissions

Emissions for the hot curing processes can be described as follows:

- *Hot-box emissions*: The patterns are generally heated by open air gas burners, producing combustion gas emissions. The off-gas may contain phenol, ammonia, formaldehyde and monoisocyanates (if the resin contains nitrogen)
- *Warm-box emissions*: Compared to the hot-box process, the emissions are significantly lower. The emissions do not contain phenol or ammonia, and also formaldehyde emissions are diminished by a factor of 4. As the pattern temperature is also lower compared to the one used for the hot-box process, the working conditions are also improved. The environmental impact is considered to be relatively low
- *Shell emissions*: Compared to the hot-box process, cured sand consumption is very low. However, the pre-coated sand contains 2 to 3 times more resin, but as the pattern temperatures are approximately the same, the resulting impact on working conditions is similar.
- *Linseed oil emissions*: As the oils are often in solution in organic solvents such as naphtha or kerosene, a large amount of VOC is generated by curing, which may result in an external odour nuisance. This problem is even more persistent during pouring. These problems, as well as poor productivity, are some of the reasons for the reduction in interest in the use of this process.

[32, CAEF, 1997]

A mass balance for a hot-box core shop is given in Table 3.42. Data were collected from a core shop of a low-pressure die-casting brass foundry [177, Silva Ribeiro, 2002].

Input	
New sand	371
Electric energy	352.9 kWh
Propane gas	7
Compressed air	187.1 kWh
Resin	8.3
Conservative	0.51
Catalyst	0.76
Coating	1.7
Output	
Cores	287.7
Sand not poured	84.3
Resin	1.4 l
Metallic and plastic containers	
Emissions (after bag filter)	
Particulate emissions	0.11
VOCs	0.83
All data are per tonne of castings sold, values in kg unless stated differently	

Table 3.42: Mass balance data for brass foundry core using a hot-box process [177, Silva Ribeiro, 2002]

3.9.5 Coating of chemically-bonded sand moulds and cores

Input	Output
– coatings ready to use or mass to be diluted with water or alcohol – heat for solvent evaporation	– VOC (alcohol-based)

3.9.6 Expendable pattern casting (Lost Foam/full mould casting)

3.9.6.1 Unbonded sand – Lost Foam

Input	Output
– EPS granulate	– sand moulds
– EPS glue	– EPS residues
– refractory coating	– products of pyrolysis and combustion
– sand	– dust

In producing aluminium castings, around 15 kg/tonne good casting of EPS granulate is consumed. Refractory coating consumption is around 20 kg/tonne good casting.

Table 3.43 shows a comparative analysis of a green sand and a Lost Foam aluminium foundry, both producing 5490 tonnes of good castings per year. It should be noted that the values do not take into account the internal regeneration. In practice, both types of foundry will apply regeneration, thus reducing the amount of residue effectively left for disposal.

Residue type	Lost Foam foundry	Green sand foundry
Foundry sand (without internal regeneration)	1.04	2.95
Filter dust (without internal regeneration)	0.056	0.22
Filter dust (with internal regeneration)	0.056	0.61
EPS residue	0.0027	-
All values in kg/tonne good casting		

Table 3.43: Comparative data for residue production from Lost Foam and green sand aluminium casting [96, Spillner, 1997]

Emission data for organic compounds are given in Table 3.44. These apply to an aluminium Lost Foam foundry producing 1.5 tonne/h compared to a green sand foundry producing 1.2 tonne/h and using 1.9 tonne/h cold-box cores. The Lost Foam foundry was equipped with a bag house and a post combustion unit. The green sand data apply to a unit with bag house filtration. The data show that the Lost Foam foundry, with the application of more intense flue-gas cleaning, emits higher levels of BTEX and formaldehyde, but a clearly lower level of organic carbon. Post combustion of the casting off-gases is needed to decompose the products from EPS pyrolysis upon pouring.

Compound	Lost Foam foundry	Green sand foundry
Benzene	35.33	8.5
Toluene, xylene, ethylbenzene, styrene	354.67	18.58
Unknown organic compounds	96.67	655.0
Total organic carbon	857.33	1283.33
PAH	1.45	1.43
Formaldehyde	18.00	2.08
Phenol	18.00	69.83
All values in g/tonne molten aluminium		

Table 3.44: Stack emission data for Lost Foam and green sand aluminium foundries [96, Spillner, 1997]

3.9.6.2 Chemically-bonded sand – full mould

Input	Output
– EPS granulate	– sand moulds
– EPS glue	– EPS residues
– refractory coating	– products of pyrolysis and combustion
– sand	– dust
– binders	

The mass flow of emissions from full mould and hollow mould casting processes are to be considered as similar. This can be seen from Figure 3.5 which shows the mass flow of organic carbon as a function of time upon pouring. Time ‘0:00’ corresponds to the starting of the pouring. The data were collected using furan-bonded sands, both for full and hollow mould making.

The full mould process shows a high emission upon pouring and an initial peak emission immediately after pouring which levels off within 1 hour. The hollow mould process shows a lower initial emission, but the levelling off goes slower and takes up to 2 hours. Therefore, the total organic carbon emission over the whole cooling step is equal for both processes. Additional measurements showed that the same profile applies for benzene, ethyl benzene, phenol and furfuryl alcohol. The maximum emission for styrene and toluene occurs after 15 – 30 minutes. This is due to an initial condensation of the molecules on the colder parts of the mould. [215, Müller, 1996]

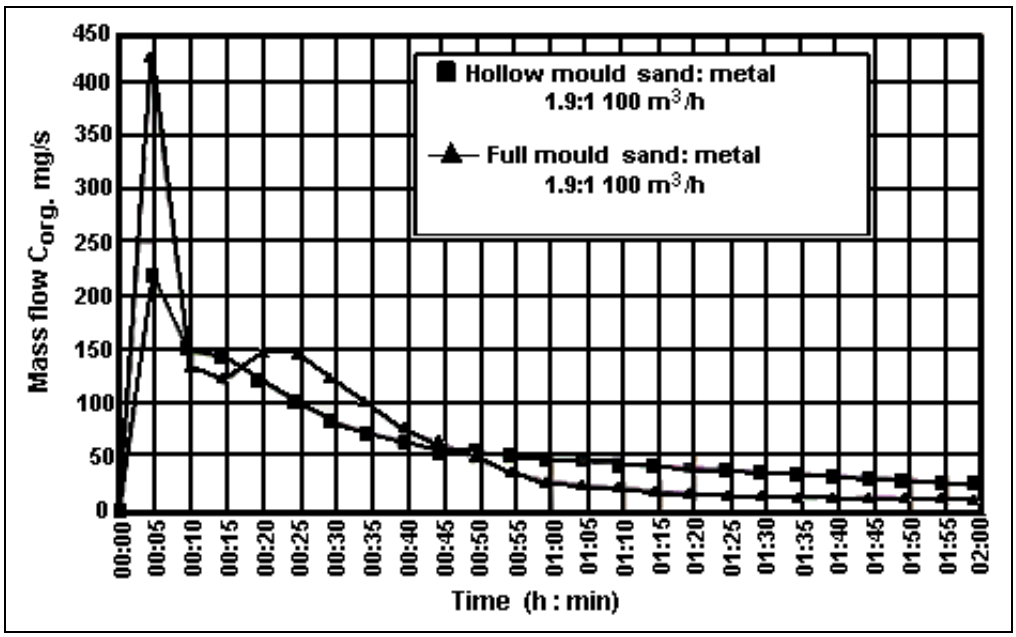

Figure 3.5: Waste gas load upon pouring in full and hollow moulds
cast alloy: lamellar iron; mould: furan bonded sand; 1.9 tonne sand: 1 tonne Fe
[215, Müller, 1996]

3.10 Casting

3.10.1 Casting, cooling and shake-out, using lost moulds

3.10.1.1 Emission levels

Input	Output
– finished moulds – molten metal	– castings – used sand – combustion products (from preheating of pouring ladles) – organic pollutants from pyrolysis and thermal degradation of binder, blackening moulds, etc. (phenol, formaldehyde, amine, hydrogen cyanide, PAH, benzene, VOC) – odour – waste from exhaust air cleaning (dry/sludge) – dust from shake-out

Whilst **preheating** ladles, combustion gases are generated as a result of using natural gas as the common energy source.

The following emission types can occur during **pouring**:
- thermally degradable components, such as exothermic sleeves, react releasing fumes and/or vapours
- chemical compounds from the binder and some blacking systems which can be released as a result of thermal degradation and/or volatilisation, e.g. combustion gases, water vapour, and volatile organic compounds. Some of the degradation products can be odorous.

Experience shows that the maximum emissions (related to total-C) only occur 10 minutes or more after pouring. CO is the main component, with the level of CO being indicative of the release of other compounds. [110, Vito, 2001]

During **cooling and shake-out,** the thermal decomposition processes proceed and volatile compounds are generated, mainly controlled by diffusion and evaporation rates.
The removal (shake-out) of the sand moulds and cores from castings is a dust-intensive procedure, as the moulds, at least partially, have to be crushed.

The **second cooling step** releases nothing except water vapour from those plants, where water spray is used as a cooling aid. [32, CAEF, 1997]

The type of emissions during casting are dependent on the binder type used. Emissions are comparable to those during the mixing stage, with the addition of pyrolysis products occurring upon contact with the hot metal. Table 3.45 gives the results from a qualitative survey of the emissions associated with the various binder types.

System name and binder constituents	Emissions to air during casting	Comments
GREEN SAND Clay Coal dust or substitute Water	Particulate matter- soot from coal burning Carbon monoxide and carbon dioxide Benzene Toluene Xylene	Potential odour (may be associated with the sulphur content of the coal)
SHELL SAND Phenol - Formaldehyde (Novalak) Resin	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Phenol*, cresols* and xylenols* Ammonia Aldehydes Benzene PAH	Odour problems more prevalent – treatment may be necessary although dispersion may suffice
ALKALINE PHENOLIC Resol - Alkaline phenol Formaldehyde resin 1. Gas hardened 2. Self-setting	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Formaldehyde Phenol, cresols and xylenols Aromatics	Odour may be a problem
PHENOLIC URETHANE 1. Gas hardened e.g. Cold-box 2. Self-setting (phenolic urethane no bake)	Particulate matter – soot from the incomplete combustion of the carbon based resins Carbon oxides Nitrogen oxides Monoisocyanates Formaldehyde Phenol, cresols and xylenols Aromatics (inc. polycyclics) Anilines Naphthalenes Ammonia	Odour may be a problem

System name and binder constituents	Emissions to air during casting	Comments
FURAN Combination resins of: Phenol Urea Furfuryl alcohol Formaldehyde	Particulate matter – soot from the incomplete combustion of the carbon based resins Carbon oxides Phenol, cresols and xylenols Formaldehyde Aromatics (inc. polycyclics) Sulphur dioxide Ammonia Aniline Isocyanic acid* Methyl isocyanate*	Odour may occasionally be a problem
HOT-BOX Combination resins of: Phenol Urea Furfuryl alcohol Formaldehyde	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Nitrogen oxides Formaldehyde Phenol, cresols and xylenols Aromatics (inc. polycyclics) Aniline Ammonia Isocyanic acid* Methyl isocyanate*	
OIL SAND Linseed oil and starch	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Butadiene Ketones Acrolein	Odour may be a problem
CO_2 PROCESS Sodium silicate	Carbon oxides	
SILICATE ESTER Sodium silicate	Carbon oxides Alkanes Acetone Acetic acid Acrolein	
* For resin containing nitrogen (urea)		

Table 3.45: Environmental impact from binder systems upon pouring, shake-out and cooling [160, UK Environment Agency, 2002]

Emission factors for iron casting in cold-setting sand moulds as used in Belgium are given in Table 3.46.

Compound	Average kg/tonne melted
CO	1.1
Aliphatic heterocyclic hydrocarbons	0.22
Aromatic hydrocarbons	0.05
HCN	0.03
Formaldehyde	0.02
Sulphur compounds (when using paratoluene sulphonic acid)	0.10
Volatile organophosphorous compounds (when using phosphoric acid)	0.11

Table 3.46: Emission factors for iron casting in cold-setting resin-bonded sand moulds [110, Vito, 2001]

The emission factors during pouring, cooling and shake-out for a mixed sand system, have been determined through an intensive measurement programme in two automotive foundries in Mexico. The foundries under study produced iron castings, using green sand moulds and chemically-bonded sand cores. The emission factors are very process-specific and vary according to changes in the mould or core composition, or changes in the process parameters such as cooling time, or in the techniques applied, such as the type of shake-out device applied. Nevertheless, the emission factors obtained provide useful information on the type of emissions and on the relative importance of the various process steps. The emission factors for the most important detected air pollutants are presented in Figure 3.6. The data show that the highest emissions occur during shake-out and only minor emission occur during pouring. Naphthalene and monomethylated naphthalenes mainly contribute to the PAH emission. Further analysis of this category revealed that many of the carcinogenic PAHs, such as benzo(a)pyrene were not detected.

The major metal emissions include manganese, lead, nickel, copper and chromium, with lead and manganese being greatest. [141, CERP, 1999]

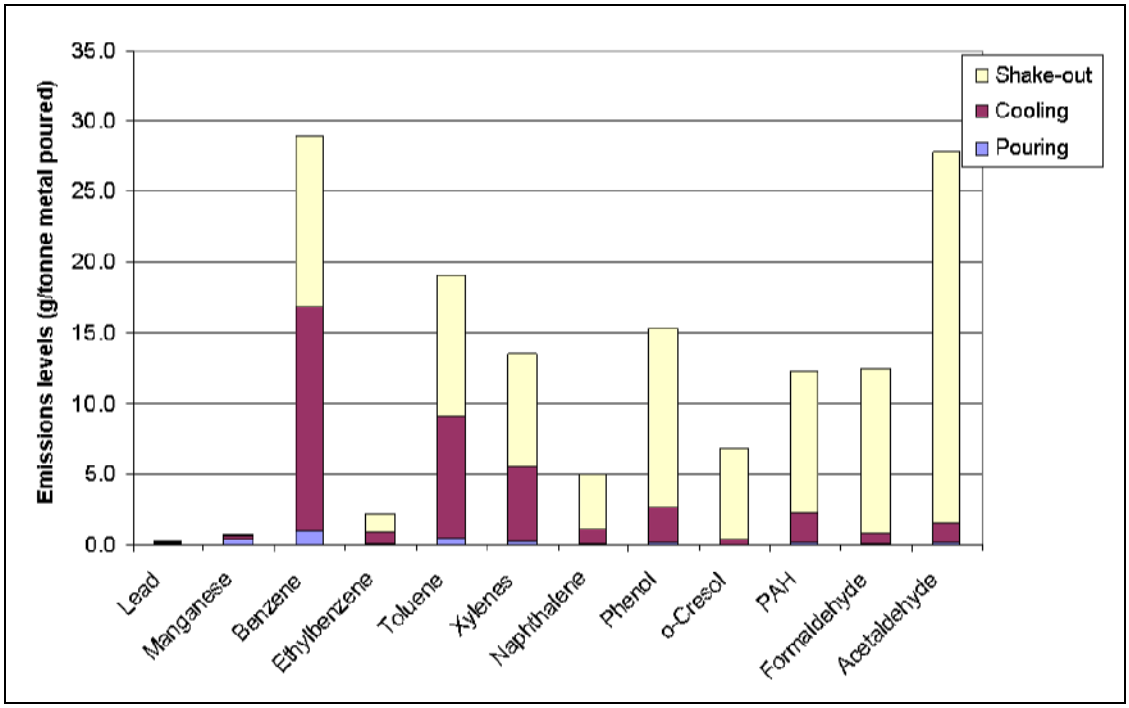

Figure 3.6: Emission levels of pollutants upon pouring, cooling and shake-out for a green sand iron foundry
[141, CERP, 1999]

Emission factors for particulate matter are displayed in Figure 3.7. These are based on measurements of total dust, PM_{10} (particles less than or equal to 10µm) and $PM_{2.5}$ (particles less than or equal to 2.5µm). Note that by definition PM_{10} includes $PM_{2.5}$. [141, CERP, 1999]

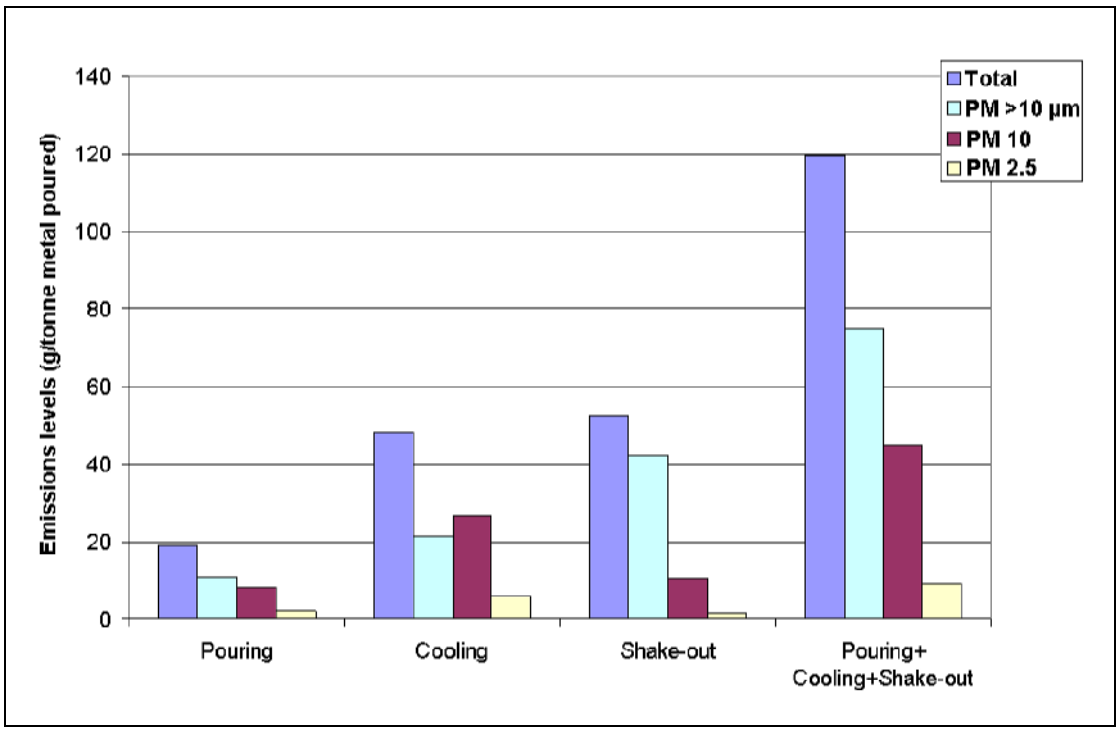

Figure 3.7: Emission levels for particulate matter upon pouring, cooling and shake-out for a green sand iron foundry
(Total = PM_{10} + $PM_{>10}$)
[141, CERP, 1999]

Data in the above figures apply to raw gas. In an Italian sector survey, emission data for cleaned exhaust flows were collected and are given in Table 3.47 [180, Assofond, 2002]. All exhaust cleaning types reach a dust emission level of <20 mg/Nm³. Wet scrubbers show the best performance, though it should be noted that the data are based on only three measurements.

Flue-gas cleaning equipment	Concentration (mg/Nm³)			Emission factor (g/tonne)*		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Bag filter	5.8	1.0	16.8	68.5	7.8	206.9
Wet scrubber	2.3	1.8	2.8	16.3	13.3	18.0
Wet multicyclone	18.6	14.6	21.9	202.2	163.6	224.4
Wet Venturi system	11.7	6.2	16.9	116.3	38.2	187.7
* Emission factor in g/tonne of good casting						

Table 3.47: Emission values and emission factors for dust emission from shake-out after flue-gas cleaning
[180, Assofond, 2002]

3.10.1.2 Sand-to-liquid metal ratios

Excessive amounts of sand in the moulding system results in unnecessary capital and operating costs. A lower sand-to-liquid metal ratio will reduce the total volume of sand in the system and, therefore, reduce the consumption of new materials.

The distribution of sand-to-liquid metal ratios for green sand in the iron sector is shown in Figure 3.8. Data were collected from a survey of the UK foundry sector. While the average sand-to-liquid metal ratio in this sector is 9:1, some foundries are operating either considerably above or below this figure. The lower ratios are generally associated with certain types of metal moulds or single-product foundries where box size/casting combinations are more easily optimised. The higher ratios are generally caused either by jobbing or short-run situations. Here, many widely varying casting configurations (and thus pattern configurations) will have been

involved or the original product/product mix will have changed significantly since the plant was designed.

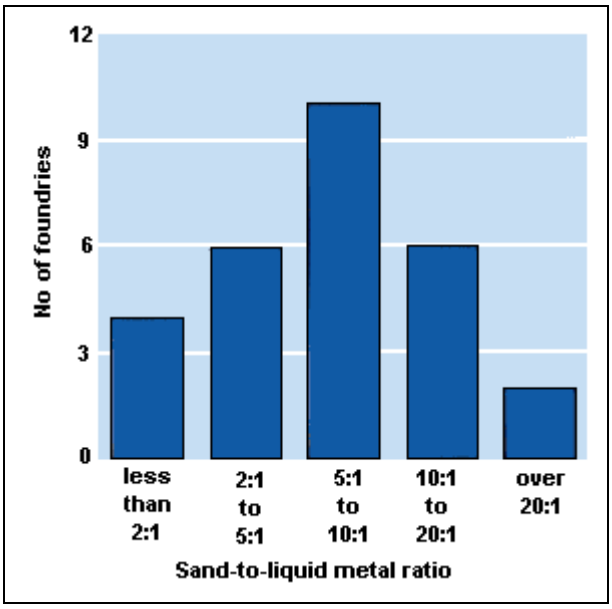

Figure 3.8: Green sand-to-liquid metal ratios in iron foundries [73, ETSU, 1995]

Figure 3.9 shows the distribution of total mixed sand-to-liquid metal ratios for green sand in the copper sector, where the average sand-to-liquid metal ratio was about 4:1. The reason this value is lower than that for the iron sector is largely because most copper foundries are product orientated with an optimised box size.

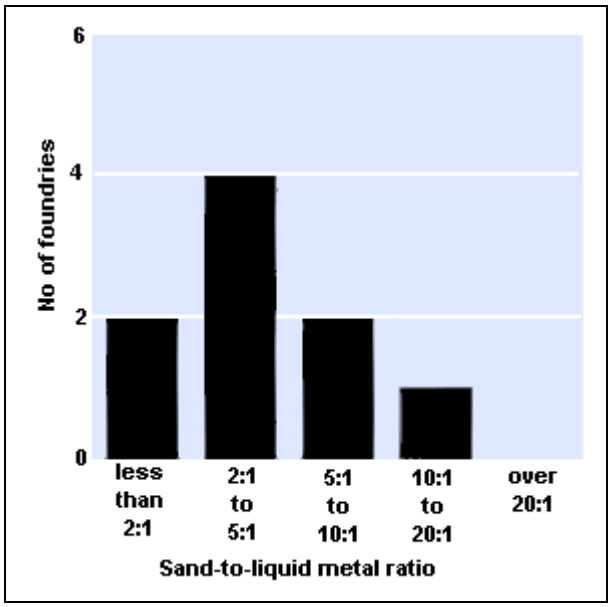

Figure 3.9: Green sand-to-liquid metal ratios in copper foundries [73, ETSU, 1995]

Data for chemically-bonded sand-to-liquid metal ratios for various metal types are given in Figure 3.10.

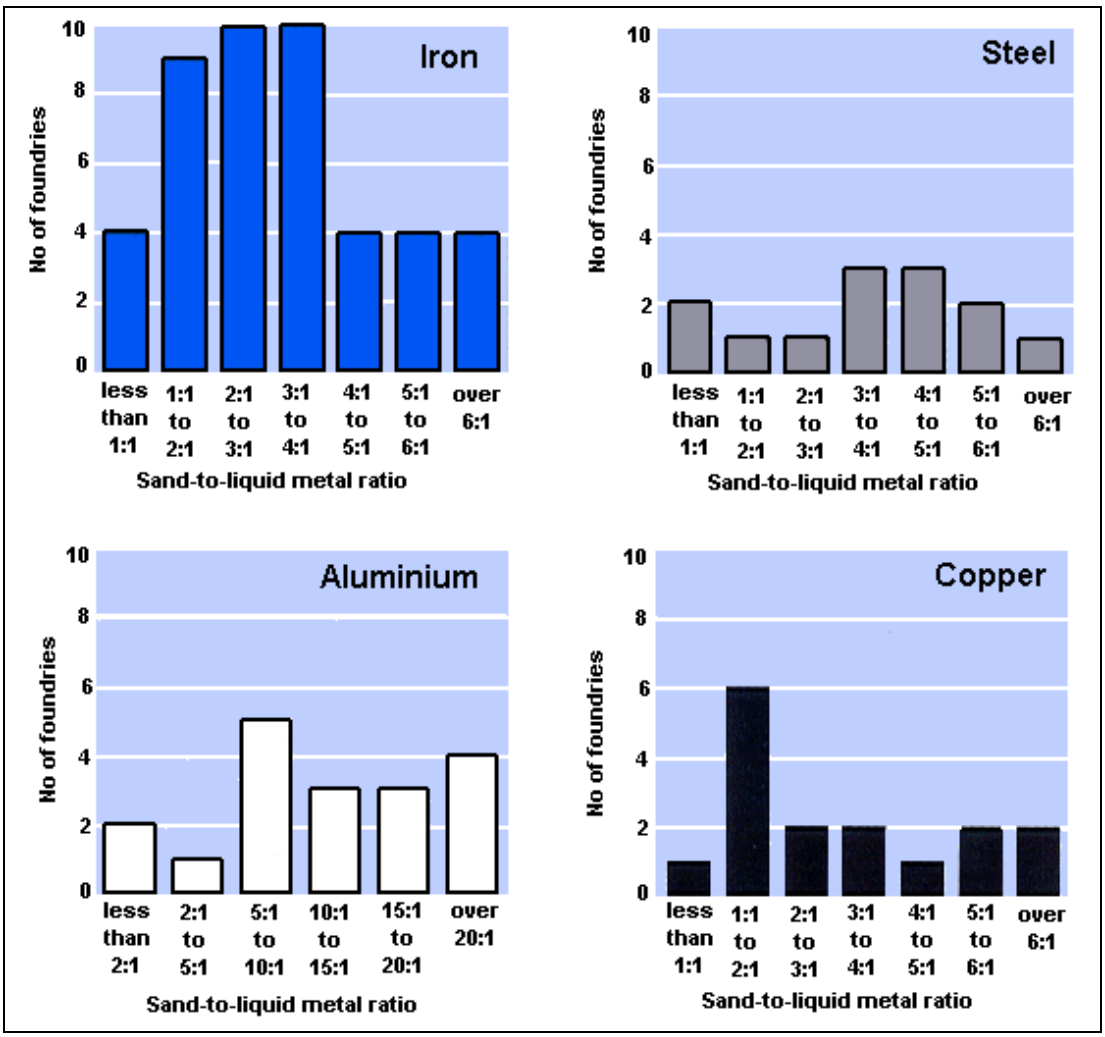

Figure 3.10: Total mixed sand-to-liquid metal ratios in UK foundries [72, ETSU, 1995]

3.10.1.3 Metal yield

The metal yield is the ratio of the amount of metal melted to the weight of the finished good castings. Five main factors affect metal yield, i.e.:

- quality requirement
- choice of mould-box size
- the extent of runner and feeder systems
- metal shrinkage
- scrap casting rate.

Metal yield does not have a direct effect on sand use. However, an increase in yield may result in fewer moulds being produced, which means that less sand is consumed overall. Lower metal yields are generally associated with higher integrity products, where superior quality standards may be required, necessitating a more extensive feeding system. Lower yields, however, may also be indicative of higher scrap rates and excessive feeding systems. In these circumstances, foundries need to review their process control and mould production methods. The average metal yields for the main alloy sectors are given in Table 3.48.

Sector	Average metal yield (%)	Range of yields reported (%)
Lamellar iron	68	40 – 90
Nodular iron	63	40 – 90
Aluminium	57	40 – 80
Copper	58	30 – 90
Steel	45	n.d

Table 3.48: Metal yield in the main alloy sectors [73, ETSU, 1995], [225, TWG, 2003]

Data were collected through a survey in the UK foundry sector and from the Portuguese foundry association (the latter for steel). A significant number of survey respondents declined to supply yield data, particularly in the aluminium and copper sectors. However, some general comments on metal yield can be made:

- the range of yields reported for lamellar iron and nodular iron was from 40 % to over 90 %
- metal yields reported by aluminium foundries were fairly evenly distributed between 40 % and 80 %. Over 50 % of aluminium foundries, however, chose not to supply data
- half the small number of copper foundries that supplied data are achieving yields of between 50 % and 60 %, though the reported range is 30 % to over 90 %.

[73, ETSU, 1995]

3.10.1.4 Used foundry sand

A review and study of foundry waste sand quality and composition was performed in Finland. Data were collected from literature and from own experiments [169, Orkas, 2001].

In several studies, chemical analyses on used foundry sands from various sources were performed. A summary of the most significant results is presented in Table 3.49. The data show that the contents of metallic and organic harmful compounds in used foundry sand are normally low. Generally, the contents of organic and metallic harmful compounds are higher in green sands compared to chemically-bonded sands. Inorganic sands are basically very clean.

Compound	Green sand (mg/kg)	Organic sand (mg/kg)	Inorganic sand (mg/kg)
Ba	35 – 118	2.4 –5.5	n.d
Cr	1.7 –13.5	1.2 –7.2	<5
Fe	2950 – 21000	640 – 16300	530 – 1700
Zn	1.5 – 1450	1.6 – 49	<10 – 30.0
Cd	0.03 – 6.7	0.01 – 0.03	0.02
Pb	1.6 – 390	0.4 – 2.1	1.3
Cu	4.7 – 5.0	2.7 – 4.4	<1.5 – 6.0
Ni	<2.5 – 20.0	0.3 – 8.5	2.5 – 8.3
Mn	76 – 78	22 – 79	25 – 34
As	0.2 – 2.1	0.2 – 1.8	<0.5 – 0.51
Phenol	1.1 – 29.6	0.1 – 14	0.03
Total PAH	1.0 – 206.6	0.1 – 8.8	<1.75

Table 3.49: Results from analyses of used foundry sands from several sources [169, Orkas, 2001]

The Castings Development Centre (CDC) analysed the PAH-values (total PAH, naphthalene and carcinogenic PAH) and phenol contents from different used foundry sands. The results are shown in Table 3.50. For a given sand production line, the variations in the PAH and phenol contents in used sand are relatively low.

	Polycyclic aromatic hydrocarbons, (mg/kg)			Phenol	
Sand system	**Naphthalene**	**Carcinogenic PAH**	**Total PAH**	**Total (mg/kg)**	**Leachable (µg/l)**
Green sand	<1.0 – 7.4	0.03 – <1.0	<10 – 11	1.4 – 63	26 – 1600
Alkaline phenolic	1.1 – 4.8	0.026 – 0.096	2.3 – 8.1	1.4 – 210	0.025 – 4400
Furan	0.87 – <1.0	0.014 – 1.5	1.0 – <10	0.18 – 15	1.2 – 19
Resin shell	0.11 – 7.1	0.01 – 0.67	0.75 – 9.3	3.7 – 3300	0.025 – 3200

Table 3.50: PAH and phenol contents of used foundry sands
[169, Orkas, 2001]

Leaching tests showed that the leaching of metals is generally low and that the leaching of chromium caused by the presence of chromite sand is negligible [169, Orkas, 2001].

3.10.2 Casting in permanent moulds

Input	**Output**
- water-based release agent - cooling water - molten metal - cores	– casting – oily mist from release agent spraying – organic pollutants from thermal degradation of core binder – metal oxide containing dusts from holding furnace – dust from shake-out of cores – waste water

Mass balance data for three different foundries using pressure die-casting of molten aluminium are given in Table 3.51.

	Foundry A	Foundry B	Foundry C
Input			
Water	802 l/tonne	935 l/tonne	1709 l/tonne
Release agent	16 l/tonne	8.26 l/tonne	1.12 l/tonne
Electricity	1103 kWh/tonne	1380 kWh/tonne	652 kWh/tonne
Output			
Waste water[1] COD pH SS Oil and grease BOD5 Al	 18000 mg/l 7.5 1300 mg/l 3000 mg/l 2000 mg/l 5 mg/l	122 l/tonne	 126 mg/l 7.5 1 mg/l 1 mg/l (total hydrocarbons) 78 mg/l 0.6 mg/l
Exhaust gas NOx VOC Dust		 0.006 kg/tonne 0.28 kg/tonne 1.8 kg/tonne	 0.14 – 0.27 kg/tonne 0.030 – 0.16 kg/tonne
All values per tonne of good casting or in mg/l effluent [1] For foundry C, waste water quality after treatment consisting in a distilling plant and cooling-evaporation towers			

Table 3.51: Mass balance data, exhaust and effluent composition for aluminium presure die-casting units
[177, Silva Ribeiro, 2002], [202, TWG, 2002]

In current die-casting practice, water-based release agents are sprayed on the open die, after dilution to a 1:50 – 1:200 ratio. Besides die coating, this spraying is used for die cooling. This explains the difference in water use displayed in the table. This practice causes a loss and spillage of water, and up to 40 % of water/agent leakage into the foundry waste water system.

Emission and consumption levels for permanent moulding processes depend on the type of alloy used, the surface area of the melt, the quantity of the sand cores which are inserted in the mould, and the surface/volume rate of the casting. The sand cores are the main sources of emissions. There is no important difference between the different casting techniques. Due to the wide variety of processes and applications, it is not possible to give average data. [202, TWG, 2002]

Electricity consumption depends on process aspects, such as the closing force of the die, which are chosen on technical grounds.

Emission factors for the casting of bronze, brass and zamac as used in Belgium are given in Table 3.52.

Alloy	CuO	SnO	PbO	ZnO	Al_2O_3	MnO
Bronze	0.06	0.04	2 – 20	625 – 6250	n.a	n.a
Brass	0.01	n.a	0.007 – 1	125 – 21500	n.a	n.a
Zamac	n.a	n.a	n.a	0.004	0.2	0.01
All data in g/tonne molten metal						

Table 3.52: Indicative emission factors for casting of bronze, brass and zamac [110, Vito, 2001]

3.11 Finishing/post-casting operations

Input	Output
- unfinished castings - abrasives - water, soap - electricity	– finished castings – dust (*sand, metal particles*) from mechanical operations – volatised metals, combustion products from thermal operations – waste water

3.11.1 Slide grinding

Table 3.53 shows input-output data for the slide grinding of aluminium castings. The effluent water goes to a water treatment system and is re-circulated into the slide grinding equipment. Abrasive rocks are used and come out unaltered, besides for some minimal wearing.

Input	
Electricity	20.7 kWh
Cleansing agent	0.5 l
Water	490 l
Output	
Liquid effluent	400 l
All values per tonne of good casting	

Table 3.53: Input-output balance for the slide grinding of aluminium castings [177, Silva Ribeiro, 2002]

3.11.2 Shot blasting

Emission levels from the exhaust gas of shot blasting have been collected in an Italian foundry survey. The results are displayed in Table 3.54. All techniques reach maximum dust emission levels below 30 mg/Nm³. The average value is below 15 mg/Nm³. The wet Venturi system is the least effective system, leaving an emission factor well above those for the other techniques. On the other hand, it also acts as is a safety device to prevent an aluminium-dust-explosion [225, TWG, 2003].

	Concentration (mg/Nm³)			Emission factor (g/tonne)		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Bag filter	5.3	0.4	19.3	53.1	0.3	327.3
Wet filtration	12.0	4.2	16.4	21.9	7.9	30.1
Wet multi-cyclone	8.2	4.2	14.8	54.9	18.5	135.4
Wet Venturi system	12.8	1.1	22.3	149.0	2.3	523.5
Emission factor data in g/tonne of good casting and for cleaned gas						

Table 3.54: Emission data for the exhaust gas from shot blasting, using various dedusting techniques
[180, Assofond, 2002]

3.11.3 Fettling

Emission levels from the exhaust gas of fettling have been collected in an Italian foundry survey. The results are displayed in Table 3.55. All techniques achieve dust emission levels below 30 mg/Nm³. The bag filter and Venturi allow maximum levels below 10 mg/Nm³. The wet multi-cyclone is the least effective system, leaving an emission factor well above those for other techniques. The emission factor is largely dependent on the amount of finishing needed and thus the type of castings made.

	Concentration (mg/Nm³)			Emission factor (g/tonne)		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Bag filter	3.0	0.4	7.5	17.0	2.3	85.6
Wet multi-cyclone	14.8	7.6	23.3	275.6	96.2	497.2
Wet Venturi system	2.5	1.1	5.9	45.5	35.5	63.4
Emission factor data in g/tonne of good casting and for cleaned gas						

Table 3.55: Emission data for the exhaust gas from fettling, using various dedusting techniques,
[180, Assofond, 2002]

3.11.4 Finishing operations in steel foundries

Concerning steel foundries, specific cutting, scarfing and welding processes are used. Average dust emission values are given in Table 3.56. These apply for the use of the following techniques:

- *Cutting* (of runner system): Tetrene-acetylene-iron oxide for stainless cutting
- *Scarfing*: Carbon electrode covered with copper
- *Welding*: Using electrodes or wire.

Finishing technique	Dust emission (kg/tonne)
Tetrene cutting	11 - 13
Scarfing	9 - 11
Electrode/Wire	3 - 3.5
All values in kg per tonne of good casting	

Table 3.56: Average dust emission from steel finishing
[202, TWG, 2002]

3.12 Heat treatment

Input	Output
– finished castings	– finished casting (heat treated)
– energy (electric, gas or fuel oil)	– combustion products from firing
– quenching: water, oil, air	– water vapour, fume, oil mist
	– NO_x, SO_2

The emissions from heat treatment furnaces mainly comprise combustion gases, particularly from gas- and oil-fired furnaces. The composition of the combustion gases depends on the fuel-type used. Oil-fired furnaces will generate SO_2-emission, which are not present for natural gas burners. Where quenching processes are carried out, emissions of fume, water vapour, or oil mist will also occur, depending on the quenching media.

Heat treatment furnaces are known to be continuous sources of well known non-air components. Emission levels are closely related to energy consumption, burner design and maintenance. Emission collection is trivial in annealing furnaces. The capture of the emissions in the different furnaces does not differ considerably, and emissions are expelled via the waste gas pipe. In general, no further waste gas treatment is applied.

Generally, quenching is a batch process. For this reason emission levels alternate substantially. Emissions from the quenching baths are regarded mostly to be irrelevant for the environment, although they may become more relevant with large scale production. Data about source strength (emission rates) and chemical compounds have not been found.
[32, CAEF, 1997]

3.13 Waste water

3.13.1 Sources of waste water

The amount of process water used in foundries is small and mainly depends on the selection of techniques for dedusting. Waste water is generated mainly in dust removal and waste gas treatment systems, which are applied in the melting shop, moulding material preparation and reclamation and in the cleaning shop. Waste water is also generated in core production, if wet scrubbers are used (depending of the core-making technique and bonding agents used). In a minority of plants (2 plants reported in Europe), water is used for wet sand regeneration. Furthermore, water is generally used for cupola shell cooling and for the cooling baths for (die) castings.

Possible sources of waste water are:
- scrap storage area and site-drainage
- sand preparation
- wet scrubbers used for dedusting in various areas of the foundry
- cooling of pressure die casting machines and tools
- vibratory finishing (slide grinding)
- cooling baths used for heat treatment.

The production-specific waste water quantity averages **0.5 m^3/t good castings**.

[160, UK Environment Agency, 2002], [195, UBA, 2003]

3.13.2 Waste water from scrap storage

Scrap may have adhering soil, and external scrap typically exhibits production-specific impurities. The adhering impurities may be washed off when it rains and may then enter the soil and groundwater. An overview of the possible impurities is given in Table 3.57:

Scrap type	Adhering impurities
Swarf	Cutting oils, emulsions (may contain chlorine)
Punching scrap	Punching oils (may contain chlorine)
Broken machine castings, not conforming to specifications	Hydraulic oils, gear oils
Scrap from cold forming and smitheries	Phosphates, zinc soaps, graphite, forming oils

Table 3.57: Possible impurities for specified scrap types [195, UBA, 2003]

If the adhering impurities are substances constituting a hazard to water (oils, emulsions), then requirements on the storage of substances constituting a hazard to water must be complied with.

3.13.3 Waste water from wet scrubbers used in cupola melting

Wet scrubbers are in use in melting shops to clean the cupola off-gas. Wet scrubbers use water to remove dust particles (average loading: 10 – 15 g/Nm^3) and gases such as sulphur dioxide from cupola off-gas. In the settling tank, a large part of the solid particles are captured and thereby almost completely removed from the scrubbing water.

The partly acid gases washed out of the cupola off-gas, such as sulphur dioxide, accumulate in the scrubbing water, causing its salt concentration to increase (e.g. the formation of e.g. sodium sulphate) and its pH to decrease. This salt accumulation is supported by evaporation losses, so it is necessary to draw the water off from time to time.

Waste water from wet dedusting systems in melting shops mainly contains:
- solids such as oxides of silicon, iron and aluminium, calcium carbonates and cyanides
- heavy metals, although with the exception of zinc, these are present only in very low concentrations
- organic pollutants, which can enter waste water via soiled scrap.

AOX (absorbable organic halides) levels in water used for the scrubbing of cupola off-gas can amount to several milligrams. Possible causes of AOX are scrap coatings and adhering chlorinated organic compounds entering the water during the gas scrubbing process. Chlorinated organic compounds can also reach the water via auxiliaries, such as commercial-grade hydrochloric acid or iron and aluminium chlorides, which are used as flocculants.

Table 3.58 gives an overview of the pollutant concentrations in filter effluent from the dewatering of sludge from the wet scrubbers of cupola furnaces.

Analyte	Units	Value
pH value		7.2 - 9.9
El. conductivity	µS/cm	1400 - 18400
Lead	mg/l	<0.01 - 2.5
Cadmium	mg/l	<0.01 - 0.03
Chromium	mg/l	<0.01 - 0.13
Copper	mg/l	0.02 - 0.89
Nickel	mg/l	0.04 - 0.23
Mercury	mg/l	< 0.001
Zinc	mg/l	1.8 - 27.9
Sulphate	mg/l	430 - 1550
Chloride	mg/l	1330 - 3947
COD	mg/l	154 - 7580

Table 3.58: Pollutant concentrations in filter effluent from dewatering the sludge from the wet scrubbers of cupola furnaces
[195, UBA, 2003]

3.13.4 Waste water from the casting, cooling and shake-out area and from mould production/sand preparation

In the casting, cooling and shake-out area and in mould production/sand preparation, insoluble fines from the moulding material are captured during dedusting, along with small organic proportions from the bonding agent used. If wet dedusting is applied, these compounds are found in the waste water flow. The inorganic solids are iron oxides and clays, which are in part finely dispersed and difficult to remove.

3.13.5 Waste water from core-making

In core-making shops, chemical scrubbers are in use. They use either acid (cold-box process) or basic (SO_2-process and Croning). The quantity of waste water discharged is dependent upon the accumulation of pollutants and salts in the circulating water. If pollution levels are too high, part of the polluted water must be drawn off.

Scrubbing solutions from cold-box and hot-box core-making contain readily biodegradable amines and phenols.

The treatment of amine-containing scrubbing solutions requires a nitrification/denitrification stage. These treatment steps can also be carried out in an external biological waste water treatment plant. An alternative to discharge is the recovery of the amines.

Following oxidation, scrubbing solutions from the SO_2 process mainly contain sodium sulphate. Since high sulphate concentrations (>600 mg/l) can lead to damage to sewerage systems, a limit value is set by the respective competent authority according to local conditions (e.g. the presence of sulphate-resistant piping and dilution with other waste water).
[195, UBA, 2003]

4 TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT FOR FOUNDRIES

In this section, techniques for environmental protection and energy saving measures are given for individual processing steps. The various techniques are structured into generic topics, which allows a thematic approach to be taken for assessing the various different foundry processes and steps.

The techniques all aim to either optimise the process or to reduce the environmental effects by, e.g.:

- careful selection and optimisation of each unit operation i.e. in: storage, melting and metal treatment, mould and core production, casting
- the reduction of emissions to air and water
- the increase in the efficient use of energy
- the minimisation and re-use of residues.

In line with the thematic approach, information has been organised in the following sections:

4.1. Raw material storage and handling
4.2. Metal melting and molten metal treatment
4.3. Mould- and core-making, including sand preparation
4.4. Metal casting
4.5. Fume, flue-gas and exhaust air capture and treatment
4.6. Waste water treatment
4.7. Energy efficiency
4.8. Sand: regeneration, recycling, re-use, disposal
4.9. Dust and solid residues: treatment and re-use
4.10. Noise reduction
4.11. Decommissioning
4.12. Environmental management tools.

In order to allow the selection of best available techniques, all techniques to be considered in the BAT decision are presented according to a standard structure. The items of this structure are explained in Table 4.1.

Name of the type of information	Type of information included
Description	Technical description of the technique
Achieved environmental benefits	The main environmental impacts addressed by the technique.
Operational data	Data on consumption and emission levels from operational plants using the technique. Any other information on how to operate, maintain and control the technique
Cross-media effects	Any side effects and disadvantages to other media, caused by implementation. Environmental effects of the technique in comparison with others
Applicability	Indication of the type of plants in which the technique may be applied, considering e.g. plant age (new or existing), plant size (large or small), techniques already installed (i.e.furnace type, moulding technique, …) and type of product (ferrous, non-ferrous)
Economics	Information on costs (both investment and operational) and possible savings, including details on how these costs have been calculated
Driving force for implementation	Local conditions or requirements which lead to or may stimulate implementation. Information on reasons other than environmental ones for implementation (e.g. increase in productivity, safety)
Example plants	Reference to plants in which the technique is applied and from which information has been collected
Reference literature	Literature which was used in writing the section and which contains more details

Table 4.1: Information contained in the discussion of each technique included in Chapter 4

This chapter presents the information for each technique. The later balancing and selection of techniques will be dealt with in Chapter 5, but based on the information of Chapter 4.

4.1 Raw material storage and handling

4.1.1 Introduction

The storage and handling of solid materials, gases and liquids is discussed in the Storage BREF [205, European IPPC Bureau, 2003]. The document discusses available techniques for e.g. heaps, silos, tanks and packaged materials (e.g. dangerous and flammable substances). These are applicable for foundry raw materials such as sand, scrap, coke, fuels (gas, oil), chemicals, additives and for residues such as used foundry sand, filter dust and slags. In this section, we will only discuss foundry-specific issues which are not covered by the storage BREF.

4.1.2 Covered storage and impermeable scrap yard

Description
The scrap storage area can be structured and managed in such a way that the following factors are taken into account:

- the composition of the furnace charge necessitates knowledge of the feed material. Applying separate storage for various metal types or grades allows control of the charge composition. This can be achieved using compartments or boxes in the storage area or bunker
- the introduction of mineral and oxide materials such as rust, soil or dirt causes increased refractory wear. The use of a cemented scrap yard prevents the entrainment of soil, dirt or water
- a roof constructed over the storage area can help keep rainwater out and can help contain dust emissions.
- a water collection and treatment system can be used to prevent pollution to soil or water.

Achieved environmental benefits
The use of a roof and a reinforced yard allows the collection of run-off water and therefore prevents uncontrolled emissions to water and soil. Direct emissions to soil are also minimised since mixing of the material with soil is prevented.

Cross-media effects
No cross-media effects apply.

Applicability
The use of an impermeable scrap yard can be applied in the storage of scrap in all new and existing foundries. Scrap is stored under a roof or with the provision of a water collection and treatment system to prevent water and soil pollution.

Driving force for implementation
Control of the charge composition improves control of the furnace operation and hence the metal composition. Also allows the minimisation of refractory wear.

Example plants
This technique is applied in the majority of the foundries.

Reference literature
[202, TWG, 2002]

4.1.3 Storage measures for binder chemicals

Description
Binder chemicals carry specific manufacturer's recommendations for storage. Failure to comply with these recommendations will result in unusable or sub-standard products that either require disposal as special waste or lead to poor casting quality due to sub-standard moulds/cores. Table 4.2 summarises the quality problems arising from the incorrect storage of liquid binder chemicals. Correct storage takes account of these problems.

Problem	Effect on product	Implications	Effect on castings
Exposure to excessive cold	Aqueous-based products may freeze	Product segregation may occur, causing mould failure. Affected products require disposal	Casting production may not be possible
Exposure to excessive heat and sunlight	Premature ageing, cross-linking of resin and increased viscosity	Poor mixing properties, low mould strengths and poor resistance to high temperatures	Fining defects
Prolonged storage or cold storage	Increased viscosity	Dispersion onto sand grains difficult. Sand mixture flows less well and is difficult to compact. Low-strength moulds	Erosion, exogenous (sandy) inclusions finning and dimensional faults
Contamination by moisture	Products containing isocyanates will deteriorate due to reaction with water	Binder performance is poor and product may need disposal	Increased risk of gas defects (pinholes)
Sediment disposal in bulk silicate storage tanks	Pumped liquid may become inconsistent	Low-strength moulds	Oversize castings and shrinkage effects

Table 4.2: Problems arising from an incorrect storage of liquid binder chemicals [71, ETSU, 1998]

Some basic measures include:
- roofed and ventilated area
- collection of spilled liquid
- locked storage area.

Depending on the climate, exposure to excessive cold or heat, and sunlight can be accounted for. Additional precautions are necessary for the storage of highly flammable liquids such as methyl formate, triethylamine (TEA), dimethylethylamine (DMEA) and mould coatings containing isopropyl alcohol.

Achieved environmental benefits
Reduction of the amount of waste chemicals arising, which are unsuitable for use.

Most binder chemicals are hazardous, and are characterised by one or more of the following properties: toxic, corrosive, flammable. These properties mean that even small spills can pose a danger to worker's health and safety, while larger releases can result in a serious incident. A major spill that is allowed to enter a surface water drain can cause serious pollution of watercourses.

Cross-media effects
No cross-media effects apply.

Applicability
This technique applies to all new and existing installations.

Driving force for implementation
Safety measures and optimisation of foundry operations.

Example plants
This technique is applied in the majority of the foundries.

Reference literature
[75, ETSU, 1996]

4.1.4 Use of clean scrap for melting and removal of sand from the return material

Description
Melting clean scrap prevents the risk of non-metal compounds being taken up by the slag and/or attacking the furnace lining. These compounds are typically lime, iron oxides, manganese oxides, and basic oxides (e.g. MgO from nodular iron returns) in combination with silicon refractory (acid). If the amount of contamination is limited, this will reduce the amount of slag formed and will allow a longer lifetime of the furnace and ladle lining. For nodular iron production using a furnace with acid refractory, the adhering silica sand may have a beneficial effect, since it neutralises the MgO coming from foundry returns.

The presence of contaminants and oxides in the furnace load, will consume part of the melting energy. Furthermore, the removal of slags necessitates a higher bath temperature to keep the slags in a liquid state.

Internally recycled scrap consists of feeders systems and rejected casting. Feeder systems are knocked off after shake-out. In general they do not retain adhering sand, due to their geometry. Rejected castings are excluded upon quality control, which is carried out after the castings are cleaned using sand blasting or shot blasting to remove all adhering sand. The use of sand-free return material therefore, in general, necessitates no extra treatment.

Achieved environmental benefits
This technique reduces the amount of slags and dust that need disposal and limits VOC-emissions. The energy consumption is reduced (by 10 to 15 %) due to the reduced amount of slag. Additionally the extracted airflow may be reduced.

Shot blasting of the scrap can be recommended for scrap where its contamination would lead to the production of excessive amounts of slag. The use of only shot-blasted scrap would actually require slag-forming additives to create the slag.

Cross-media effects
If foundries only accept clean scrap, the overall recycling rate for dirty scrap will reduce. This will generate a need for additional cleaning operations and increase the disposal of scrap.

The use of cleaning techniques to remove sand from return material consumes energy. This is balanced however by the energy gained in the melting stage.

Operational data
An energy consumption to clean 30 - 40 kg of sand from 1 tonne of casting of 12 - 15 kWh has been reported for an operational foundry. The consumption level is dependent on the size and type of casting.

For a steel foundry using EAF melting, an increase in molten metal recovery (poured metal/charged metal) of 2 to 3 % has been reported.

A typical metal charge for EAF is: 55 % foundry steel scrap; 40 % internal returns; 5 % metal correction additions.

Applicability
The removal of sand from internal scrap can be applied in all new and existing foundries. The use of clean scrap for melting can be applied in all foundry types, but the choice of the scrap grade should be related to the techniques installed for melting and gas cleaning. If the whole sector shifts to clean scrap, this will generate a problem for the recycling of dirty scrap.

The use of clean ferrous scrap (both steel and pig iron) will lead to increased purchase costs and will require investment in new cleaning equipment. There are no difficulties caused by scrap surface oxidation nor by using pig iron ingots during melting in cupola furnaces (reduction process). Electric furnaces will have difficulties only with contaminated scrap which does not comply with the parameters for steel scrap used in foundries.

Cupola furnaces can easily melt scrap which is not clean. There is little coke overconsumption and little environmental consequence, if the gases are correctly treated.

Limiting the slag is very important for good operation of the coreless induction furnace. The operation is more affected by the scrap cleanliness than the other furnace types.

The use of dirty scrap has no adverse effects on rotary furnace operation but is the main determining factor for dust emissions. There is little environmental consequence if the gases are correctly treated.

Economics
The price for clean scrap (i.e. class 1) is 20 to 30 % higher than that for contaminated (i.e. class 2) scrap. Furthermore, disposal costs for slags and dust are reduced by applying this technique.

Driving force for implementation
High disposal fees for residues and high prices for the refractory.

Example plants
This technique is commonly applied in foundries.

Reference literature
[103, Vereniging van Nederlandse Gemeenten, 1998], [110, Vito, 2001], [202, TWG, 2002]

4.1.5 Internal recycling of scrap ferrous metal

Description
Internal scrap is produced from the knock-off of feeders and runners, in quality control and in finishing operations. The relative amount of internal scrap produced can be calculated from the metal yield as defined and described in Section 3.10.1.3. In order to minimise residue production, internal scrap is returned to the scrap metal feed of the furnace.

For steel foundries, a 100 % use of return metal is uncommon, due to the amount of dissolved gas. Operators consider 60 % to be the maximum amount of return metal (feeders, scrap castings,...) in the charge metal. Swarf and turnings may cause excessive molten metal oxidation.

Internal scrap recycling may also be limited in the case of nodular base iron melting, as a high amount of silicon (about 1 % in most cases) is added in the liquid iron during the metal treatment. In some cases re-melting the whole internal scrap is not possible because the final silicon would be too high (typically 2.5 – 3 % in the castings).

In the case of grey or nodular iron, lead or bismuth are very noxious for the properties of the metal after solidification. If there has been a pollution incident the returns (internal scrap) must not be recycled.

Achieved environmental benefits
Minimisation of residues through recycling of raw materials.

Cross-media effects
No cross-media effects apply.

Applicability
This technique applies to all new and existing installations.

Economics
The technique does not involve any additional costs.

Driving force for implementation
Minimisation of residues, optimal use of metal.

Example plants
The technique is applied in all European foundries.

Reference literature
[202, TWG, 2002]

4.1.6 Internal recycling of magnesium scrap

Description
"In cell" recycling:
Clean feeders can be directly melted in the melting furnaces. Because of oxides and other inclusions, the possible amount of recycling is limited. Specialised equipment for exact analytical and metallographical control is necessary.

"In house recycling":
Here the scrap is treated and recycled at a separate recycling-plant on-site at the foundry. Two techniques may be applied:
- *Fluxless re-melting:* Re-melting of Mg scrap under a covering gas in a hearth type furnace; applicable only to class 1 scrap. Advantages are the low additional investment and low energy consumption
- *Salt re-melting:* Re-melting of Mg scrap under a salt cover. Is applicable to the processing of all scrap classes except used fluxes and sludge (not treated). If only class 1 – 2 scrap is used, HP (high purity) magnesium alloys may be produced.

Both techniques can be used to produce Mg-ingots or molten metal for liquid charging.
Both in fluxless and salt-covered re-melting, dross (the floatings on the melt) and sludge (the sinkings in the melt) are generated, as well as residues retaining a residual metal content (70 - 80 % Mg for sludge, 60 – 90 % Mg for dross). For recovery of the metal content, three options exist:
- salt re-melting (in the same or a separate furnace)
- re-melting in the aluminium industry
- utilisation in the desulphurisation of iron or steel.

If the scrap is re-melted in a fluxless melting furnace, the salt re-melting of dross and sludge involves the operation of a separate furnace.

The re-melting of mixed class scraps is performed using salt re-melting. The mixed scrap needs pretreatment. Table 4.3 gives a survey of the input-outputs of a pretreatment installation.

Inputs	Equipment	Outputs	End-of-pipe technology
- oily or wet Mg-turnings (>2 % oil/water) - electricity	**Centrifuge**	- Mg-turnings (<2 % oil/water) - oil/water-emulsion	
- centrifuged and all other turnings - electricity	**Turning–press (T = 400 °C)**	- pressed turning - exhaust air	Particle separator for the vaporised oil
- feeders, bad castings - dross (without salt, from the foundry process) - electricity	**Shredder (if necessary)**	- shredded material - dust	

Table 4.3: Inputs and outputs for a magnesium scrap treatment plant [202, TWG, 2002]

The recovery of metal from the re-melting salt residue is done using dry crushing and screening with magnetic separation or by using a wet washing system. The wet system produces a magnesium fraction and a sludge, which, after dewatering, may be used in fertiliser industry.

Achieved environmental benefits

The main benefit is the optimised recycling of magnesium. Internal recycling has the added benefit of eliminating transport to an external recycling plant. The metal efficiency of the recycling is increased by type-specific melting.

Cross-media effects

Fluxless re-melting involves the use of sulphur containing protective gases, which contribute to global warming (SF_6) or are poisonous (SO_2). This issue is discussed in 4.2.7.1.

Operational data

Experimental mass flow diagrams for the re-melting of class 1 scrap are given in Figure 4.1 and Figure 4.2. These include the internal re-melting of sludge and dross.

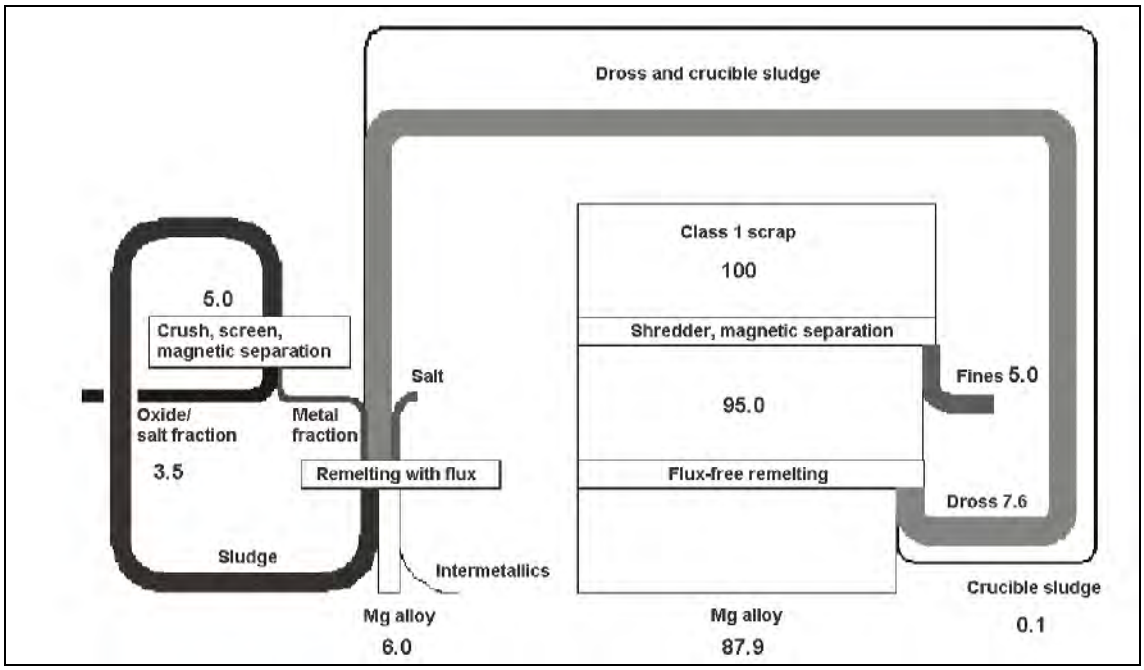

Figure 4.1: Mass flow diagram for the fluxless re-melting of magnesium class 1 scrap [206, Ditze and Scharf, 2000]

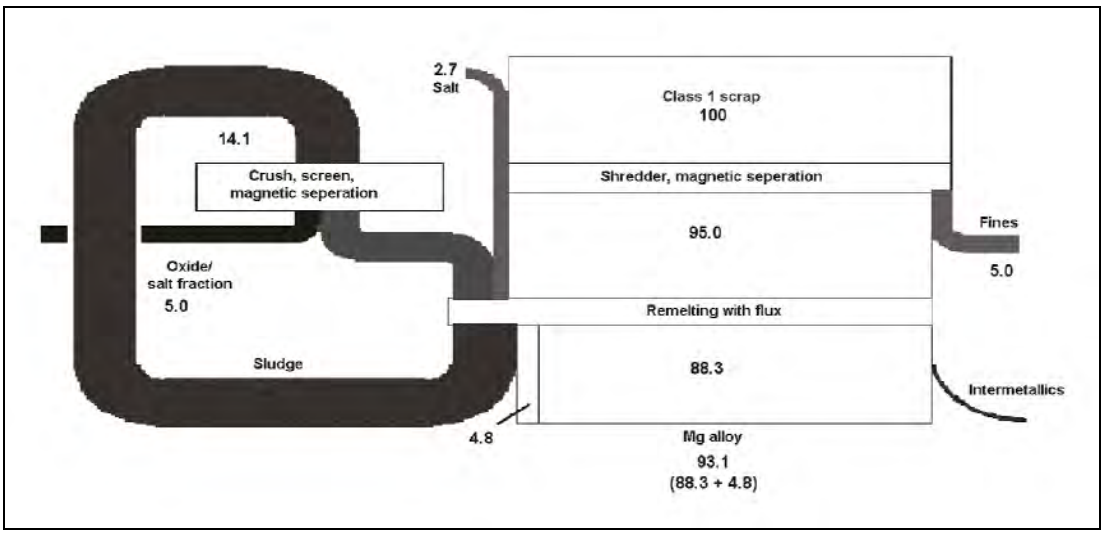

Figure 4.2: Mass flow diagram for the salt re-melting of class 1 magnesium scrap [206, Ditze and Scharf, 2000]

Operational data from a 2000 tonne/yr salt re-melting plant for mixed treated scrap (3 furnaces with a capacity of 600 kg each) give consumption levels of salt: of 3.4 kg/tonne scrap and natural gas: of 26.5 Nm^3/tonne scrap.

The wet treatment of the salt fraction produces a magnesium fraction (43 %) and a sludge (57 %). The sludge is dewatered using a membrane filter press and the water is re-circulated into the process.

Applicability
This technique is applicable for new and existing magnesium foundry installations.

Economics
Costs for external recycling are estimated to be approximately EUR 1200/tonne, depending on the type of transport used, the transport distance and the local market. The costs for in-house recycling are EUR 500/tonne, a difference of EUR 700/tonne. For a single plant with 1500 tonnes/yr recycling material this means a potential saving of more than one million euros per year.

The given data are general and have to be adapted individually for each enterprise. Depending on the products and the processes used, the expenses needed for separation of the waste have to be taken into account. The waste has to be collected specifically for every alloy and every procedure.

Further factors of major influence are:

- depreciation (approximately 10 % in a depreciation period of 5 years)
- personnel costs (35 – 40%)
- cost for new material (approximately 30%) to substitute the material loss (estimated 7%)
- costs for energy, maintenance, spare parts, salt, disposal (20 – 25%).

The amortisation of a flux-based facility with two furnaces is in the range of 8 to 11 months. The amortisation of a continuous facility with 500 kg magnesium per hour will likely take a few months more.

Driving force for implementation
Optimisation of magnesium use, with a reduction of the amount of magnesium sent for disposal.

Example plants
TCG Unitech, Kirchdorf/Krems (A): uses an in-house recycling facility.
No fluxless re-melting plants have been reported in Europe, although the melting technology is available on the market.

Reference literature
[202, TWG, 2002], [206, Ditze and Scharf, 2000], [223, Rauch, et al., 2003]

4.1.7 Recycling of used containers

Description
Suppliers of chemicals and additives may take back their empty containers (plastic, wood, metal) for recycling. The use of the largest size container possible may be considered.

Achieved environmental benefits
Prevents waste and further stimulates recycling.

Cross-media effects
If containers are returned without further cleaning, no cross-media effects apply.

Applicability
This technique is applicable in all new and existing installations.

Economics
Economic data differ from site to site and depend on the conditions agreed with the supplier.

Driving force for implementation
Prevention and recycling schemes for waste and packaging waste regulations.

Example plants
This technique is commonly applied in European foundries.

Reference literature
[110, Vito, 2001]

4.2 Metal melting and molten metal treatment

4.2.1 Cupola furnaces

In this section, techniques concerning melting practices and furnace operation will be discussed. These techniques may apply either to cold or hot blast operation, or to both. Flue-gas related techniques, such as post combustion and flue-gas cleaning, are discussed in Section 4.5.2. That section also discusses the conversion of cold blast to hot blast cupola furnaces.

4.2.1.1 Optimisation of furnace operation

Description
The amount of dust and exhaust gases resulting are directly related to the amount of coke charged per tonne of iron. Therefore, all measures that improve the thermal efficiency of the cupola will also reduce the emissions from the furnace.

Possible good melting practice measures include:

- *Operating the furnace in its optimum regime as much as possible*: For any given cupola, the influence of the blast rate and the coke charge on the tapping temperature of the metal and the melting rate, can be expressed in the form of a net diagram or Jungblüth diagram. A net diagram is only valid quantitatively for the cupola for which it was obtained. It displays how the metal temperature and melting rate behave upon changes in the blast rate and coke charge, and allows determination of the point (or line) of optimal thermal efficiency
- *Avoiding excess temperatures* of the melt and reducing the superheating temperatures by taking measures during the handling of tapped metal
- *Uniform charging*: taking care during charging to get a uniform distribution of metal and coke
- *Improving the control* of the charge weight, the blast airflow and the metal temperature
- *Minimising air losses*: The correct supply of air is essential for efficient cupola operation. This is often hampered by air losses. Therefore, it is important to pay close attention to the prevention of all leaks to ensure efficient operation. Slag holes on intermittently tapped cupolas are often left open and are frequently oversized, resulting in considerable air losses. Air losses are particularly common for hot blast cupolas. They take place in the heat-exchanger. The consequence is that oxygen must be injected in the tuyères instead of the air which is lost
- *Avoiding "bridging" in the cupola*: Bridging and scaffolding are the hanging or non-descent of cupola charges in the cupola shaft. This causes a loss of melting efficiency, and in severe instances melting can be completely stopped
- *Utilising good lining practice*: As melting proceeds, the diameter and the area of the melting zone increase due to lining erosion and wear. This affects the operation, moving it away from the optimum. Minimising the lining attack is therefore an energy saving measure. For satisfactory and economic cupola operation the melting zone needs to be efficiently repaired after each melt.

Achieved environmental benefits
Increased energy efficiency, reduction of cokes consumption, reduction of residues.

Cross-media effects
No cross-media effects are reported

Applicability
This technique applies to all new and exisiting cupola furnaces.

Driving force for implementation
Optimisation of furnace operation.

Example plants
Good melting practice measures are applied in all cupola foundries.

Reference literature
[32, CAEF, 1997], [44, ETSU, 1993], [202, TWG, 2002]

4.2.1.2 Quality control of coke input

Description
The quality of the coke used has a direct bearing on the efficiency of cupola operations. It particularly affects the initial temperature carbon pick-up and the sulphur content of the iron. Specifying the foundry coke involves testing the following contents:

- *Fixed carbon*: The higher the carbon content, the higher the calorific value
- *Ash content*: A high ash content is undesirable since it lowers the calorific value of the coke and generates a greater volume of slag in the cupola
- *Volatile matter*: Volatile matter is undesirable since it reduces the fixed-carbon content, and thus the calorific value of the coke
- *Sulphur*: Sulphur is well known as an unwanted element in any type of cast iron and leads to SO_2 emissions. The lower the sulphur content of the feedstock coke, the better. The sulphur content of the coke depends on the sulphur content of the feedstock coal. Unfortunately there is no known method to remove sulphur from coal
- *Moisture*: Moisture in the coke when dispatched from the coke oven is undesirable, since it reduces the amount of carbon available by weight. However, it is necessary for the coke to contain some moisture, to avoid fires on conveyer belts and in lorries and wagons
- *Size*: The size of the foundry coke directly affects the coke consumption per tonne of iron melted and also the melting rate. To achieve optimum performance the coke size dispatched from the coke oven generally needs to be sized such that the furnace coke has a mean size diameter greater than 90 mm, with no more than 4 % smaller than 50 mm. The content of fines will influence emissions of dust during (un)loading and handling.

Achieved environmental benefits
Optimising the coke input results in a higher process efficiency.

Cross-media effects
No cross-media effects apply.

Operational data
Typical properties of foundry coke are given in Table 4.4:

Property	Typical value (%)	Limit value (%)
Ash	5.8 – 5.9	6.5 max.
Volatile matter	0.3 – 0.4	0.8 max.
Sulphur	0.68 – 0.70	0.75 max.
Moisture	1.5 – 2.5	3.0 max.
Strength M80 Micus index M10 Micus index	 81 – 82 8 – 8.5	 78.0 max. 9.0 max.
Fixed carbon	93.7 – 93.8	93.0 min.
Higher calorific value	32200 kJ/kg	31800 kJ/kg

Table 4.4: Typical properties of foundry cokes
[197, Nalonchem, 2002]

The data in Table 4.4 are taken from supplier specifications. Local standards may use higher limit values.

Applicability
The technique is applicable to all new and existing cupola installations.

Economics
In general, low sulphur feedstocks are more expensive.

Driving force for implementation
To improve the efficiency of the foundry process.

Example plants
This technique is commonly applied in European foundries using cupola furnaces.

Reference literature
[44, ETSU, 1993], [225, TWG, 2003]

4.2.1.3 Operation with acidic or basic slag

Description
A flux is used to render the slag fluid enough to separate from the iron and to allow it to flow freely from the cupola. The most commonly used flux is limestone (calcium carbonate), which calcines in the cupola shaft to form lime, a basic oxide, which then combines with the other slag-forming constituents (mainly acidic in character) to provide a fluid slag.

The basicity of a slag is given by the following ratio: (CaO % + MgO %)/SiO_2 %

Most cupolas operate with an acidic or slightly basic slag (basicity <1.2). Basic cupolas (basicity up to 2) offer 3 advantages:
- higher carbon
- lower sulphur
- possibility of charging lower quality scrap.

But they present the following disadvantages:
- silicon losses are high
- refractory costs are high, unless operating with a liningless cupola
- fluxing material costs are higher
- metal analysis is more difficult to control than acid cupola melting.

Achieved environmental benefits
For acidic cupolas, dry filters can be used. The slag of basic cupolas has a higher melting point. So a flux based on CaF_2 is generally used to make it fluid. In this type of cupola, there are emissions of fluor-containing components. This necessitates the application of wet scrubbers for efficient capture of these components.

Applicability
This technique applies to all new and existing cupola installations. If basic slag is used, a wet dedusting is necessary.

Example plants
This technique is commonly applied in European foundries using cupola furnaces.

Reference literature
[44, ETSU, 1993], [202, TWG, 2002], [225, TWG, 2003]

4.2.1.4 Increasing shaft height of CBC

Description
The required shaft height for cupolas at various melting rates is given in Table 4.5. These shaft heights optimise the preheat for the descending burden. However, if the gas is to be burned at the charge-hole, a shorter shaft height may be considered. In general, the shorter the shaft, the hotter the top gas and the greater the ease of combustion – either spontaneous or assisted by an afterburner.

Melting rate of Cupola (tonne/h)	Height from tuyères to charging door sill (m)
Up to 5	4.9
5 – 8	5.8
>8	6.7

Table 4.5: Shaft height requirements

The thermal efficiency of the cold blast cupola furnace can be improved by increasing the shaft height. In general, the higher the furnace shaft, the longer the combustion gases remain in contact with the charge, and the more heat is transferred to the charge.

Achieved environmental benefits
Depending on the installation type, the height must be optimised to allow burn-out of the gases and efficient heating of the charge.

Cross-media effects
No cross-media effects apply.

Operational data
Operational data are given in Table 4.6. The modification involves a doubling of the upper zone volume. This results in a reduction of coke consumption from 140 to 115 kg/tonne, which is a relative reduction of 18 %. It should be noted that in general an optimal shaft height follows the rule-of-thumb: 'height = 5 x diameter at tuyères'. The initial situation in the example furnace was therefore sub-optimal.

	Cupola before modification	**Cupola after modification**
Diameter		
- melting zone (m)	1.4	1.4
- upper zone (m)	1.4	1.7
Heigth over tuyères (m)	5	6.5
Coke ratio (kg/tonne)	140	115

Table 4.6: Example data for the change in coke consumption upon shaft height increases [202, TWG, 2002]

Applicability
Optimisation of the furnace height needs to be performed at the design stage of the furnace, otherwise height increases will usually only be performed during major re-building works of the furnace.

Driving force for implementation
To increase the efficiency of the furnace operation.

Example plants
Operational data are taken from an example plant in France.

Reference literature
[32, CAEF, 1997], [44, ETSU, 1993], [202, TWG, 2002]

4.2.1.5 Installation of secondary row of tuyères for a cold blast cupola (CBC)

Description
The thermal efficiency of the cold blast cupola furnace can be improved by the installation of a secondary row of tuyères. These provide extra oxygen above the combustion zone, which induces the oxidation of the CO in the combustion gases, the CO being formed by the endothermic reduction of CO_2 by C (coke). This technique liberates the "latent" heat of the combustion gases, thus improving the thermal efficiency of the cupola.

The divided blast cupola is equipped with two rows of tuyères, each supplied with a measured and controlled quantity of blast air. Compared with a normal cupola, fitted with a single row of tuyères, the divided blast cupola enables:

- a higher metal tipping temperature and higher carbon pick-up to be obtained for a given charge-coke consumption
- the charge coke consumption to be reduced and, if required, the melting rate to be increased, whilst maintaining a given metal tapping temperature.

To obtain the maximum benefit from divided blast operation, the blast should be divided 25 - 50 % top and 75 – 50 % bottom. The 2 rows should be spaced about 1m apart (cold blast) to 0.5 m (hot blast). Each row of tuyères needs to be provided with its own blast supply system.

Achieved environmental benefits
A reduction in coke consumption and an increase in thermal efficiency.

Cross-media effects
No cross-media effects apply.

Operational data
By the use of two rows of correctly-spaced tuyères with the blast equally divided between them, the metal tapping temperature can be increased by approximately 45 – 50 ºC for a given coke consumption. Alternatively, the coke consumption can be reduced by 20 – 32 % and the melting rate increased by 11 – 23 %. When operating with a divided blast but without reducing the coke charge, so that a higher melting temperature is obtained, the carbon pick-up tends to increase slightly (by approx. 0.06 %), and the melting loss of silicon tends to also increase, by approximately 0.18 %.

With divided blast operation, the lining burn-out extends further into the furnace shaft. At the start of a melt it is therefore necessary to measure and adjust the coke bed height. On melts of short duration, i.e. those less than about 2 – 3 hours, the saving in coke charge does not usually compensate for the additional requirements of bed coke. Nevertheless, even on short melts, the higher tapping temperature and the higher carbon pick-up obtainable with divided blast operation can be an advantage to many foundries.

Other reported advantages are:
- the exit gas temperature is only 250 ºC, compared to the conventional cupola, where the temperature is 450 ºC
- it can take 100 % bigger chunks of re-melting scrap
- it is possible to increase the steel scrap ratio in the metal charge.

Additional operational data are given in Annex 1.

Applicability
The second row of tuyères is applied as a standard technique for new cold blast cupola installations and may be applied to existing installations during reconstruction. This technique is not normally applied for hot blast operation

Economics
The divided blast cupola has been well proven in practice as a means of obtaining economic operation for a modest investment cost.

The capital cost of converting existing cupolas to divided-blast operation is low compared to the savings obtained. BCIRA quoted one British foundry where the payback period was only fourteen weeks. A large Canadian foundry saved CAD 170000 in one year for a conversion cost of only CAD 18000. An additional benefit from a lower coke use per tonne of iron is the lower sulphur content, this saves on the desulphurisation plant and gives a higher quality iron.

Additional economic data are given in Annex 1.

Driving force for implementation
To increase the efficiency of the melting operation.

Example plants
In France, all the recent cold blast cupolas use 2 rows of tuyères: STAUB (Merville), FONTE ARDENNAISE (Vivier au court), BERNARD HUET (Vivier au court). There is also 1 hot blast with 2 rows: FIDAY GESTION (Chassey les Scey)

Reference literature
[32, CAEF, 1997], [196, Unido, 2002], [202, TWG, 2002], [225, TWG, 2003]

4.2.1.6 Oxygen enrichment of blast supply

Description
The thermal efficiency of the cold blast cupola furnace can be improved by oxygen enrichment of the combustion air. This gives rise to a higher combustion temperature of the coke. In this way coke consumption can be decreased or higher temperatures of the tapped metal can be obtained.

Compared with normal operation, the continuous use of oxygen enables one of the following improvements to be made:
- a higher metal temperature, higher carbon pick-up and lower melting loss of silicon for the same coke consumption, or
- a lower coke consumption for a given metal temperature, with no increase in carbon pick-up or reduction in the melting loss of silicon, or
- an increased output from an existing cupola, as a result of the increased melting rate.

Oxygen injection provides the possibility of reacting quickly to process drifts, and then compensating for small changes in process conditions. Thus, oxygen injection is often used intermittently, usually whenever the process requires adjustment.

The effectiveness of the oxygen depends on the method by which it is introduced into the cupola. Three processes have been developed:
- *Direct enrichment of the blast supply*: Oxygen is fed into the main blast, this technique is applied in the majority of the cold blast cupolas
- *Injection into the well*: Oxygen is injected into the coke bed from a ring-main which supplies water-cooled injectors, whose number depends on the cupola size. Oxygen used in this way is at least twice as effective as when it is used to enrich the blast supply directly. However, this type of injection is confined to continuously-tapped cupolas, since with intermittent tapping there is a risk that slag and or metal may rise to the level of the injectors. The technique was developed in the UK but it has not found widespread application
- *Injection at the tuyères*: Oxygen is introduced into the cupola through injectors inserted into each tuyère or into alternate tuyères. The effectiveness of this method lies between direct blast injection and well injection methods. This technique is used in 20 – 30 % of cases, but more in hot blast operation.

The principles of oxygen injection are depicted in Figure 4.3.

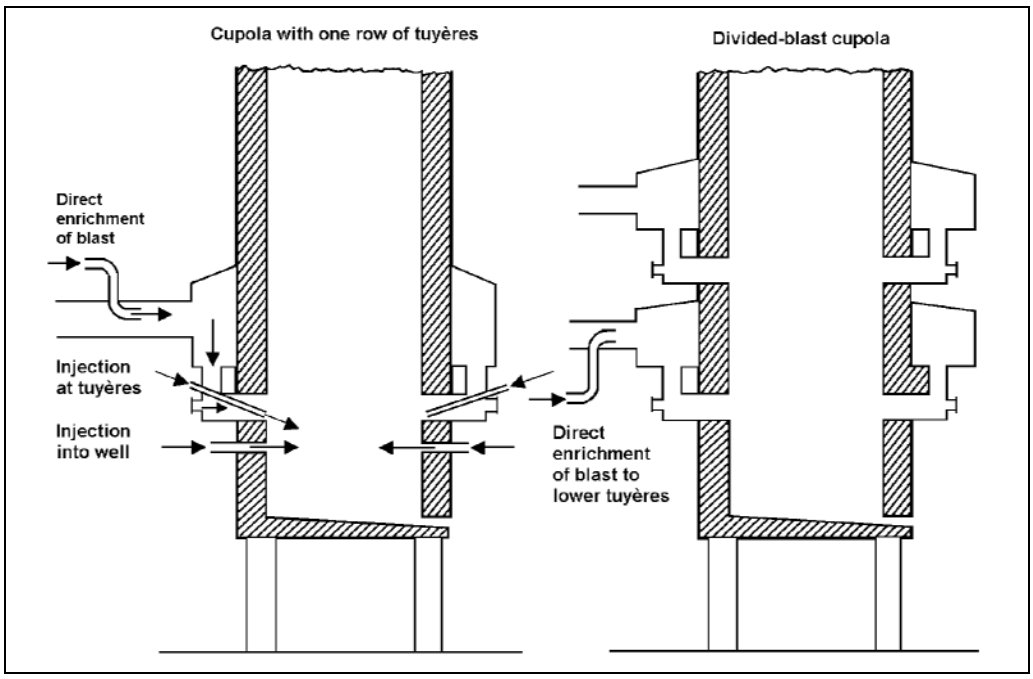

Figure 4.3: Various methods of oxygen injection
[44, ETSU, 1993]

Achieved environmental benefits
The application of oxygen results in a reduced coke consumption and a better process control. Additionally, a reduction in the emission of dioxins and furans from cold blast cupolas have been reported (see Section 4.5.1.4).

Cross-media effects
The technique requires oxygen which is produced off-site and involves a consumption of electric energy.

Operational data
Compared to conventional cold blast operation with one row of tuyères, the increase in tapping temperature obtained for a given charge of coke, can be expected to be as follows:

- blast enrichment + 15 ºC
- well injection + 85 ºC
- tuyère injection + 40 ºC

Divided blast operation with a direct enrichment of blast air, results in an increase in the tapping temperature of 85 ºC compared to cold blast operation. In divided blast operation, neither well injection nor tuyère injection give any greater benefit than the simple method of direct injection.

An important application of oxygen has been to increase the melting rate of an existing cupola, well beyond its usual optimum melting capacity. In divided blast cupolas, the melting rate increases by around 6.8 % and the tapping temperature by about 20 ºC for each 1 % of direct oxygen enrichment in the blast air. If an increase in temperature is not required and the coke charge is reduced, an even greater increase in the melting rate can be obtained for the same blast rate and oxygen enrichment.

Additional operational data are given in Annex 1.

Applicability
Today, almost all European hot blast cupolas inject oxygen through the tuyères. For cold blast furnaces, the use of oxygen enrichment can be considered as the standard technique. In this case, enrichment of the blast supply is usually applied. The oxygen level of the oxidising air mixture is usually between 22 and 25 % (i.e. an enrichment of 1 % to 4 %).

Economics
The effect that using oxygen has on melting costs greatly depends on the price of oxygen, which in turn is related to the amount used. Foundries with larger outputs can generally buy oxygen more cheaply. The economic case for using oxygen has to be established on a case-by-case basis.

The substantial increase in outputs obtainable has enabled foundries to increase outputs without high capital investments in new plant, and to reduce costs and overtime payments, so much so that the overall reduction in costs amply justify the cost of oxygen. Such improvements must take into account the related core and mould making capacity.

Driving force for implementation
To optimise the efficiency and control of the melting process.

Example plants
This technique is commonly applied in European foundries using cupola furnaces.

Reference literature
[32, CAEF, 1997], [156, Godinot, 2001]

4.2.1.7 Superheating of HBC blast air

Description
An alternative technique for increasing the flame temperature is to superheat the blast air to 800 – 900 ºC. For this, injection of an air plasma, or heating in tubular resistance heaters is applied. Experience has shown that increasing the blast temperature by 200 ºC, from 550 ºC to 750 ºC, which takes 60 kWh per tonne of iron, saves 10 kg of coke per tonne melted. The main benefit, more important even than saving coke, is the flexibility: the hourly output can be increased by 30 % without modifying the melting bed. Additionally, the application of (plasma) superheating allows a change in raw material from clean cast iron to steel, with a subsequent positive economic effect.

Achieved environmental benefits
Reduced coke consumption and increased efficiency of the process.

Cross-media effects
Electrical heating causes an increase in electricity consumption (58 kWh/tonne).

Operational data
Operational data are given in Annex 1. The heating of the blast air produces a lower flue-gas volume as compared to hot blast long campaign operation. As compared to oxygen injection, the flue-gas volume and electricity consumption is larger.

Applicability
The technique applies to new and existing HBC furnaces.

The technique (both with electrical and plasma heating) achieves a similar effect as injection of oxygen through the lances, but can be applied in a more complex installation and produces a larger flue-gas volume. Additionally, oxygen injection allows make-up for leaks in the air circuit.

Economics
Economic data are given in Annex 1.

Driving force for implementation
To optimise the efficiency and to control the melting process.

Example plants
PSA, Sept-Fons, France
Three foundries in France apply tubular resistance heating.

Reference literature
[156, Godinot, 2001]

4.2.1.8 Minimal blast shut-off periods for HBC

Description
A cupola blown just intermittently will not operate efficiently, and will result in a reduced metal tapping temperature, as shown in Figure 4.4.

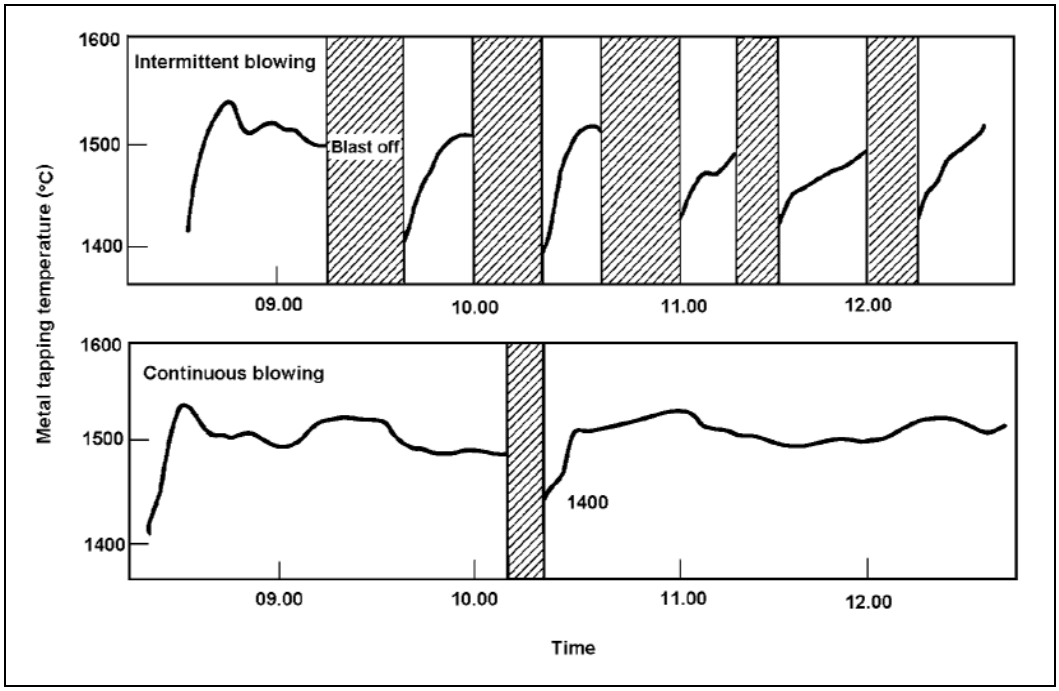

Figure 4.4: Effect of blast shut-off periods on tapping temperature in a post-blast cupola [44, ETSU, 1993]

Frequently shutting off the blast due to only intermittent demands for metal:
- reduces the average tapping and pouring temperatures and increases the extent of their variations, with a consequent risk of producing defective castings
- increases the variation in metal composition, particularly the carbon and silicon content, with a danger of then producing 'off-grade' metal
- increases the coke consumption, through the operators' attempt to improve the tapping temperature
- affects the degree of nucleation in the iron and increases its shrinkage tendencies.

Moulding and casting schedules are therefore programmed to produce a reasonably constant demand for metal, thereby minimising or even eliminating the need for blast shut-off periods or for large variations in the blast rate.

Where large fluctuations in demand are unavoidable, the installation of an electric holding furnace might be considered. This can provide a large buffer reservoir for metal, to take up variations in demand, so that the cupola can be operated continuously at a reasonably consistent blast rate. It can also be used to help even out variations in temperatures and composition.

Achieved environmental benefits
Reduction of cokes consumption. Higher process energy efficiency.

Cross-media effects
Operating the electric holding furnace incurs a higher energy consumption.

Applicability
This technique is applicable to all new and existing cupola furnaces.

Economics
The economics of installing a holding furnace must be very carefully considered, particularly in foundries with relatively low production rates.

Driving force for implementation
To increase the efficiency of the foundry process.

Example plants
The applicable blasting regime is part of the operational considerations in all European foundries using cupola furnaces.

Reference literature
[44, ETSU, 1993]

4.2.1.9 Cokeless cupola furnace

Description
In the cokeless cupola, the metal charge is heated by the combustion of natural gas. Instead of the traditional coke bed, a bed of refractory spheres on a water-cooled grid supports the metal charge. The molten metal droplets run through this bed and are collected in the well at the bottom of the furnace. The life of the spheres exposed to the superheating temperatures of the metal is limited. A cokeless cupola is therefore run at a reduced temperature (1400 ºC instead of 1500 ºC) and superheating of the liquid metal is done in an attached gas-fired or induction furnace (duplex operation).

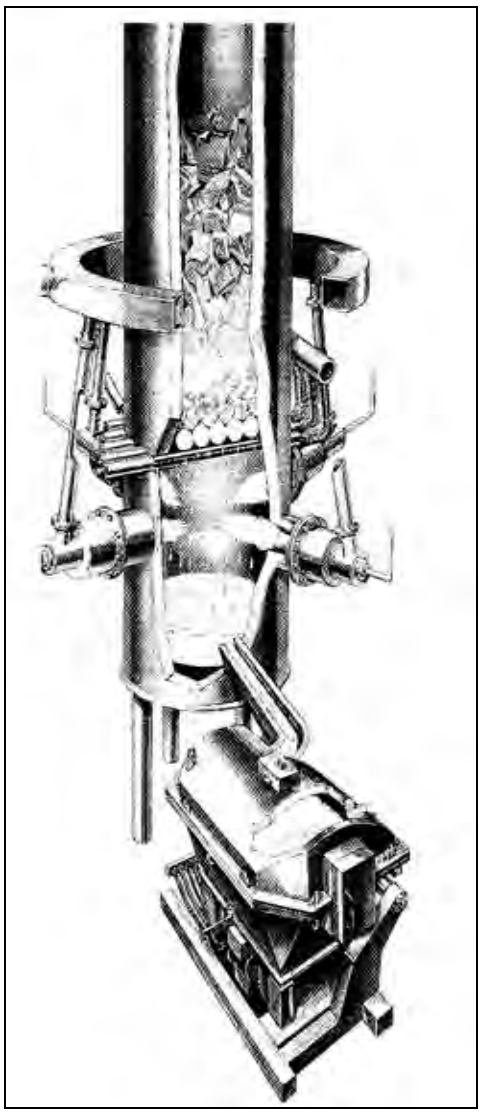

Figure 4.5: Cokeless cupola furnace in duplex operation
[110, Vito, 2001]

An important operational factor is that the cokeless cupola has to be run continuously. There is a high risk of clogging and blocking on the cooled grate bars. In case there is a need to stop the metal flow (e.g. due to problems in the moulding shop), the power of the burners can be reduced to 35 – 40 %, in order to compensate for wall heat-losses. The need for continuity needs to be balanced with the usage of refractory in the melting zone. Therefore, melting campaigns of one week are typically used.

The oxidising atmosphere and relatively low flame temperature cause increased oxidation losses. This limits the possibility to feed in steel. A maximum amount of 35 % of steel is used in the production of nodular iron, though 20 % can be considered general practice. The quality of the feed needs to be well controlled since the cokeless cupola is more susceptible to bridging than the coke-fired cupola.

In the production of nodular iron, an important advantage of the cokeless cupola is that there is no resulphurisation, so the melt may be used immediately after recarburisation.

Achieved environmental benefits
Besides a higher thermal efficiency, this furnace has other environmental advantages. The combustion of natural gas instead of cokes has the following consequences for the flue-gas:

- less dust (0.8 kg/t metal charge instead of 10 to 15 kg/t metal charge for cold blast cupola)
- no CO or SO_2 and less CO_2 (120 kg/t metal charge instead of 450 kg CO_2/t metal charge for cold blast cupola)
- the flue-gas rate is smaller (495 m³/t metal charge instead of 770 m³/t metal charge for cold blast cupola without water-cooled refractory), and hence the dedusting installation can be designed much smaller.

Cross-media effects

The use of cokeless cupola melting necessitates duplex operation, in order to allow superheating of the iron. For superheating in an induction furnace, there is an increased need for electrical power compared to the hot blast operation.

Operational data

Operational data are given in Table 4.7. The furnace is generally operated at an air factor of $\lambda = 1.15$. The capacity of the furnace may be high (often in the range 10 – 12 t/m².h). The amount of spheres is 1 – 1.4 % of the metal charge. The energy efficiency of the cupola, without taking the coupled induction furnace into account, is in the range of 70 %.

	Units	**Consumption (per tonne of molten metal)**
Natural gas consumption		
Preheating of the furnace	m³	600
Melting	m³	48.0
Electrical energy consumption		
a) Superheater		
Superheating	kWh	64.0
Holding	kWh	15.0
b) Auxiliary equipment	kWh	25.0
Consumption of lining material		
Furnace shaft	kg	5 – 8
Syphon	kg	0.7
Superheater	kg	0.5
Water consumption	m³	0.4
Oxygen consumption	m³	19.7
Metallic charge	**Components**	Part (%/t)
	steel	25 – 35
	pig iron	20 – 30
	returns/cast iron scrap	35 – 55
Alloying and additives	**Components**	Part (%/t)
	Carburiser	1.1
	Briquettes – Si	0.8
	Ceramic balls	0.95
	Slag forming constituent	0.3

Table 4.7: Typical operational data for a cokeless cupola furnace [202, TWG, 2002]

Due to the absence of cokes (and CO), no latent heat is lost from the cokeless furnace system. Full heat recuperation from the flue-gas occurs in the shaft. In duplex configurations (for example in conjunction with an induction furnace), efficiencies in the range of 40 to 60 % may be obtained. Thermal efficiencies for coke fired cupolas vary between 25 % (cold blast) and 45 % (hot blast, long campaign).

Emission data for cokeless and hot blast cupola furnaces are compared in Table 4.8. These apply for the following configurations:

- cokeless cupola: below-charge exhaust capture; oxidising atmosphere (λ = 1.15); no post combustion; dry filtration
- hot blast cupola: below-charge exhaust capture; post combustion in separate chamber, followed by recuperation and dry filtration.

	Cokeless				Hot blast cupola			
	Working conditions		**Nm³/t**	**kg/t**	**Working conditions**		**Nm³/t**	**kg/t**
Gas	50 Nm³/tonne							
Energy	500 kWh/Nm³							
λ	1.15							
Coke					12 %			
Steel					50 %			
Recarburi-sation					1.9 %			
Total combustible carbon					9 %			
Flue-gas			550				2930	
CO_2		9.1 %	50	98		6 %	176	346
H_2O		18.2 %	100			-		
O_2		2.7 %	15			15 %		
CO		<1 %	<5.5	<6.9		10 mg/Nm³		29 g/t
NO_x		155 – 375 mg/Nm³		85 – 210 g/t		205 mg/Nm³		150 g/t
SO_2		-				100 mg/Nm³		300 g/t

Table 4.8: Emission data for cokeless cupola and hot blast cupola [170, Godinot and Carlier, 1999]

The following observations can be made:

- the cokeless cupola emits five times less flue-gases than the hot blast cupola. This is mainly due to the post combustion, which brings excess air into the combustion chamber of the hot blast cupola. As a consequence, the cokeless cupola can be equipped with a smaller flue-gas treatment system
- the cokeless cupola emits 3 to 4 times less CO_2 than the hot blast cupola
- the cokeless cupola emits more CO, which is combusted in the case of the hot blast cupola
- NO_x and SO_2 emission levels are low compared to current emission limit values (e.g. for France, 500 mg/Nm³ and 300 mg/Nm³ respectively)
- if dry filtration is applied, both techniques have low dust emission values.

Applicability

The technique applies to new installations, producing medium to large series. The cokeless cupola needs a constant and continuous working regime. Due to high oxidation losses and a high risk of bridging, the technique requires a clean feed with a steel content of max. 35 %. Since no sulphurisation occurs, the technique is of special interest for the production of nodular iron.

Economics

Data on operational costs (for 1999) are presented relative to operational costs of hot blast cupolas (set at 100%) in Table 4.9. The values apply for a 12 tonnes/h equipment and have been based on a study of 3 cokeless cupolas operating in Europe.

		Raw materials (%)	Auxiliary materials (%)	Melting energy + Fluids (%)	Comparative index
Grey cast iron	Cokeless gas cupola	83	6	11	116
	Hot Blast coke cupola	69	8	23	100
Nodular cast iron	Cokeless gas cupola	81	6	13	104
	Hot Blast coke cupola	69	8	23	100

Table 4.9: Operational costs for cokeless cupola, relative to hot blast cupola (set at 100%) [202, TWG, 2002]

The tabled values were calculated in 1999, however since then, there has been an increase of the price of coke. From this table it may be concluded that, in Europe a 12 t/h cokeless cupola:
- melts the more expensive grey cast iron
- melts nodular base iron with a price very similar to hot blast cupola.

The comparison is very dependent on the local price of energy and materials.

Driving force for implementation
To reduce cupola emissions.

Example plants
- Düker, Laufach (D): 15 tonne/h nodular iron
- Düker-Kuttner, Lingotes Especiales, Valladolid (E): 16 tonne/h grey an nodular iron
- Hayes Hydraulic Castings (GB), 5 - 6 tonne/h lammellar and nodular iron.

Reference literature
[32, CAEF, 1997], [110, Vito, 2001], [170, Godinot and Carlier, 1999]

4.2.1.10 Gas-fired coke-cupola

Description
The principle of the coke-gas cupola is to replace part of the coke with gas. There are two techniques for burning natural gas in the cupola:
- using air-gas burners, located above the tuyères
- using oxygas burners, located in the tuyères.

At present, the coke/air-gas cupola furnace finds limited implementation in Europe. This may be attributed to the difficulty in controlling the process and the increased complication of the furnace shell.

The oxygas burner was introduced in 1994. Besides oxygas firing, it allows the introduction of dust into the tuyères for recirculation, although in practice this option is not applied. The oxygas burners are placed in 1/3 – 1/2 of the tuyères. About 10 % of the coke energy is replaced by natural gas, leading to a gas consumption of 8 to 16 Nm^3/tonne. This is associated with a total oxygen consumption (burners + lances) of 40 to 60 Nm^3/tonne. The application of this technique allows a greater flexibility in the production and/or metallurgy.

The effect and use of the oxygas burner depends on the cupola concerned. In cold blast cupola furnaces, the technique is used to ensure easy restarts or to reduce the proportion of coke. In hot blast operation, the technique is used to increase the furnace capacity without modifying the melting bed. The replacement of part of the coke with CH_4 results in a reduction in flue-gas volume. This is used as a means of increasing the furnace capacity, without over-saturating the installed flue-gas cleaning system.

The technique results in an increase in the carbon content of the melt and allows an increase in the amount of steel in the charge. The process provides a means of injecting FeSi, which is less expensive in powder form than as ore. These properties result in a beneficial economic effect.

Achieved environmental benefits

The replacement of part of the coke with CH_4 results in a reduction in the flue-gas volume. In addition, the flue-gas is made more combustible due to the higher CO and H_2 contents. If post combustion is present, the resulting flue-gases will show lower levels of organic compounds and CO.

The replacement of coke by natural gas reduces the emission levels of SO_2.

The technique allows the possibility of recirculating cupola dust into the melt. Although, after some initial trials, this application has not been fully developed.

Reducing the level of coke in the cupola increases the risk of bridging.

Cross-media effects

The production, storage and use of oxygen increases the safety risks. Oxygen production is done through cryogenic distillation or Vacuum (Pressure) Swing Adsorption, which both involve elctricity consumption. The consumption of the latter technique is 0.35 – 0.38 kWh/Nm³ O_2. Oxygen production is often done by an external supplier, who delivers the oxygen to a storage tank or directly through a pipeline.

Operational data

The AGA-Rayburn Foundry (Coalbrookdale, UK) equipped 3 out of 8 tuyères of their cold blast cupola with oxygas burners. This allowed a reduction in the overall proportion of coke from 15 % to 10 %. There was a resultant drop in the sulphur content of the produced iron, this then allowing a reduction to be made in the amount of pig iron used, and thus yielding an economic gain.

Fritzwinter foundry (D) equipped 3 out of 6 tuyères of their 20 – 25 tonnes/h hot blast cupola with oxygas burners. This allowed an increase in production capacity to 28 tonnes/h, without the need to change the melting bed, nor the flue-gas cleaning system. The effect on the flue-gas composition before burning is given in Table 4.10.

	With oxygen without oxygas burners	**With oxygen with oxygas burners**
H_2	0.8 – 1.2	2.2 – 2.4
CO	14 – 15	19
O_2	2	2

Table 4.10: Effect of oxygas burners on the flue-gas composition for a hot blast cupola values in %
[184, Godinot and Ressent, 2002]

Applicability

The technique may be applied on both cold blast and hot blast cupolas in both new and existing installations. The advantages drawn from the application (increased flexibility, economical benefit, reduced flue-gas volume, increased capacity) will depend on the specific melting conditions of the installation under consideration. The technique has been reported to cause difficulties for controlling the process and also increases the complication of the furnace shell required.

Economics
Operational costs before and after switching a cold blast cupola to oxygas operation for the above-mentioned Aga-Rayburn foundry (UK) are given in Table 4.11. Prices are forecasts as calculated by CTIF (F).

Input	Units	Unit price	Without burners		With burners	
		EUR	Consumption per tonne	Cost EUR/tonne	Consumption per tonne	Cost EUR/tonne
Coke	Tonne	198	0.15	29.7	0.1	19.8
Gas	Nm³	0.15	0	-	16.5	2.5
Oxygen	Nm³	0.38	14	5.4		
		0.23			40	9.2
Pig iron	Tonne	164.6	0.2	32.9	0	-
Scrap iron	Tonne	125.8	0.2	37.7	0.5	62.9
Total	EUR/tonne			105.7		94.4
All values per tonne molten metal						

Table 4.11: Operational costs for cold blast cupola with and without oxygas burners [184, Godinot and Ressent, 2002]

Operational costs decrease from EUR 105/tonne to EUR 94/tonne molten metal. The economic gain can mainly be attributed to the reduced proportion of pig iron. This also stresses the fact that the balance will differ for each specific foundry.

Driving force for implementation
To increase flexibility of the foundry and/or to increase the production capacity of existing installations without changing the installation layout.

Example plants
- AGA-Rayburn Foundry (Coalbrookdale, UK)
- Fritzwinter foundry (D)

Reference literature
[156, Godinot, 2001], [184, Godinot and Ressent, 2002]

4.2.2 Electric arc furnace

4.2.2.1 Shortening melting and treatment time

Description
Improved control methods can lead to shorter melting or treatment times. Some examples are:
- closer control of the composition (e.g. C, S, P content) and the weight of the charged materials and slag forming materials
- reliable temperature control of the melt, this can improve the yield of the refining reactions and avoid overheating
- more efficient methods for sampling and deslagging, these can reduce furnace downtime.

Secondary metallurgy, using AOD/VODC treatment, shortens EAF time and has a positive impact on energy conservation. The technique is discussed further in Section 4.5.7.1.

Achieved environmental benefits
Increased furnace efficiency through shorter melting times and reduced downtime.

Cross-media effects
No cross-media effects apply.

Applicability
This technique applies to all new and existing EAF furnaces.

Driving force for implementation
Increase the efficiency of the melting and treatment operation

Example plants
This technique finds widespread application in European foundries using EAF melting.

Reference literature
[32, CAEF, 1997], [202, TWG, 2002]

4.2.2.2 Foamy slag practice

Description
The *foamy slag practice*, currently in use in the steel production industry, consists in simultaneously injecting oxygen and carbon (in the form of coal dust) into the slag at the end of the melting. The foam of slag is produced by the action of CO bubbles. The CO gas comes from the oxidation of carbon in the metal by the injected oxygen and also from the reduction of the iron oxides (FeO) by the injected carbon.

Creating a foamy slag improves the heat transfer to the charged units and protects the refractory material inside the furnace. Because of the better arc stability and less radiation effects, slag foaming leads to a reduction in energy consumption, electrode consumption, noise levels and increased productivity.

Achieved environmental benefits
Reduction of energy consumption and electrode consumption, lower noise levels and reduction of flue-gas volume.

Cross-media effects
As the volume of the slag rises so larger slag buckets may be needed. After tapping, the slag degasses again. There is no reported adverse impact on the possibilities for re-use of the slag.

Operational data
Table 4.12 gives the operational data for a 60 tonne arc furnace and indicates the mains savings in energy, time, refractory and electrodes.

	Units	Normal slag	Foamy slag
Total power	MW	25	30
Radiation loss arc to flue-gas	MW	6	0
Flue-gas flow	m³/h	41000	28000
Final temperature	°C		
- metal		1630	1630
- slag		1603	1753
- flue-gas		1463	1607
- refractory		1528	1674
Energy-input	kWh/tonne		
- electricity		50.8	37.7
- fossile (coal)		37.1	22.6
Energy-output	kWh/tonne		
- metal (ΔH)		10.4	10.4
- slag (ΔH)		1.1	9.4
- furnace losses		20.7	14.1
- flue-gas losses		53.6	24.8
- other losses		2.5	1.6
Heating time 1584 - 1630 °C	min	11min 45sec	7min 30sec
Heating rate	°C/min	3.9	6.1

Table 4.12: Energy and temperature data for EAF furnace melting with normal slag and foamy slag
[202, TWG, 2002]

Slag density is reduced from 2.3 tonne/m³ to 1.15 – 1.5 tonne/m³.

Applicability
This technique applies to new and existing EAF foundries that practice oxygen injection.

Driving force for implementation
Increasing the efficiency of furnace operation.

Example plants
No specific example plants were reported, but the technique finds application in several European foundries.

Reference literature
[32, CAEF, 1997], [202, TWG, 2002], [211, European IPPC Bureau, 2000]

4.2.3 Induction furnace

4.2.3.1 Process optimisation: optimising charge materials, charging and operation

Description
Process optimisation options for coreless induction furnaces include:

- *Optimise feedstock condition*: This involves avoiding rusty and dirty inputs, utilising optimum size and density input/scrap, and using cleaner carburisers. These measures shorten the melting time, reduce the specific energy needed for melting and/or reduce the amount of slag formed
- *Close furnace lid*: Oxidation is reduced by avoiding badly fitting lids and unnecessary/prolonged openings, by quick charging, or by using a protective atmosphere over the melt (N_2). Opening times need to be minimised to prevent energy losses. The necessary opening times for charging, removing slag, temperature measuring, sampling and pouring vary between 50 % and 25 % of the shift time. The latter figure applies for new furnaces, working in optimised conditions. A well-fitted closed lid limits the surface heat loss to about 1 % of the input power. When open, the heat loss can amount to up to 130 kWh/tonne for a 10 tonne capacity unit. When melting under a closed lid, care should be taken not to overheat the furnace
- *Restrict holding to a minimum*: Since melting is the first step in the foundry process chain, a shortening of the holding time can only be obtained by an integrated process optimisation for the whole foundry process and by minimising delays, problems and irregularities in any of the foundry departments. During holding, composition adjustment is performed based on the results of an analysis made on a chill cast sample. Optimisation of the sampling, testing and adjusting procedures is another measure for reducing the holding time
- *Operate at maximum power input level*: Furnaces are more efficient in their use of energy when they are being operated at maximum power input levels, and best results are obtained when the available power can be fully utilised for the largest proportion of the melting cycle. This also includes reducing cold start melts (optimise production programme), and allowing follow-up using monitoring and computer control
- *Avoid excessive temperature and unnecessary superheating*: It is important that the metal reaches the required temperature just at the time that the moulding department is in a position to receive it. Good co-operation between the melting and moulding shop is essential in order to minimise the electricity usage
- *Optimise high temperature melts for slag removal* (good balance): Low melting point slag build-up can be reduced by heating the furnace up to elevated temperatures (1580 ºC vs. 1450 ºC normal). This results in a higher energy consumption, and can affect the metallurgical aspects of the melt. If the slag is allowed to build up on the furnace lining, this can affect the electrical efficiency of the furnace. Slag removal requires the opening of the furnace lid, and thus causes a thermal loss. A good balance needs to be found between increasing the melt temperature and the slag removal practice

- *Prevent slag build up*: More common and more troublesome are instances where high melting point build-up is involved. This mainly results from charging sand and, in the case of iron melting, metallic aluminium into the melt. Some furnace operators have attempted flux additions and cleaning routines but prevention is better than cure in this respect. This involves minimising the presence of sand and Al in the raw materials
- *Trickle the oxygen injection*: Instead of using conventional decarburisation
- *Minimise and control the refractory wall wearing:* The refractory life depends on the choice of materials as a function of the slag chemistry (acidic or basic), the operational temperature (steel, cast iron, non-ferrous), and the care taken upon relining (sintering). The lifetime may vary from 50 (steel, cast iron) to 200 – 300 (cast iron) melts. Operational control measures are taken to follow the refractory wear. These include visual inspection, physical measurement and instrumental monitoring programmes. Good charging practice measures prevent the cumulative effects of physical chokes and mechanical stresses. These include the use of automatic charging systems, hot charging, avoiding high drops and the use of compact and dry scrap.

Achieved environmental benefits
Increased furnace efficiency through shorter melting times and reduced downtime.

Cross-media effects
No cross-media effects apply.

Operational data
A typical coreless furnace can melt a tonne of iron and raise the temperature of the liquid metal to 1450 ºC using under 600 kWh of electricity. However, in practice, only a few foundries can achieve this level of specific consumption on a week-by-week basis. Some foundries consume in the region of 1000 kWh for every tonne of iron produced by their coreless furnaces. Prevailing circumstances in many foundries can restrict the scope for good energy management, but in fact almost all coreless melting operations could be improved in some way, in order to achieve a worthwhile saving in the quantity of electricity used per tonne of iron processed.

Applicability
This technique applies to all new and existing induction furnaces.

Driving force for implementation
Increasing the efficiency of furnace operation.

Example plants
Process optimisation measures are commonly applied in European foundries using induction furnaces.

Reference literature
[32, CAEF, 1997], [47, ETSU, 1992], [110, Vito, 2001], [145, Inductotherm], [225, TWG, 2003]

4.2.3.2 Change from mains frequency to medium frequency furnaces

Description
Medium frequency (250 Hz) furnaces have a higher power density (up to 1000 kW/tonne) than mains frequency (50 Hz) furnaces (300 kW/tonne). This allows the use of a smaller crucible (up to a factor of three smaller) which results in a smaller total heat loss. The thermal efficiency of medium frequency furnaces is 10 % higher than for the mains frequency types. Additionally, mains frequency units need to be operated with a molten heel of up to 2/3 of the crucible capacity to optimise specific energy consumption and also require specific starter-blocks for cold start-up. Medium frequency furnaces can readily be started with a cold charge and can be emptied at the end of each working shift or melting batch.

When a foundry converts from mains frequency melting to operating a medium frequency installation, it is important that the furnace personnel undertake some retraining. Operating techniques formally used to date will have to be abandoned, and new specific procedures designed to give good specific energy consumption will have to be adapted. If retraining is overlooked, the available improvements in energy usage may not be fully realised.

Achieved environmental benefits
Increased energy efficiency of the melting operation.

Cross-media effects
No cross-media effects apply.

Operational data
Operational data are given in Section 3.2.4.

Applicability
This technique applies to new installations and for major refurbishments of existing installations

Driving force for implementation
To increase the efficiency of the foundry operation.

Example plants
The technique is commonly applied in foundries installing a new furnace.

Reference literature
[47, ETSU, 1992]

4.2.4 Rotary furnace

4.2.4.1 Increasing the furnace efficiency

Description
All measures that increase the thermal efficiency of the furnace will in turn lead to a lower CO_2 output. A major improvement has been achieved by introducing oxygen instead of air as the combustion medium. This is discussed in Section 4.2.4.2.

Further improvements of furnace yield can be obtained through tight control and optimisation of:
- burner regime
- burner position
- charging
- metal composition
- temperature.

Achieved environmental benefits
The optimisation results in lower amounts of dust and residues and in higher energetic efficiency.

Cross-media effects
No cross-media effect apply.

Operational data
An optimisation programme on a 3 tonnes/h cast iron melting furnace suggested the following as good operational practice:

- use of clean scrap and loading in the following order: (1) ingots and materials with low Si-content; (2) internal return material and foundry scrap; (3) alloying elements and melt protection; (4) steel scrap
- melt protection: use of anthracite for melt protection (2 % of metal charge) and silicon (2 %)
- rotation: in discontinuous phase, 1/3 of a rotation every minute with a total of 7.5 turns until the phase change. During continuous rotation: 1.7 rotations/minute
- power and angle of burner: use a parallel burner-head position for the lower injectors. Start at maximum power during 20 minutes, reducing 10 % every 20 minutes until change of phase (60 minutes after start).

Using these measures, a metal efficiency (molten metal/charged metal) at >95 % could be maintained.

Applicability
The principles of the optimisation are generally valid for iron melting in rotary furnaces using oxygen burners. The operational data have been established for a 3 tonnes/h furnace. For furnaces of other sizes, a site-specific optimisation is necessary.

Driving force for implementation
Optimisation of furnace operation and to increase the melting efficiency.

Example plants
Process optimisation measures are commonly applied in European foundries using rotary furnaces.

Reference literature
[204, Carnicer Alfonso, 2001]

4.2.4.2 Use of an oxyburner

Description
Flame temperatures are increased by the application of pure oxygen instead of air in the burners used for melting or preheating the pouring ladles. This enables a more efficient heat transfer to the melt and reduces the energy use.

If the air supply is blocked by a tight closure of the recipient, no NO_x can be formed through the oxidation of atmospheric nitrogen. Additionally, the total flow of flue-gases from an oxyburner is smaller due to the absence of nitrogen ballast. This allows the application of a smaller dedusting installation.

Achieved environmental benefits
The techniques reduce energy consumption and lower the emissions of NO_x and CO_2, through higher combustion temperatures.

Cross-media effects
The production, storage and use of oxygen increases the safety risks. Oxygen production is done through cryogenic distillation or Vacuum (Pressure) Swing Adsorption, which both involve electricity consumption. The consumption of the latter technique is 0.35 – 0.38 kWh/Nm³ O_2. Oxygen production is often done by an external supplier, who deliver the oxygen to a storage tank or directly through a pipeline.

Fuel or heavy oil gives rise to SO_2 or NO_x emissions, depending on their S or N content. The use of cleaner carburants such as natural gas and propane will not cause any additional pollution, except for CO_2, as is the case for all combustion processes.

Operational data
Table 4.13 gives, for the "oxygas" melting of cast iron and various furnace capacities, the theoretical consumption of several fuels and of oxygen per tonne melted:

Energy source	Units	Furnace capacity (tonnes)				
		3	5	8	12	20
Light fuel oil	kg/tonne	33 – 38	33 – 38	33 – 38	32 – 37	32 – 37
Natural gas	Nm^3/tonne	38 – 43	38 – 43	38 – 43	38 – 42	38 – 42
Propane	Nm^3/tonne	15 – 17	15 – 17	15 – 17	14 – 16	14 – 16
Oxygen	Nm^3/tonne	130 – 150	130 – 150	130 – 150	130 – 145	130 – 145

Table 4.13: Table of energy consumptions (minimum melt)
[148, Eurofine, 2002]

Oxygen enrichment used in conjunction with a recuperator generally achieves a 30 % energy saving. Additionally, the higher combustion temperature assists in reducing the overall emissions. The exhaust gas volume is also reduced. Full oxy/fuel firing may offer energy savings of up to 50 %, and can reduce the exhaust gas volume by up to 72 %.

A German installation's change from oil-air firing to gas-oxygen firing caused a reduction in noise emissions of 15 – 18 dB(A) in the immediate vicinity of the furnace, dependent on the point of analysis. At the installation border, a value of 48 dB(A) was measured. With the application of energy recuperation for charge preheating, a total energy saving of 53 % was reported.

Applicability
This technique can be applied on any rotary furnace and in the preheating of pouring ladles. Oxyburners do not find implementation in non-ferrous foundries, although they are used e.g. in secondary copper smelting.

Economics
Investment costs: EUR 3400 – 4500.
Operational costs: dependent on process operation.

Driving force for implementation
Optimisation of furnace operation and to increase melting efficiency.

Example plants
This technique finds wide application in ferrous foundries using rotary furnaces.

Reference literature
[23, Brettschneider and Vennebusch, 1992], [32, CAEF, 1997], [110, Vito, 2001], [103, Vereniging van Nederlandse Gemeenten, 1998], [148, Eurofine, 2002], [163, UK Environment Agency, 2002], [232, Novem, 2000]

4.2.5 Selection of cupola vs. induction or rotary furnace for cast iron melting

Description
Given the fact that various melting techniques show overlapping fields of application, a basic technique is the selection of the melting technology. In this selection the decisive criteria include:

- metal type
- continuous or batch production
- size of the series
- metal throughput or capacity
- flexibility towards input material type and cleanliness
- flexibility towards alloy change
- type of product made
- emissions and other environmental considerations
- availability of raw materials
- availability of fuels/electricity.

The application of the different melting techniques is very dependent on the indicated criteria. From the discussions mentioned above, the following generalities can be deduced:

- *Metal type*: Electrical furnace better placed for nodular or alloyed cast iron
- *Continuous production:* Cupola is better placed
- *Batch production*: Electrical or rotary furnace is better placed
- *Flexibility towards input material type and cleanliness*: Cupola is better placed
- *Flexibility towards alloy change*: Induction and rotary furnace is better placed
- *Environmental considerations*:
  - cupola is better placed only if well de-dusted, cokeless show better environmental performance than HBC or CBC
  - induction has lower CO, SO_2, NO_x, dioxin, slag, but this it needs to be borne in mind there will also be emissions from the required electricity production.
- *Availability ofraw materials:* When cheap scrap is available, the cupola is better placed

In fact, all these criteria must be considered together. Table 4.14 gives a summary, based on the technical considerations. Economic data for the various cupola types and the induction furnace are given in Annex 1.

On the basis of the stated criteria, the replacement of the cupola by induction or rotary furnaces may be considered. The selection of induction or rotary furnaces is given priority over cold blast cupolas for small foundries casting a variety of products in several European countries (e.g. Austria, Belgium (Flanders)).

CRITERION		ONLY GREY CAST IRON					GREY + NODULAR	ONLY NODULAR CAST IRON			ONLY MALLEABLE CAST IRON
Type of product made		**Counter weights**	**Sewer castings, pipes, urban furniture**	**Enameled castings, heating appliances**	**Mechanical parts**		**Mechanical parts**	**Sewer castings, pipes, urban furniture**	**Mechanical parts**		**Mechanical parts**
Size of series		**Medium to large**	**All**	**Medium to large**	**Batch to small**	**Medium to large**	**All**	**All**	**Batch to small**	**Medium to large**	**Medium to large**
Cupola	Cold blast	++	++ (<10 - 15 t/h)	++ (<10 - 15 t/h)		++ (<10 - 15 t/h)			(+)		
	Hot blast	+	++ (>10 - 15 t/h)	++ (>10 - 15 t/h)	0	++ (>10 - 15 t/h)		++ (>10 - 15 t/h)	0	+ (>10 - 15 t/h)	
	Cokeless				0	+		+	0	+	
Induction			+	+	++	++	++	+	++	++	++
Rotary furnace		(+) batch			++	+	++	(+) batch or small series	++		++

++: technically more adapted;
+: technically adapted
(+): adapted in some cases
0: not adapted

Table 4.14: Technical choice of the melting equipment for cast iron melting [202, TWG, 2002]

Achieved environmental benefits
Replacement of a cupola by an induction or rotary furnace results in a reduction in the direct emissions of CO and SO_2 and a reduced amount of slag. Induction furnaces show a reduced emission of NO_x and a lower risk of dioxin formation. The indirect emissions generated by the use of induction furnaces, depend on the local electricity generation infrastructure.

Cross-media effects
Replacement of a cupola by an induction furnace generates a strong increase in electricity consumption.

Applicability
The replacement of a cold blast cupola by an induction or rotary furnace is applicable under the criteria stated above and upon major refurbishment of the installation.

For new installations, the criteria of Table 4.14, apply besides local and site-specific considerations. If cupola and induction or rotary furnaces are indicated as most adapted, the induction and rotary types may be preferred on the basis of their environmental benefits.

Economics
A survey of economic data for the various types of cupola furnaces and for the induction furnace is given in Annex 1.

In Table 4.15, a summary is given of cost data collected by an example Spanish foundry that wanted to replace an existing cupola by a rotary or electric furnace. No emission collection or filtration equipment costs are included. Data are from 1997 - 1998. The comparison involves the following three systems:
- cold blast cupola: 3.5 tonne/h capacity
- oxygas rotary furnace: 3 tonne capacity
- 2 medium frequency induction furnaces: 2 + 1 tonne capacity.

The cost calculation was performed for melting costs for a melting production of 1 tonne/h, working 8 hours/day. For the induction furnace a distinction is made between peak-time electricity costs and off-peak-time. Since electricity is the major component of the costs, this distinction makes a big difference to the final cost. Operation of the induction furnace during off-peak time (night-time) results in costs comparable to rotary furnace costs. The data show that the investment has a 5 – 9 years payback period.

Costs in EUR/tonne of molten metal	**Cupola**	**Rotary**	**Induction**	
Energy	30.7	29.8	40.8 27.2	(peak) (valley)
Refractory	3.6	1.3	1.4	
Man power	52.9	22.7	22.7	
Raw materials	205	205	205	
Total cost	292	259	270	
Yearly costs in EUR				
Cost for melting 1320 tonne/year	385000	341000	356000 338000	(peak) (valley)
Savings	none	44000	29000	(peak)
			47000	(valley)
Investment	none	250000	260000	
Building		Not needed	Needed	

Table 4.15: Example plant cost data for replacement of an existing cupola with a rotary or induction furnace
Data from 1997 - 1998, Spain
[202, TWG, 2002]

Driving force for implementation
Reduction of direct emissions from cast iron melting.

Example plants
Most Austrian foundries, which are small and medium-sized enterprises, have changed from cupola melting to induction furnaces. As a consequence there are only three Austrian foundries left which still use cupola melting.

Reference literature
[202, TWG, 2002], [110, Vito, 2001], [225, TWG, 2003]

4.2.6 Hearth type furnace

4.2.6.1 Use of an oxyburner

See Section 4.2.4.2.

4.2.7 Other furnace types

4.2.7.1 Alternatives to the use of SF_6 as a cover gas for Mg-melting

Description
Alternative covering gases for magnesium melting are of big interest due to the high global warming potential of the generally used SF_6. The substitution of SF_6 has been the topic of research for several years. A worldwide research project to develop and propose alternatives is currently being co-ordinated by the International Magnesium Association and will be finalised in 2004. Gas mixtures containing HFC-134a (CF_3CH_2F) and Novec 612 (perfluoroketone, $C_3F_7C(O)C_2F_5$) have been successfully tested. Research is on-going on the applicability of both compounds. HFC-134a falls under the restrictions of the Kyoto protocol. Both compounds show a lower global warning potential than SF_6: SF_6 GWP = 23900; HFC-134a GWP = 1300; Novec 612 GWP = 1.

At present, SO_2 is a viable alternative. Some magnesium foundries have long experience with this gas, and never turned to SF_6 when this gas was first introduced at the beginning of the 1970s. SO_2 reacts with liquid magnesium and builds a protective film on the surface. A mixing unit for blending a low concentration SO_2-air mixture is available. Furthermore, handling procedures for SO_2 have been established to reduce workers exposure and risk.

The protective gas is supplied through a manifold with several outlets. The positions of the outlets are chosen to give protection to all areas of the metal surface. Areas closer to hatches that will be opened frequently during operation need a higher flow of gas than areas where interaction with the surrounding atmosphere is small.

In order to optimise safety and minimise gas consumption, totally encapsulated melting and casting processes are applied.

If replacement is not feasible, the following technical measures allow a reduction of SF_6 consumption and emissions:
- improved sealing of furnaces
- fully automatic cover gas dosage
- electronic control of both gas mix and flowrate
- reduction of overdosing.

Achieved environmental benefits
The replacement of SF_6 avoids using this greenhouse gas, which has a GWP of 22200 over a 100 years time horizon.

Cross-media effects
SO_2 is a toxic gas and exposure limit values for workers should be taken into account. The occupational exposure limit in most countries is 2 ppm (5 mg/m³) over 8 hours. Sulphur- and oxygen-containing deposits may form on the furnace wall. Under unfavourable conditions these deposits can be immersed into the molten metal where they cause reactions leading to metal eruptions from the surface. Frequent removal of scaling can prevent this from happening.

The technique results in emissions of small amounts of SO_2, the amount depending on the foundry capacity and the number of furnaces. One estimate could be 50 – 500 kg per year for melt protection.

Operational data
The consumption of SF_6 depends on the melting technique used, and varies between less than 0.1 and 11 kg/tonne of finished castings. Technical improvements and measures have resulted in a reduction in the average specific SF_6 consumption, from over 3 kg/tonne of casting to 0.9 kg/tonne. Application data are given in Section 3.4.1.

In an undisturbed melt, the use of SO_2 would be typically 0.7 % in air at a flowrate of 5 to 10 litre/minute. In closed (but not airtight) furnaces, such as the melting and dosing furnaces of die-casting machines, pure SO_2 is applied. Small amounts of air entering through the lid are needed to provide the covering action. If a carrier gas is used, nitrogen is the preferred gas because of its inertness. The SO_2 is then mixed in concentrations of 1 – 2 %.

Mass balance data for the fluxless re-melting of magnesium scrap are given in Section 4.1.6.

Applicability
There is a great potential to reduce the SF_6 consumption, but at the moment it does not seem possible to fully replace it during non-standard situations. SO_2 may be applied in general during normal melting operations. When repairing the furnace, SF_6 remains needed as a protection gas, due to the health risks correlated with SO_2 exposure. Additionally, SO_2 cannot be used to extinguish magnesium fires. In this case also, SF_6 remains in use.

Economics
The price of SF_6 has increased dramatically over the last few years. Conversion from SF_6 to SO_2 will therefore have an associated economic cost. Table 4.16 gives estimates for the running expenses for the use of SF_6 and SO_2 based on information from a die-caster running three die-casting machines and the results from industrial scale trials. Even though the figures are only rough estimates, they clearly show that there is a large cost saving potential when substituting SO_2 for SF_6.

Property	Units	SF_6	SO_2
Concentration of gas	%	0.4	0.7
Price	EUR/kg	36.5	4.5
Inverted density (at 0 °C and 1 atm)	l/kg	153	350
Yearly consumption of gas	kg/yr	339	259
Cost/year	EUR	12373	1165
Data for 3 die-casting machines, run at 300 days/yr, 24 h/day with flowrate of gas to each machine of 10 l/min			

Table 4.16: Cost comparison between SO_2 and SF_6 used for protective gas atmospheres [190, Schubert and Gjestland]

If a new investment is considered, the SO_2 gas system, meeting all modern safety and dosage requirements, costs EUR 70000, for a 1000 tonnes/yr plant. A new SF_6 system costs EUR 23300. Operational data, accounting for this investment and for the use of 1.5 % of SO_2 and 0.2 % of SF_6, both in nitrogen, are given in Table 4.17. The total annual cost for SO_2 is some EUR 2500 more than for SF_6, on the other hand 12300 tonnes of CO_2 equivalent emissions are avoided. The bigger the plant, the less the annual costs differ between the two systems. At an annual output of 1500 tonne/yr, the turning-point is passed and the CO_2 reduction cost turns negative.

General Casting Data		
Capacity of the ovens	2000 kg	
Maximum smelting performance	1000 kg/h	
Casting time per day (Cold chamber)	13.2 h	
Working days	250/yr	
Utilisation	76 %	
Gross melting weight (shot weight)	2000 t/yr	
Scrap factor	50 %	
Net weight of the Mg parts	1000 t/yr	
Sales per year (EUR 15.00/kg)	EUR 15 million	
Surface of the Mg baths	6 m^3	
Gas (carrier + cover gas) per m^2 surface	300 litres per hour, all year long	
Extra gas dosage while charging	+ 25 %	
Gas Data	**SF_6**	**SO_2**
Carrier gas	nitrogen	nitrogen
Cover gas concentration in carrier gas	0.2 vol. %	1.5 vol. %
Cover gas dosage per hour	46.9 g	154.2 g
Cover gas dosage per year	514 kg	1688 kg
Coefficient cover gas/net Mg output	0.51 kg/t	1.69 kg/t
Emissions in tonnes CO_2 equivalent	12278	-
Cost Data	**SF_6**	**SO_2**
1 kg cover gas	EUR 20.00	EUR 3.00
1 m^3 carrier gas (nitrogen)	EUR 0.20	EUR 0.20
Invest-cost of new gas equipment	EUR 23333	EUR 70000
Discount rate per year	10 %	10 %
Depreciation period	10 yr	10 yr
Annualised invest cost of equipment	EUR 3797	EUR 11392
Operating cost of cover gas	EUR 10274	EUR 5065
Annual running cost (without nitrogen)	EUR 14072	EUR 16457
Additional total cost of using SO_2	-	EUR 2385
Specific emissions reduction cost	-	EUR 0.19/tonne CO_2 eq.
Share of additional cost in sales		0.02 %
Note: Most data are valid only for this 1000 tonne/yr plant and will change with plant size		

Table 4.17: Operational and cost data for a new die-casting plant of 1000 tonne/yr Mg output [218, Harnisch and Schwarz, 2003]

For existing installations, the reduced cost for SO_2 consumption needs to pay back the investment cost for the conversion of the cover gas installation. The payback time is dependent on the actual cover gas consumption. Based on an SF_6 consumption of 0.9 kg/tonne, the turning point at which the total costs of using SO_2 get lower than the comparable cost of SF_6 is below 900 tonne/yr output. At 500 tonnes/yr the SO_2 is still more expensive, but the specific reduction cost of 1 tonne CO_2 eq. amounts to EUR 0.31. The share of additional costs in the plants sales amounts to 0.04 %. Therefore at this capacity, the technique can also be considered.

As a conclusion, it is found to be economic to use SO_2 instead of SF_6 as a cover gas in magnesium die-casting, at least in plants with an annual metal output of 500 tonnes and more, regardless of whether the plant is to be newly built or still runs with SF_6.

Driving force for implementation

Reduction measures for greenhouse gas emissions, in particular, the Kyoto climate protocol controlling the use of fluorinated gases: HFCs, PFCs and SF_6. These gases have a high global warming potential but are not ozone depletors. This will form the basis for the EU Directive on the use of fluorinated gases. Furthermore, some regions have already issued proposals to ban its use, such as e.g. Denmark, Germany and Austria.

Example plants

LM Leichtmetall Systemtechnik, Felbach (D)

In Austria, Denmark and Sweden SF_6 is no longer used as a cover gas.

Reference literature
[182, Closset, 2002], [190, Schubert and Gjestland], [191, IMA, et al.], [192, Gjestland and Westengen, 1996], [194, UNEP IPCC, 2002], [218, Harnisch and Schwarz, 2003]

4.2.8 Non-ferrous metal treatment

4.2.8.1 Aluminium degassing and cleaning using an impeller station

Description
The degassing of aluminium is needed to remove hydrogen from the melt. The removal or reduction of small amounts of undesirable elements and impurities necessitates treatment of the melt with halogens, such as chlorine, fluorine or bromine. This treatment is referred to as cleaning, and is usually combined with the degassing treatment.

Adequate degassing with physically operating treatment processes does not achieve sufficient cleaning in most aluminium castings. Vacuum degassing achieves a very low hydrogen content in the melt but, at the same time, the lower number of nuclei means that crystallisation is less effective.

In a combined degassing and cleaning process, gas mixtures of argon and chlorine or nitrogen and chlorine are introduced into the melt. The chlorine concentration in the carrier gas must be optimised in order to ensure good cleaning as well as low emissions. In most cases, only a degassing treatment is necessary. This treatment is done without Cl_2-gas. Depending on the treatment vessel, the efficiency of the degassing can be improved with porous plugs and impellers.

In some isolated cases, an Ar/SF_6-mixture has been used. The latter is a greenhouse gas with a high global warming potential, which falls under the Kyoto protocol. (see also Section 4.2.7.1)

Achieved environmental benefits
The use of an impeller with Ar/Cl_2 or N_2/Cl_2 avoids the use of hexachloroethane in the cleaning treatment of aluminium. The use of hexachloroethane was banned from 30 June 2003 in the EU.

Cross-media effects
The application of this type of degassing unit has allowed an end to using hexachloroethane for degassing and cleaning purposes.

Operational data
A mixture of nitrogen with 3 % Cl_2 is generally used for combined degassing and cleaning. For degassing only, Cl_2 is not necessary.

A mobile impeller station can be used for holding furnaces and ladles of 50 – 250 kg of Al. The treatment takes 3 to 5 minutes. A metal treatment unit is used for capacities from 400 to 1000 kg Al. The melt is treated for 1.5 to 5 minutes with a gas flow between 8 and 20 litre/minute. The graphite rotor has a life of 100 – 150 treatments, depending on the temperature of the melt.

Applicability
Impeller stations have been developed for holding furnaces and ladles from 50 to 1000 kg of molten aluminium.

Economics
Investment costs are given Table 4.18.

Description	Cost (EUR)
Impeller plant including accessories	15000
Facilities for mixing of argon gas with chlorine	40000
Total	**55000**

Table 4.18: Investment costs for an impeller station
[178, Wenk, 1995]

Driving force for implementation
European Directive 97/16/EC prohibiting the use of hexachloroethane in the manufacturing or processing of non-ferrous metals.

Example plants
The technique is commonly applied in aluminium foundries.

Reference literature
[175, Brown, 1999], [178, Wenk, 1995],

4.3 Mould- and core-making, including sand preparation

4.3.1 Selection of the mould type

The selection of the mould type is mainly based on technical criteria. The applicability of the various moulding types is summarised in Table 4.19. Additionally, Table 4.20 gives the general properties of various systems.

	Lost moulds				Permanent moulds				
	Moulding methods				Casting technique				
	Green sand moulding	Shell sand	Phenol/Furan	Pep set/water glass	Low-pressure die-casting	Pressure die-casting (hot)	Pressure die-casting (cold)	Centrifugal casting	Continuous casting
Cast Iron									
Grey cast iron	X	X	X	X	O			X	X
Nodular cast iron	X	X	X	X				X	X
Malleable cast iron	X	O	X	O					
White cast iron	X	X	X						
Steel									
Unalloyed	X	X	X	X				X	
Low alloy steel	X	X	X	X				X	
Highly alloyed manganese steel	X	X	X	X				X	
Stainless and heat resistant	X	X	X	X			O	X	
Heavy Metals									
Brass	X	X	X	X	X				
Bronze	X	X	X	X					
Copper	X	X	X	X	X		X	X	X
Zinc alloys					O		X	X	
Light Alloys									
Aluminium alloys	X	X	X	X	X		X		X
Magnesium alloys	X	O	X	X	X	X	X		
Titanium	O	O	X	X	O				

X: The method can be used
O: The method is possible but not often employed

Table 4.19: Applicability of the various moulding types [126, Teknologisk, 2000]

	Green sand casting	Chemically-bonded sand	Low-pressure and gravity die-casting	High-pressure die-casting
Relative cost in quantity	Low	Medium high	Low	Lowest
Relative cost for small number	Lowest	Medium high	High	Highest
Permissible weight of casting	Up to about 1 tonne	Up to a few hundred tonnes	50 kg	30 kg
Thinnest section castable, centimetres	0.25	0.25	0.3	0.08
Typical dimensional tolerance, centimetres (not including parting lines)	0.03	0.02	0.07	0.02
Relative surface finish	Fair to good	Fair to good	Good	Best
Relative mechanical properties	Good*	Good*	Good*	Best
Relative ease of casting complex design	Fair to good	Good	Fair	Good
Relative ease of changing design in production	Best	Fair	Low	Lowest
Range of alloys that can be cast	Unlimited	Unlimited	Copper base and lower melting point metals preferable	Aluminium base and lower melting preferable
(*) Mechanical properties may be enhanced by heat treatment				

Table 4.20: Technical properties of the various moulding types [42, US EPA, 1998]

4.3.2 Moulding with clay-bonded sand (green sand moulding)

4.3.2.1 Preparation of clay-bonded sand by vacuum mixing and cooling

Description

The mixing and cooling process are combined into a single process step. This is achieved by operating the sand mixer under reduced pressure, which results in cooling by the controlled vaporisation of the water. The special mixer needs to be hermetically closed. It has a pressure casing and is connected to a vacuum system. The layout of the system is given in Figure 4.6.

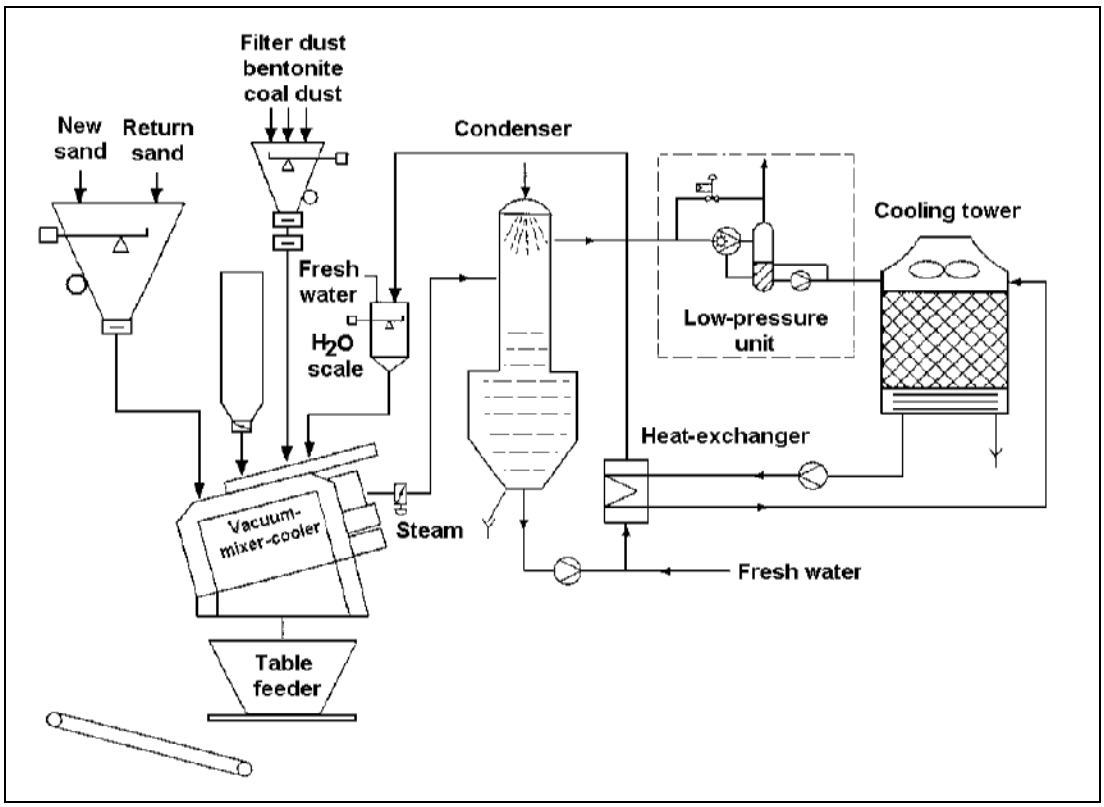

Figure 4.6: Moulding-sand preparation plant with vacuum mixer-cooler [207, Drews, 1996]

As compared to a normal mixing plant (Figure 2.28), this technique does not require a separate cooler and associated equipment. The vacuum plant therefore is a more compact size. Since the total airflow is reduced, the vacuum installation has a smaller central dust extraction filter. The size and energy consumption of the filter are 50 % of that of a conventional plant. The reduction of the airflow, results in a reduced removal of active bentonite and thus in an overall reduction of additive consumption. Due to the enclosed operation, the technique is not affected by outside climatic conditions.

The use of steam in the absence of air leads to a quick activation of the bentonite, resulting in a very quick attainment of the optimal compressive strength for the bonded sand.

Water is added in two separate stages:
- water to moisten the return sand to the prepared sand moisture content
- water to cool the sand by vaporisation to the required temperature of 38 – 40 ºC.

The disadvantage of the system is the operation and management of the vacuum system. The process also affects the sand technical properties (e.g. compressive and tensile strength, permeability), which diminish after 72h ("the 72h effect"). This can be prevented by re-mixing for about 90s.

Achieved environmental benefits
Reduction of the total airflow results in a reduced off-gas volume and amount of dust for disposal, as well as a reduced consumption of binder as compared to conventional cooling and mixing plants (although this also depends on the efficiency of the regeneration plant). Additionally, the system uses less energy.

Cross-media effects
No cross-media effects apply.

Applicability
The technique is applicable in new green sand installations.

Economics
The commercial limits of application appear to be processes where sand cooling is required and which have a capacity of >60 tonnes of sand per hour.

Driving force for implementation
Reduction of dust for disposal and minimisation of additives consumption. Limitation of space.

Example plants
In Japan, a vacuum mixing and cooling plant has been in operation since 1993, with a prepared sand throughput of 100 m³/h.
Various installations are also currently running in Italy, France, Germany and England.

Reference literature
[143, Inasmet and CTIF, 2002], [207, Drews, 1996], [214, Gerl, 2003]

4.3.3 Moulding and core-making with chemically-bonded sand

4.3.3.1 Minimisation of binder and resin consumption

Description
The minimisation of chemicals consumption can be achieved through optimisation of the process controls and material handling. The latter category is dealt with in Section 4.1. In this section process measures are discussed.

Overuse to compensate for poor process control is the most common way in which binder chemicals are wasted. For instance, key parameters that relate to good binder management include:

- *Sand consistency*: Use of a sand quality which is consistent with the binder system. Good management of sand storage and sand testing (purity, grain size, shape, moisture) are of the main importance. A low content of fines and maximum amount of re-used sand will reduce the amount of resin needed
- *Temperature control*: The sand temperature must be maintained in a narrow range, with regular checks and adjustment of the amount of hardener addition. Positioning the sand heater just before the mixer allows close temperature control
- *Mixer maintenance and cleaning*
- *Mould quality*: Checking, solving and preventing moulding defects
- *Addition rates*: The appropriate binder addition depends on the binder type, the surface area of the sand and the size of the casting
- *Mixer operation*: Optimisation of the mixer performance involves monitoring and control of its operation.

Table 4.21 lists the mixing process variables that are easy to measure using readily available instrumentation. Interfacing the controls with an alarm system allows the operator to be alerted to any ‘out-of-specification’ condition. This needs to be corrected by cleaning, maintenance and recalibration before a major problem develops.

Process variables	Comments	Instrumentation
Sand flow	Can vary as a result of obstructions at the discharge gate that reduce/stop the sand flow or worn/loose stop nuts that produce a faster flow	Impact plate flowmeters
Sand temperature	Determines the speed of hardening and the amount/type of hardener required	A process control instrument can be used to adjust hardener additions to compensate for changes in sand temperature
Power consumption	Provides an indicator of mixer cleanliness	Motor load monitor
Resin and hardener flowrate	Can vary as a result of worn pumps, viscosity changes with temperature, blockages or leaks in pipework and nozzles, sticking of non-return valves, etc.	Positive displacement, electromagnetic or coreolis flowmeters
Operating hours	Useful for assessing performance against capital and maintenance costs	

Table 4.21: Process variables and how they indicate mixer performance [71, ETSU, 1998]

For foundries that require greater sophistication, a range of fully automated mixer control systems are available. These systems use microprocessor technology to provide automatic corrective control of mixed sand production and need only limited operator involvement. The additional benefits achievable with automated control systems are mainly due to the much reduced dependence on the operator and the more rapid correction of variations in conditions. The latter is also performed without having to stop production.

Achieved environmental benefits

Optimisation of the binder and resin use results in a minimisation of the consumption of chemical additives.

Volatile organic compounds make up to 50 - 60 % by weight of the binder components. The amount depends on the binder system type. Most are emitted during sand mixing and metal pouring. A reduction in the use of binder results in a corresponding reduction of VOC emissions.

Cross-media effects

No cross-media effects apply.

Operational data

In most cases, reductions of 5 % in binder levels and 1 % in scrap moulds are easily achieved using modern mixer control systems. Many foundries have realised savings that have been considerably higher. Reductions in binder addition of 5 to 25 % have been reported for various foundries, as well as almost eliminating scrap moulds production.

The installation of an automated mixer control system in an iron foundry using cold-setting resins allowed the foundry to reduce the resin addition rate from 10 kg/minute (1.22 % resin to sand weight) to 8.89 kg/minute (1.09 %), which correspondingly resulted in a 10 % saving in the amount of catalyst used. The number of defective moulds fell by over 60 % and cost savings of over GBP 37000/year (1995 UK prices) were achieved.

Applicability

This technique applies to all new and existing foundries using chemically-bonded sands. Mixing monitoring control equipment can be retrofitted to existing plants.

Economics
For a tonne of mixed sand, the binder addition is typically only 1 – 3 % by weight, but in terms of cost, binders account for 30 – 60 % of the total raw material cost. It is estimated that cost savings of 5 – 10 % could be achieved through better management of binder materials.

Incorporating all the equipment suggested in Table 4.21 in a mixer system costs around GBP 10000 (1997 UK prices). However, due to the significant improvement in process control, this capital investment will have a relatively short payback time. Although the cost of installing an automated control system is approximately twice that for simple on-line monitoring, substantial cost savings are possible.

Some example economic data are given in Table 4.22. These refer to the iron foundry described under the "operational data" heading of this section.

Cost type	**EUR**
Saving due to 60 % reduction in defective moulds	6416
Saving due to 10 % reduction in resin use	29966
Saving due to 10 % reduction in catalyst use	9050
Total saving in material cost	**45433**
Annual running cost	320
Estimated annual maintenance cost	24
Net cost saving	**45088**
Purchase cost of unit	24166
Payback period	7 months

Table 4.22: Annual savings, cost and payback for example plant mixer control (1995 prices)
[75, ETSU, 1996]

Driving force for implementation
Optimisation of operational costs and minimisation of VOC emissions.

Example plants
Good binder management measures are used in the vast majority of the foundries using bonded sand.

Reference literature
[71, ETSU, 1998], [75, ETSU, 1996], [202, TWG, 2002], [225, TWG, 2003]

4.3.3.2 Minimisation of mould and core sand losses

Description
Modern mould and core-making machines allow the production parameters of the various product types to be saved in an electronic database. This allows easy change-over to new products, without the loss of time and materials from finding the right parameters by simply using trial and error. For new products, the settings for similar products may be used to shorten the optimisation time.

Achieved environmental benefits
Reduction of the amount of waste sand and energy, through minimisation of the test run period.

Cross-media effects
No cross-media effects apply.

Applicability
Series production of small series with high production throughput. An errorless change-over requires good control and continuity of the sand quality.

Economics
The investment cost for a core shooting machine depends on the core volume, and range from EUR 150000 (5 l) to EUR 400000 (100 l). Operational costs are 5 – 10 % of investment costs per year.

Driving force for implementation
Optimisation of processes that require frequent change of core or mould type.

Example plants
This technique is applied in several foundries around Europe.

Reference literature
[110, Vito, 2001]

4.3.3.3 Best practice for cold-setting processes

- *Phenolic*: The temperature of the sand is kept as constant as possible, i.e. at around 15 ºC - 25 ºC, which is low enough in order to prevent emissions caused by evaporation. Direct contact between the resin and catalyst has to be avoided as the reaction is exothermic and can be violent

- *Furan*: The temperature of the sand is very important for this process and is kept as constant as possible, around 15 – 25 ºC; in order to control the setting time of the binder and to minimise catalytic additions. Direct contact between the resin and catalyst needs to be avoided as the reaction is exothermic and can be violent

- *Polyurethane (phenolic isocyanate):* The sand temperature is kept between 15 and 25 ºC, to maintain process control and to minimise emissions. Best practice is to work with three pumps and to mix the catalyst and the phenolic resin with isocyanate and sand directly in the mixer [202, TWG, 2002]

- *Resol – ester* (Alkaline phenolic ester hardened): The temperature of the sand is controlled and kept at an optimal level of 15 – 35 ºC. The process is less sensitive to temperature fluctuations than other self-hardened systems. The velocity of hardening is managed by the choice of the hardener type [225, TWG, 2003]

- *Ester silicate:* The sand temperature is controlled within the range 15 – 25 ºC. As moulds and cores pick-up moisture, they need to be used as quickly as possible after achieving full strength. Prolonged storage can only be done in dry conditions.

4.3.3.4 Best practice for gas-hardened processes

- *Cold-box:* Amine vapours need to be captured at the core-making machine. Any excess amine is captured through the core-box. Additionally, it may also be necessary to ventilate the core storage area. When possible, hoods are placed over the moulding or coring machines as well as over the temporary core storage area.
  Amine consumption can be minimised to the extent that its consumption matches the production needs of the sand cores, since the cost of the raw material and its treatment is high. Minimisation of amine consumption is helped by optimising the amine distribution process within the core, typically through a simulation and optimisation of the gas flow [202, TWG, 2002].

The sand temperature has to be maintained as constant as possible, between 20 and 25 ºC, otherwise a too low temperature will involve a longer gassing time, thus resulting in a larger amine consumption. A too high temperature drastically reduces the lifetime of the prepared sand.
Water is detrimental to this process. The moisture of the sand has to be maintained below 0.1 %, and the gassing and purging air must be dried.
Note: Amines are flammable and explosive in some proportions with air. Considerable care is required in their storage and handling, and the supplier's instructions need to be observed at all times.

- *Resol (Alkaline phenolics methy formate hardened):* It is advisable to ventilate the working area, at least in order to prevent any danger of fire. Methylformate consumption needs to be minimised to such an extent that its consumption matches the production needs of the sand cores. The sand temperature has to be maintained higher than 20 ºC, in order to prevent the condensation of methylformate. Methylformate vapours are heavier than air; this should be kept in mind when designing the exhaust system.
  Note: Methylformate is flammable when its concentration in air reaches 6 to 20 % and explosive in some proportions with air. Considerable care is required in storage and handling, and the supplier's instructions need to be observed at all times.

- *Resol-CO_2:* The resin has low contents of unreacted phenol and formaldehyde, and their emission levels, even during the gassing and purging periods, are very low. It is advisable to ventilate the working area. [225, TWG, 2003]

- *SO_2 hardened phenolic or furan:* The working area has to be ventilated, and the emissions collected at the emission point by totally hooding the moulding or coring machines and by applying venting.
  These collected gases must be treated before emission. This is easily completed by a scrubber containing a sodium hydroxide solution. The pH and the concentration of the scrubbing solution have to be continuously supervised. The scrubbing solution needs to be occasionally replaced to remove concentrated salts, it then requires disposal as a hazardous waste.
  Sulphur dioxide consumption needs to be minimised to the extent that its consumption matches the production needs of the sand cores.
  Normally, the purging cycle lasts 10 times longer than the gassing cycle.

- *SO_2 hardened epoxy/acrylic (free radical curing).* As for gassing and purging, collection and treatment are described in the SO_2 hardened furan resins section. The best gassing conditions for achieving cores with good characteristics require:
  - the sand to be dry before use
  - the blowing or shooting air to be dried too
  - the concentration of sulphur dioxide in CO_2 or nitrogen to be from 5 % to 100 %, depending on the resin used (minimal for acrylic, maximal for epoxy/acrylic)
  - the purging cycle to last 10 times longer than the gassing cycle.

4.3.3.5 Replacement of alcohol-based coatings with water-based coatings

Description
Coatings are applied to the surface of moulds and cores to create a refractory barrier at the mould-metal interface and to ensure a good surface appearance. Coatings serve to reduce veining, erosion and metal penetration defects and also help to reduce finishing operations. Alcohol-based coatings are mainly based on isopropylalcohol. The coating is dried by evaporation or by a burning-off of the solvent. This produces VOC emissions. Water-based coatings have been developed as an alternative.

The advantages of water-based coatings are:
- safety (no fire risk)
- workers health (less exposure to organic vapours)
- reduced costs of reagents (water vs. alcohol)
- mostly better surface finish of castings.

The difficulties for implementation are:
- the need for greater (process) time and space. Also cores need a longer drying time, which results in the need for a drying line, passing through a drying furnace
- changing the process requires a case-by-case optimisation period
- growth of bacteria, which cause short shelf-life of coatings (1 - 2 weeks) and causes odour emissions
- cost of re-approval by specific customers in aerospace and defence related applications.

Water-based coatings can be dried in ambient air, or by using a drying furnace or a microwave or an infra-red furnace. They generally need a longer drying time compared to alcohol-based coatings. The drying does not generate noxious emissions, but may cause odour emissions. Drying is done using a drying line, which transports the cores from the core-making to the mould assembly, thus allowing for the necessary drying time. The line may also pass through a drying furnace. Microwave and infra-red drying is applied for small, medium and large series.

The different rheological properties of water-based coatings compared to solvent-based coatings has necessitated the development of new application techniques. These allow a constant coating quality.

Achieved environmental benefits
A life cycle assessment (LCA) study evaluated the impacts of water- and alcohol-based coatings. The use of water-based coatings with drying in ambient air shows clear environmental benefits, mainly due to the reduced emission of VOCs and the low energy use. When a stove is used for drying, the reduced emissions are partially counterbalanced at the LCA-level by an increased energy use. The overall environmental index using a drying stove shows a small benefit over isopropyl alcohol (IPA) use and burning-off.

Cross-media effects
Aqueous coatings contain a variety of (organic) chemicals to enhance their properties. This may affect the emission profile upon shake-out.

Drying the aqueous coating results in an increased volatilisation of binder solvents. This may cause increased odour emissions, due to the evaporation of BTX-containing core solvents.

Water-based coatings require a higher use of energy due to transport (during air drying) and drying in a furnace.

Drying in ambient air may result in a reduction of the air temperature in the foundry. In a Dutch foundry, an overall reduction of the ambient temperature of 2 ºC was experienced. This results in a higher consumption of fuel for heating during wintertime.

Operational data
Changing from IPA-based to water-based coatings is becoming more widespread in various foundries nowadays. Automotive foundries have changed the majority of their production to water-based, leaving solvent-based coatings being used only for specific applications (see applicability).

Operational data were obtained from a Dutch foundry. When drying in ambient air, the air velocity is the main factor (rather than temperature or humidity). In order to allow sufficient air velocity over the drying trajectory, additional fans and ventilators were installed in the foundry. In order to reach a good and constant quality, the fines content of the (regenerated) core-making sand was reduced. Water-based coatings can cause a swelling of the fine residual (bentonite and coal dust) particles, which then causes core defects.

Operational data were obtained from a foundry in France, operating a stove with a capacity of 540 cold-box cores, which is heated with a natural gas burner. Two ventilators are used to evacuate the fumes and to mix the fresh air. The design temperature of the hot air is 165 ºC. A heat balance was set-up on the basis of measurements using 0.4 kg cores with a humidity of 5.5 %. The balance, as given in Figure 4.7, applies for a throughput of 390 cores, which is equivalent to 72 % of full capacity.

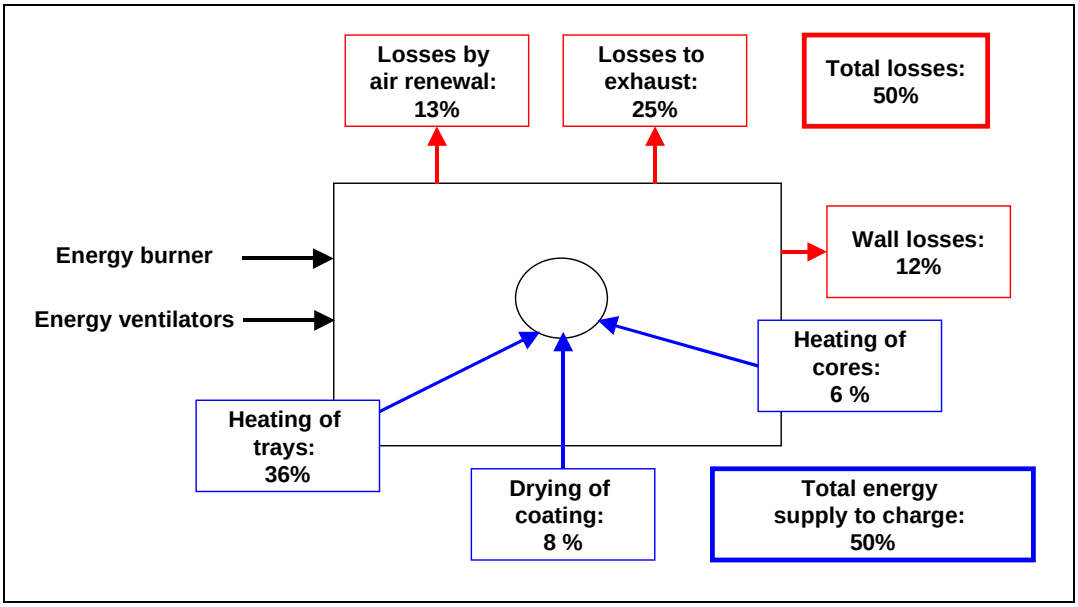

Figure 4.7: Thermal balance of a stove for core drying, working at 72 % capacity [143, Inasmet and CTIF, 2002]

The balance shows that 50 % of the energy is lost, with indeed effectively less than 10 % being used for core drying. The balance gives a consumption of 8.5 kWh per kg of water evaporated, which corresponds to 465 kWh per tonne of cores at a throughput of 156 kg/h. When the stove works at a lower capacity rate, the losses increase further. Similar measurements in another foundry confirmed the high (>50 %) losses and low (<10 %) effective energy use. Energy efficiency can be increased using microwave drying. This will be discussed in Section 4.3.3.6.

Applicability

Water-based solvents can be used in most situations. However, alcohol-based coatings cannot be replaced in some specific applications and will still need to be used:

- for big or complicated moulds/cores, where drying problems may occur due to difficult penetration of drying air
- for water glass bonded sands
- in Mg casting: water creates $Mg(OH)_2$ and thus causes technical problems
- in the production of manganese steel with MgO-coating.

The implementation of water-based coatings is applicable for new and existing large-scale, large series foundries. For new and existing small-scale foundries, the implementation may be hindered by technical or economic factors.

Economics

The investment cost depends on several factors, such as the available space for a drying line in the foundry, the choice of the drying technique, and the need to adapt the sand mix.

The complete replacement of alcohol-based coatings by water-based coatings in a Dutch iron foundry, using ambient air drying involved a total investment of EUR 71000. This included the installation of ventilators and optimisation of the sand quality. A reduction of the IPA-emission of 161 tonne/yr corresponded to EUR 62.5/tonne IPA emission reduction.

The operational costs involve increased controls of the coating and cores (viscosity, layer thickness, water content, product quality) and amount to EUR 9000/yr. Drying 1 tonne of coating consumes 2100 kWh of energy.

On the benefits side of the economics balance is the reduction in expenses for the purchasing of solvent. For bigger foundries, examples exist where investment in a water-based system was paid back in 2 years, on the basis of the reduced purchasing costs of the alcohol only.

The operational cost of drying is EUR 0.01/kg (non-ferrous foundry in France).

Driving force for implementation
Pressure from authorities increasing attention to the emissions of organics.

Example plants
- PSA Sept-Fons (F)
- Fonderie Bréa, Montluçon (F)
- De Globe b.v., Weert (NL).

Reference literature
[129, infoMil, 1999], [143, Inasmet and CTIF, 2002], [149, Beauvais and Choplin, 2001]

4.3.3.6 Microwave drying for water-based coatings

Description
Water-based coatings require a drying treatment. The application of microwave furnaces for this purpose gives operational advantages over the use of ambient or heated air drying. Microwaves of 2450 MHz frequency are used, and have the following properties:
- good selectivity of energy transfer: The microwave energy is transferred preferentially to the water molecules, rather than the sand material. This implies a preferential and homogeneous drying of the surface, even for complex cores
- self adaptive coupling: The drying mechanism provides a self-controlling homogenisation of the humidity of the material
- quick drying: The speed of drying depends on the applied power. The high drying velocity results in a limitation of the water-core contact time. This results in a good mechanical stability of the cores.

The application of microwave drying presents difficulties in the following cases:
- heterogeneous loading of the furnace (with a range of core masses and volumes)
- use of cores or inserts with iron
- inhomogeneous drying of thicker parts of the coating
- risk of deformation of complex cores.

Achieved environmental benefits
Increased energy efficiency of the drying process.

Cross-media effects
Microwave drying also brings polymerisation reactions to a further completion. This reduces the gaseous emissions in the proceeding stages of the foundry process (i.e. pouring, cooling, shake-out).

Operational data
The use of microwave drying has not been implemented on an industrial scale, although large-scale industrial tests have been performed. The results of these tests are given below. One test campaign has been run using a 50 kW microwave furnace. The stove was loaded to 50 % of its capacity with a charge of 800 kg of cores. Cores are placed on plastic trays, which are not heated by the microwaves. The thermal balance is given in Figure 4.8. It shows that more than

30 % of the energy input is used for drying. Additionally, the cores are only slightly heated up (temperature at exit = 40 ºC), which allows immediate handling. The data from two measurement campaigns are given in Table 4.23, and compared to analogous campaigns on hot air furnaces (as discussed in 4.3.3.5).

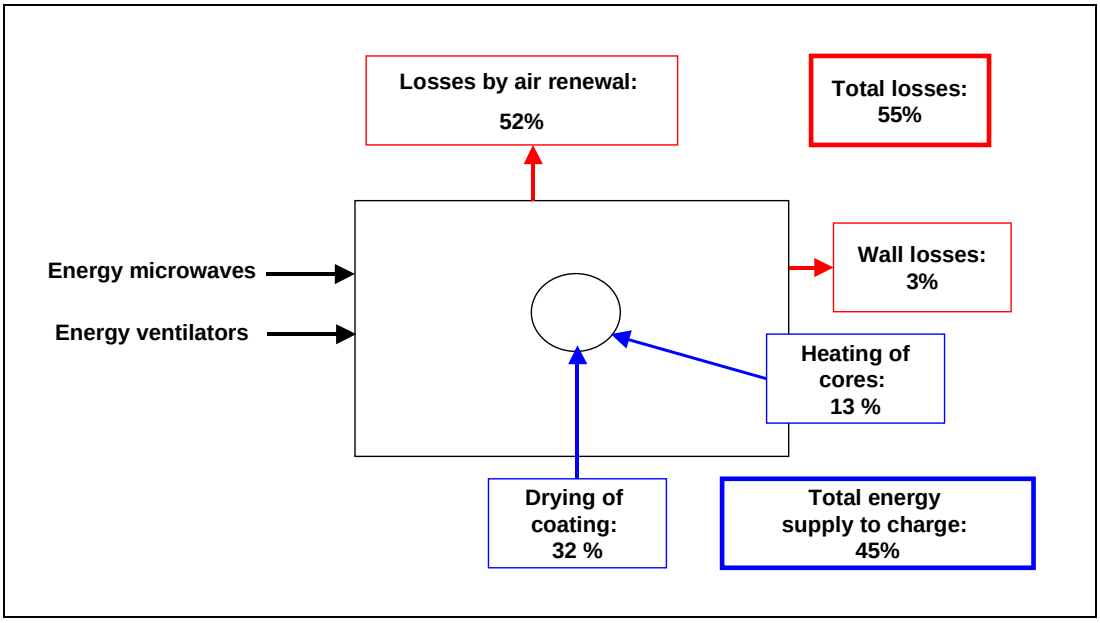

Figure 4.8: Thermal balance for the microwave drying of cores for a 50 kW furnace working at 50 % capacity [143, Inasmet and CTIF, 2002]

Furnace type	Foundry A Hot air	Foundry B Hot air	Foundry B Microwave	Foundry C Microwave
Core load	156 kg/h	270 kg/h	800 kg/h	500 – 900 kg/h
Humidity	5.5 %	2.7 %	2.7 %	2 – 3.2 %
Thermal energy supply	73 kW	70 kW	50 kW	40 kW
Duration	48 min	113 min	8 min	8 min
Specific consumption per kg evaporated water	8.5 kWh	9.3 kWh	2.3 kWh	2 kWh
Specific consumption per tonne wet cores	465 kWh	280 kWh	63 kWh	-

Table 4.23: Results of test campaigns on core drying, using hot air and microwave furnaces [143, Inasmet and CTIF, 2002]

The data show that the drying time is considerably reduced from 1 – 2 h to less than 10 minutes. Additionally, the energy consumption is reduced by a factor of 4 – 5, and the throughput is increased.

Applicability

This technique is applicable for the drying of all water-based coatings. Furthermore, it allows the greater applicability of water-based coatings to more complex core shapes and smaller series.

Economics

Microwave drying represents high investment costs. The actual investment is proportional to the power requirement, which corresponds to the amount of water to be evaporated. The high investment is partially counterbalanced by:

- higher energy efficiency, though the technique uses electricity rather than gas in the hot air furnace
- reduced solvent cost for water-based vs. solvent-based
- reduced maintenance costs due to a more compact installation compared to the use of (hot) air drying or a cooling line.

Driving force for implementation
Pressure from authorities, with increasing attention being paid to the emissions of organics, combined with the need for higher energy efficiency.

Example plants
The technique is reported to be applied in foundries in France and Spain.

Reference literature
[143, Inasmet and CTIF, 2002], [225, TWG, 2003]

4.3.3.7 Use of non-aromatic solvents for cold-box core production

Description
Classical cold-box systems use organic solvents. These cause releases of noxious and odorous VOCs during core production and storage. Furthermore VOC emissions (benzene, toluene, xylene) occur during pouring, cooling and shake-out. Alternative solvents for cold-box core production are based on protein or animal fat (e.g. vegetable-oil methyl esters) or on silicate esters. These solvents are not noxious to workers health, nor inflammable and therefore transport and storage are easier.

The low volatility of the vegetable-oil methyl esters enhances the storage capabilities in humid atmospheres and their persistence when applying water-based coatings.

The resulting cores have a higher strength, lower sticking of the sand and good shake-out properties.

Achieved environmental benefits
There is no vaporisation due to the high boiling point (about 300 ºC) and thus there is no solvent odour emission during storage.

VOC emissions are reduced during core manufacturing and storage, and (more importantly) during pouring, cooling and shake-out.

Cross-media effects
Vegetable-based solvents cause increased fume production during pouring and (in the case of die-casting) upon opening of the die. This is due to the low evaporation and consequently high residual solvent content upon pouring. This effect does not occur with silicate ester solvents.

Protein and animal fat based solvents produce a distinctive odour, and have been reported to cause odour problems inside the foundry.

Operational data
Table 4.24 shows operational emission values for benzene, toluene, xylene and phenol, as measured in one aluminium green sand foundry. Measurements were performed both at the shake-out grate and in the exhaust-air stack. Data are given for the traditional cold-box system and for one using vegetable-oil based solvents. A clear reduction in BTX and C-emissions is observed (25 – 50 % of stack emissions).

Compound	At shake-out			At exhaust-gas stack		
	Aromatic based (mg/m³)	Vegetable-based (mg/m³)	Difference (%)	Aromatic based (mg/m³)	Vegetable-based (mg/m³)	Difference (%)
Benzene	0.08	0.05	- 44	0.1	0.07	- 30
Toluene	0.12	0.05	- 58	0.08	0.06	- 25
Xylene	0.09	0.04	- 56	0.09	0.05	- 41
Phenol	14.8	14.6	- 2	7.2	6.57	- 9
Total C	61.0	29.5	- 52	37.0	18.5	- 50

Table 4.24: Emission data for cold-box core systems in an aluminium foundry, measured at the shake-out grate and in the exhaust-air stack
[189, Hüttenes-Albertus, 2002]

Results of emission measurements in a German iron foundry are given in Table 4.25. For this table, the measured emission of each compound is expressed relative to the emission of the same compound for the aromatic-based system. For example: the emission of toluene at the second cooling is only 58 % of the toluene emission for the aromatic system. The table shows a clear reduction of VOC emissions in the second cooling and shake-out phase.

	Benzene	Toluene	Xylene	Phenol
Pouring and cooling 1	83	100	100	100
Cooling 2	78.5	58	46	74
Shake-out	78	78	78	12
Emission data expressed as %, relative to emission of the aromatic based system (set at 100 % for each measurement)				

Table 4.25: Emissions (%) of selected compounds from vegetable-based cold-box core systems
[216, Hobelsberger, et al., 1997]

The total mass flow reduction of the specified compounds was:
- benzene: - 21 %
- toluene: - 26 %
- xylene: - 30 %
- phenol: - 62 %

A survey measurement of the total carbon emission over the full foundry process is given in Figure 4.9. The data show that the vegetable-based solvents partially result in a shift of emissions from the core-making area to the finishing area. Nevertheless an overall reduction of 17 % carbon emission reduction is reached.

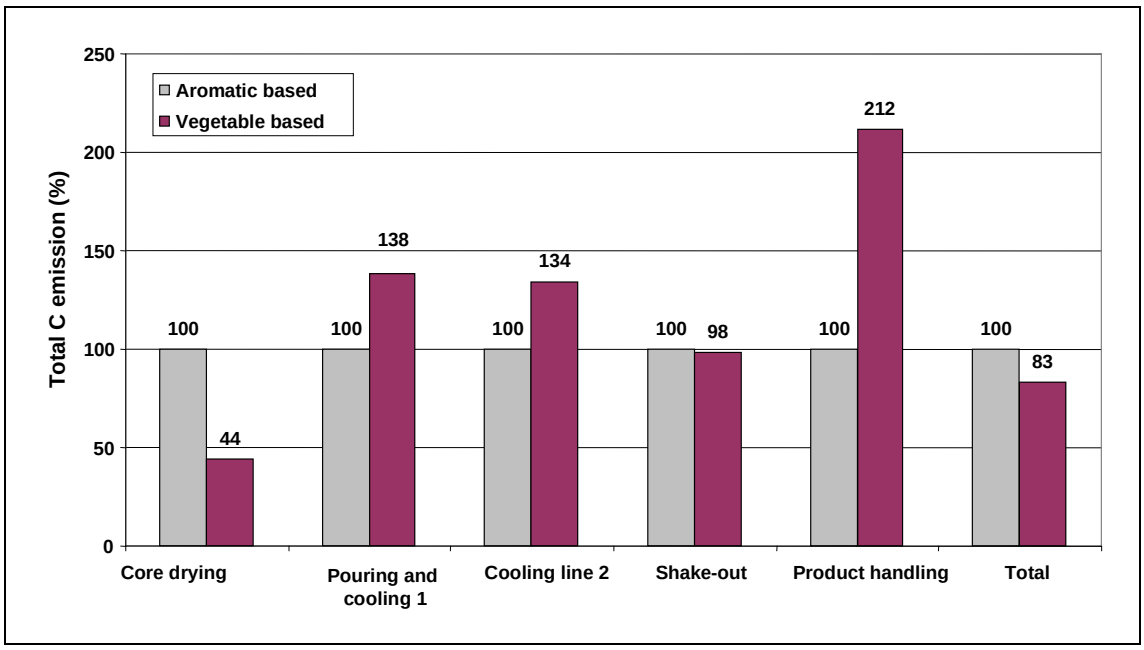

Figure 4.9: Total carbon emissions from various process steps, using aromatic- and vegetable-based solvents
(values in % expressed relative to emission of the aromatic based system)
[216, Hobelsberger, et al., 1997]

Applicability

Non-aromatic solvents can be applied in all processes using cold-box sand. The technique is relatively new and operational results as stated above need to be confirmed through repeated application. The technique has been implemented in foundries for the full range of automotive castings, as well as in castings for machinery, and in the construction and electronics industry. Both ferrous and non-ferrous applications are reported.

Economics

Data from the Italian foundry association indicate that non-aromatic solvents have a cost that is double that of the aromatic equivalent, e.g. EUR 0.82/kg against EUR 0.36 – 0.48/kg.

Operational data from a large series ferrous foundry showed that binder prices for aromatic cold box were around EUR 2/kg (2001) and went up with some 30 %, upon changing to the non-aromatic system. After one year (2003), the price lowered again however, to a level 10 % above the price of the traditional system.

Driving force for implementation

To reduce VOC and odour emissions.

Example plants

The technique is reported to be used in large-scale foundries in Germany.

Reference literature

[143, Inasmet and CTIF, 2002], [189, Hüttenes-Albertus, 2002], [202, TWG, 2002], [216, Hobelsberger, et al., 1997], [225, TWG, 2003]

4.3.4 Alternative moulding/core-making methods

4.3.4.1 Lost Foam casting

Description
The general principles of Lost Foam casting have been described in Section 2.5.7.1. Due to the absence of binders, the technique produces a reduced amount of solid waste and emissions compared to sand casting methods.

The technique allows the production of pieces with tighter tolerances, less feeder and riser channels and better as-cast features. This all results in less machining and clean-up time.

Lost foam foundries include a foam workshop, a melting shop and a casting shop. They do not have an extensive core-making shop and finishing shop. The foam shop involves foaming machines, steam generators and coolers and ambient air dryers.

The Lost Foam models are made of polystyrene (EPS) or PMMA, with small amounts of pentane, glue and a mineral coating. Since both EPS and pentane are pure hydrocarbons, organic carbons are formed upon pyrolysis of the model. In order to minimise emissions of the organic decomposition products of EPS, post combustion of the off-gases is performed.

The technique uses unbonded sand, which results in no binder–related emissions upon pouring and shake-out and which may be internally re-used without major treatment. EPS pyrolysis results in a slow build-up of organic material in the sand. This may be prevented by de-dusting and partial renewal of the circulating sand. A 5 % renewal is sufficient to maintain sand quality. The evacuated sand may be thermally regenerated for internal re-use.

Achieved environmental benefits
Since unbonded sand is used, the technique shows no binder-related emissions upon pouring. However pyrolysis of the EPS or PMMA results in organic decomposition products, which necessitate post combustion.

The use of energy in the Lost Foam process is significantly lower than in conventional casting methods. This is mainly due to the reduced energy uses for post casting operations, melting and sand preparation. The production of cores for conventional moulding methods is relatively more energy intensive than the production of the foamed model.

LCA analysis has confirmed that the environmental benefit as stated above, can be extended to an overall better environmental performance of the Lost Foam process over sand casting, in as far as the casting of core-intensive castings are concerned. For simple castings (e.g. lids), the life cycle approach shows that there is no overall better performing process.

Cross-media effects
The technique represents a reduction in energy consumption and a decrease in mould making and casting finishing operations. The off-gases show increased values of BTEX and formaldehyde, but emissions only occur during pouring and they can be more easily captured and treated. The technique produces a reduced amount of residual sand and dust and the sand may be more easily regenerated (shortened thermal treatment).

An LCA-based assessment of the Lost Foam process (also taking into account processes outside the foundry borders) shows a lower overall environmental impact for the production of core-intensive castings.

Operational data
Emission data and data on residue production have been given in Section 3.9.6.1. The technique results in lower residue production compared to a sand foundry of equal capacity. Flue-gases need more intensive cleaning (post combustion) and (after cleaning) result in higher organic compound (BTEX, formaldehyde) stack emissions.

Comparative consumption levels for the production of a comparable compressor casing using sand casting and Lost Foam casting are given in Table 4.26. This shows the higher amount of return material in the melt and the lower weight of the casting. For the Lost Foam method, the total amount of moulding-sand is greatly increased, while no cores are used.

Input material	Green sand	Chemically-bonded sand	Lost Foam
Cast iron	98.0	98.0	96.1
Foundry returns	30.0	30.0	38.1
Weight casting	68.0	68.0	58.0
Moulding-sand	256.8	233.0	1101.4
Core sand	122.0	150.7	n.a.
Weight foam model + feeder	n.a.	n.a.	0.212
All data in kg n.a: not applicable			

Table 4.26: Operational data for the production of a similar cast iron compressor casing, using various methods
[130, de Wilde and ten Houten, 1999]

Applicability

This technique applies to the serial production of small and medium sized products in ferrous and non-ferrous metal. Maximum casting sizes are 1000 x 1000 x 550 mm. The technique finds most of its implementation in aluminium foundries and has a 2 % share of aluminium casting.

Since the technique implies a basic change in the mould making procedure and infrastructure, it applies primarily to new installations. Application in existing foundries requires a conversion of the foundry process with regard to the moulding, pouring and finishing operations and a review of these stages for each of the castings produced. To introduce Lost Foam for a given casting requires funds, manpower and the necessary time and flexibility, as well as the co-operation of the customer.

Economics

Economic data for an aluminium Lost Foam installation are given in Table 4.27. Investment costs include equipment, installation, start-up and training.

Investment costs	Description	EUR
Model making equipment	Model making machine Steam generator Coating installation	1300000
Casting equipment	Automatic casting machine	2540000
Off-gas cleaning	Dry dedusting Thermal regenerative treatment	608000
Sand preparation	Sieving, cooling, transport	160000
Total	*Investment, installation, start-up, training*	*4608000*
Operational cost		**EUR/tonne good casting**
Consumption	EPS-granules, glue, coating, steam, combustibles	202
Foundry details: aluminium castings, 5500 tonne/yr production good castings, 6864 tonne/yr production molten metal		

Table 4.27: Economic data for an aluminium Lost Foam foundry
[96, Spillner, 1997]

Driving force for implementation

To reduce wastes from sand casting and to reduce energy consumption.

Example plants

Several example plants are reported in Germany and France.

Reference literature
cast iron: [130, de Wilde and ten Houten, 1999]
aluminium: [96, Spillner, 1997], [143, Inasmet and CTIF, 2002]

4.3.4.2 Ceramic shell moulding

Description
Ceramic shell moulding is a patented process (Replicast®) in which a polystyrene model is covered with a ceramic shell (2 – 3 mm thickness), based on ethyl silicate and refractory sand. The shell is hardened using ammonia and sintered at 1000 ºC. The sintering cures the shell and burns away the polystyrene model. The metal is then poured into the shell.

The sintering furnace is equipped with post combustion to reduce emissions.

The technique allows a casting design with no parting lines, cores and draft angles and reduced feed metal. This reduces the need for finishing and machining operations.

Achieved environmental benefits
The technique results in a minimisation of dust emissions from moulding and finishing, as compared to sand moulding. The emissions of VOC are eliminated as no gas is emitted for the inert ceramic mould. Additionally the amount of waste (dust, metal) is reduced. The reduction of feeder systems results in a higher yield of castings per melt.

Cross-media effects
No cross-media effects apply.

Operational data
Operational data from the owner of the technique are reported in Table 4.28, for the casting of valves, as compared to sand casting.

Property	Relative weight reduction (%)
Finished weight of castings	20 – 26
Feed metal	24 – 60
Poured metal	24 – 50

Table 4.28: Relative weight reduction for ceramic shell casting of valves as compared to sand casting
[219, Castings Technology International, 2003]

Applicability
The technique applies for the fabrication of castings which need a high surface finish, in low-carbon alloys such as ultra low carbon stainless steel and nickel-based alloys with a finished weight of up to 550 kg. The ceramic shell process is a patented process and may only be used in accordance with the terms and conditions of the licence granted to the licensee.

Driving force for implementation
Regulation of VOC emissions and high disposal costs for residual wastes.

Example plants
- CMS srl, Urbisaglia (I): 2 automated shelling lines, producing steel valves up to 150 kg finished weight
- Saint-Gobain SEVA, Chalons-sur-Saone (F): steel and super alloy components for glass industry.

Reference literature
[110, Vito, 2001], [219, Castings Technology International, 2003]

4.3.5 Permanent (metal) moulds and pressure die preparation

4.3.5.1 Minimisation of release agent and water consumption

Description
A water-based solution of release agent is sprayed on the open HPDC die before closing it. This allows cooling and coating of the die. Some simple process measures allow the minimisation of the release agent and water consumption. These will also prevent the formation of a mist. These measures are:

- *Automated spraying process*: Robotisation of the spraying process allows a careful control of the amount of release agent used and adaptation of the amount used to the local needs of the cast piece
- *Optimise dilution factor*: The release agent dilution factor should be chosen such that the spraying action has the required balance between coating and cooling of the die
- *Apply in-die cooling*: The cooling action may be partially taken over by internal cooling using an integrated water circuit.

Achieved environmental benefits
Minimisation of water and chemicals consumption. Prevention and/or reduction of (diffuse) emissions.

Cross-media effects
No cross-media effects apply.

Applicability
This technique applies to HPDC foundries. The extent to which the minimisation can be applied depends on the type of castings and the machines used.

Driving force for implementation
Minimisation of consumptions and emissions.

Example plants
This technique is applied in major HPDC plants, e.g. in the manufacture of car parts (D, F).

Reference literature
[202, TWG, 2002]

4.3.5.2 Closed-mould application of release agent

Description
A release agent is applied to the closed die-casting mould in a vaporised form. The high temperature results in a condensation and deposition of a release agent film. This technique is an alternative to the spraying of a water-based solution of the release agent onto the open die. It allows the water usage to be reduced and also reduces the consumption of release agents. The active substances for the process, i.e. getting the casting out of the die, are very similar to the open-mould technique: paraffin wax, aliphatic carbons, polysiloxanes, polyglycol.

Water spraying, however, also causes the necessary cooling of the die surface. The alternative technique therefore requires enhanced temperature management (mainly by a cooling effect), by means of an internal die cooling system. This may be obtained by reducing the thermal oil temperature. Combined water spraying and closed-mould release agent application is possible in places where the moulds cannot achieve complete thermal equilibrium by means of internal cooling systems alone.

Achieved environmental benefits
The technique allows a reduction in the usage of both water and the release agent. This results in a lower amount of waste water and reduced emissions of steam containing oily particles. The active compounds of the release agent are comparable to the traditional ones. Emissions due to decomposition of the release agent (and upon opening the die to get the casting out) therefore are comparable in nature to those with the open-mould technique.

Cross-media effects
The technique requires an increased effort to cool the dies. In simple cases, this may involve a lowering of the thermal oil temperature, but for more complex dies, it may involve the application of an additional cooling circuit.

Operational data
Some operational examples in aluminium foundries have been reported. These result in a 50 – 80 % reduction in the spraying time, and a 80 % reduction in sleeve-parting agent consumption.

Applicability
The technique is applicable in existing installations, but may require the production of specific dies with integrated or adapted cooling circuit. The applicability is limited to specific types of castings, dies and casting machines and is mainly based on technical considerations. This technique is not a general alternative for the application of release agents.

Driving force for implementation
Foundry strategy to reduce waste water production and to reduce the consumption of water and chemicals.

Example plants
Some operational examples in aluminium foundries have been reported.

Reference literature
[189, Hüttenes-Albertus, 2002], [202, TWG, 2002]

4.4 Metal casting

4.4.1 Improvement of metal yield

Description
Metal yield is defined as the ratio of metal melted to the weight of finished castings. The difference between the two values is due to metal losses (e.g. melting losses, spilt metal, grinding losses) and return metal (e.g. pigged metal, runners, scrap castings). An improvement of the metal yield involves reducing the metal loss and amount of return metal.

Improving metal yield is possible using one or more of the following measures:
- applying on efficient method: proper design of runners, risers, ingates, pouring basin and optimised box yield (castings/metal poured in a mould). A valuable tool in designing on efficient method is the use of computer aided simulation of pouring and solidification
- applying good procedures in melting and pouring operations: in order to reduce melting losses, excessive pigging, scrap rates, etc.
- applying good practice in the moulding and core-making departments: in order to reduce scrap due to deficiencies in the mould- and core-making operations.

Achieved environmental benefits
Increasing the metal yield results in a lower consumption of energy, sand and additives per unit of good casting. The overall efficiency of the process is increased.

Cross-media effects
No cross-media aspects apply to this technique.

Operational data
Table 4.29 provides a guide to the typical yields obtained for different types of iron casting production. It is not possible to recommend a target yield figure which can usefully be adopted by a particular foundry, as so much depends on the type of metal, type of casting, the production facilities and the market which has to be served. It is therefore necessary that a foundry sets individual targets, based on an analysis of its own current performance.

Casting type	Yield (%)
Heavy grey iron, simple shape	85 – 95
Medium sized grey iron jobbing or small batch	65 – 75
Mechanised repetition, general quality small to medium sized grey iron engineering and municipal castings	65 – 75
Mechanised repetition, high quality small to medium sized grey iron engineering castings, relatively simple design	60 – 65
Mechanised repetition, high quality small to medium sized grey iron engineering castings, complicated heavy cored design	55 – 60
Medium sized nodular iron jobbing or small batch	50 – 60
Small or very small grey iron repetition	45 – 55
Mechanised repetition of malleable iron and small nodular iron castings	40 – 50

Table 4.29: Typical metal yields for different iron casting types
[45, ETSU, 1990]

In response to a questionnaire, 82 UK foundries reported their metal yield performances for the period 1981 - 1987. The improvement in yield per metal type (weighted average) are given in Table 4.30.

	Yield in 1981 (%)	Yield in 1987 (%)	Improvement in yield (%)
Grey iron	60.5	63.0	2.5
Nodular iron	51.8	55.7	3.9
Malleable iron	36.4	39.2	2.8

Table 4.30: Weighted average of yield performances in 82 UK ferrous foundries, 1981 - 1987
[45, ETSU, 1990]

Applicability
The technique is applicable in all existing ferrous and non-ferrous foundries.

Economics
Improving the metal yield is possible through simple low-cost practical measures and controls. The benefits may be high since every percentage improvement results in a corresponding reduction of melting energy consumption and a reduction in the consumption of sand and chemicals.

The introduction of a computer-aided simulation for pouring and solidification requires investment and training costs.

Driving force for implementation
Optimisation of process efficiency.

Example plants
Metal yield considerations are part of good operational practice in the majority of European foundries.

Reference literature
[45, ETSU, 1990], [140, EU Thematic Network Foundry Wastes, 2001]

4.5 Fume, flue-gas and exhaust air capture and treatment

4.5.1 General principles

Various process steps in the foundry have the potential to produce dust, fume and other gases, e.g. material storage, handling and processing. Techniques to reduce emissions to air involve prevention, minimisation and fume collection.

Furnace sealing (or the use of sealed furnaces) combined with process control may be applied to prevent or contain emissions from a process plant. Sections 4.5.2 – 4.5.6 covering furnaces indicate where furnace sealing is possible and where other collection techniques may be used to provide integral gas collection.

Other techniques are available to collect the emissions that cannot be prevented or contained. Gases and fumes that escape from the processes are released into the working area and then escape into the surrounding environment. They may affect operator health and safety and contribute to the environmental impact of the process. Process gas collection techniques are used to prevent and minimise these fugitive emissions. Hoods are designed to be as close as possible to the source emission while leaving room for process operations. Movable hoods are used in some applications. Some processes use hoods to collect primary and secondary fumes.

Fugitive emissions may be very important, but are hard to measure and quantify. Methods of estimating ventilation volumes or deposition rates can be used to estimate them. One reliable method, which has been applied to primary copper smelting, shows that the magnitude of fugitive emissions can be much more significant than collected and abated emissions. Fugitive emissions can be more than two to three times the quantity of controlled emissions. [155, European IPPC Bureau, 2001]

The melting shop, core-making shop, sand plant and post-casting shop are considerable sources of emissions. The emitted air pollutants are mainly dust (possibly with heavy metal particles), sulphur dioxide, carbon monoxide and odorous organic compounds. Table 4.31 gives the results of a survey of the pollutants generated in the different parts of the ferrous foundry process. Both inorganic and organic compounds are listed as individual and group compounds. Dust emissions are of specific importance, since thermal processes can generate considerable amounts of heavy metals.

SOURCE → / RELEASES ↓	Raw material storage and handling	Furnace operations	Desulphurisation of molten iron	Nodularisation	Preparation of cores and moulds	Casting	Shake-out, reclamation	Fettling, dressing and finishing of castings
Oxides of sulphur		X	X		X	X	X	
Oxides of nitrogen		X			X	X	X	
Carbon dioxide		X	X	X	X	X	X	
Carbon monoxide		X	X	X	X	X	X	
Hydrogen sulphide					X	X	X	
Ammonia					X	X	X	
Oxides of iron		X	X	X		X	X	X
Alkali metal compounds		X	X					
Alkaline-earth metal compounds		X	X	X		X		
Metal oxide particulates		X	X	X		X	X	X
Non-metallic particulates	X	X	X		X	X	X	X
Metallic iron		X						X
Hydrogen cyanide					X			
Sulphur			X					
Amines/amides					X	X		
Dioxins		X						
Volatile organic compounds		X			X	X	X	
Acid vapours		X			X	X		
Noise		X			X		X	X

Substances include their compounds, except where separate reference to the compound is made.

Releases to air may also be released to land or water, depending upon the abatement technology employed, e.g. via collected dusts, sludges or liquors.
Some releases are specific to a particular binder system

Table 4.31: Survey of air emissions from different ferrous foundry stages [160, UK Environment Agency, 2002]

The principles and techniques for waste gas collection and treatment are the same for foundries and (primary) non-ferrous metal industries, therefore for a full discussion of the principles the reader is referred to the BREF document on non-ferrous metal industries. Section 4.5.1.3 details a short survey of the techniques that apply.

4.5.1.1 Reduction of fugitive emissions

Description

Fugitive emissions occur when emissions from specific process sources are not collected. Besides the process-related emission sources mentioned in Section 4.5.1, potential sources of fugitive emissions to air include:

- storage areas (e.g. bays, stockpiles, heaps)
- the loading and unloading of transport containers
- transferences of material from one vessel to another (e.g. furnace, ladle, silos)
- the mixing and curing of chemical binders (inorganic and organic chemical emissions)
- mould coatings (solvents)
- conveyor systems for moving material around
- pipework and ductwork systems (e.g. pumps, valves, flanges, catchpots, drains, inspection hatches, etc.); these type of emissions are discussed in detail in the LVOC-BREF
- poor building containment and extraction
- bypass of abatement equipment (to air or water)
- an accidental loss of containment from a plant or equipment failure, including leakages, e.g. from the sand reclamation plant
- spills.

In order to minimise fugitive dust emissions, the following techniques may be employed:
- the covering of skips and vessels
- the avoidance of outdoor or uncovered stockpiles
- where outdoor stockpiles are unavoidable, using sprays, binders, stockpile management techniques, windbreaks, etc.
- cleaning wheels and roads (i.e. avoiding the transfer of pollution to water and wind)
- using closed conveyors, pneumatic conveying (although note the higher energy needs), and minimising drops
- vacuum cleaning of the moulding and casting shop in sand moulding foundries, with the exception of areas where the sand has a technical or safety-related function, e.g. the pouring area, and with the exception of hand-moulding jobbing foundries
- keeping outside doors shut, e.g using an automatic shutter system or flaps
- carrying out good housekeeping, i.e. ensuring that regular inspections are carried out by responsible and delegated staff as a practice of good housekeeping and keeping up-to-date records.

Fugitive emissions to water may arise from subsurface structures or defective surfacing. These types of fugitive emissions can be minimised by the following actions:
- establishing and recording the sources, direction, and destination of all installation drains
- identifying and recording all subsurface sumps and storage vessels
- carrying out routine programmed inspections
- having an inspection and maintenance programme of impervious surfaces and containment kerbs
- being able to justify where operational areas have <u>not</u> been equipped with:
  - an impervious surface
  - spill containment kerbs
  - sealed construction joints
  - connection to a sealed drainage system.

Achieved environmental benefits
A reduction of uncontrolled emissions.

Cross-media effects
No cross-media effects apply.

Applicability
These techniques are applicable to all new and existing installations.

Driving force for implementation
Limiting fugitive emissions will limit the overall odour and dust emissions to the close vicinity of the plant. For installations in crowded areas, maintaining good relations with neighbours could therefore be a driving force for implementation.

Example plants
Vacuum cleaning of the moulding and casting shop: applied in various visited green sand foundries.

Reference literature
[160, UK Environment Agency, 2002], [163, UK Environment Agency, 2002], [155, European IPPC Bureau, 2001]

4.5.1.2 Use of a multi-flue stack

Description
In order to obtain maximum advantage from thermal buoyancy, hot emissions may be combined into the minimum practicable number of chimneys. A multiplicity of discharge points may thus be avoided. This is particularly important when new plants are being designed or when changes are being made to existing processes.

Achieved environmental benefits
Gathering multiple off-gas streams into one stack allows control of the emissions and increases the total volume (and load) going to treatment and thus reduces the total emission level.

Cross-media effects
No cross-media effects apply.

Applicability
This technique can only be implemented in new plants or when existing installations require substantial changes.

Driving force for implementation
To increase the possibility to measure and control the foundry operation.

Example plants
This technique finds multiple implementation around Europe.

Reference literature
[160, UK Environment Agency, 2002]

4.5.1.3 Abatement techniques

Description
For cleaning collected off-gases, various wet and dry systems may be used. Selection of the appropriate technique depends on the composition, flow and conditions of the off-gas stream. The design of the abatement process is critical. Factors such as efficiency, suitability of the method and the input and output loading of the material to be collected are used. A full discussion of the working principles is given in the BREF document for non-ferrous metal industries. The following techniques are used in the foundry industry.

- Dust and particle removal:
  - cyclones
  - fabric or bag filters
  - wet scrubbers
- Gas scrubbing systems (SO_2, Cl, amine removal):
  - wet scrubbing using scrubber towers, venturi scrubbers and disintegrators.
- Oil-mist separators:
  - wet electrostatic precipitators
- CO and organics removal:
  - post combustion
  - biofilter.

For dust and particle removal, both wet and dry systems are used. The main advantage with using dry systems is that the dust is captured dry, which allows its subsequent re-use. Furthermore, no pollution is transferred to another medium, as is the case for wet systems. For gaseous compounds, such as SO_2 and chlorides, bag filters are inefficient, since they are not adsorbed onto the filter surface. Experiments with lime injection have not provided good results. The following describes the system used for dust and particle removal:

- *Cyclones*: If the right measures are taken (i.e. heat resistant steel, refractory lining) a cyclone filter may be used for dedusting hot flue-gases (500 – 600 ºC). The efficiency is too low to achieve emission levels in the 20 mg/Nm³ range. The cyclone is mainly used as a spark separator in front of a bag filter. Cyclones are used as a pretreatment step to other abatement systems
- *Multicyclones*: The separation efficiency of a cyclone increases with decreasing diameter. The use of a parallel series of small cyclones allows the separation of small dust particles, without a sharp increase in the pressure drop over the cleaning equipment
- *Bag filter*: This type of separator is widely applied in various parts of the foundry process, due to its good efficiency and low emission values. It can achieve good efficiencies in controlling the fine particulate matter found in melting operations. Sub-micron particles such as metallic oxides may be separated as well. For proper operation, the following measures need to be taken: flue-gas cooling (T = 130 - 160 ºC) and separation of sparks (using a cyclone). The post combustion of organic material (to reduce the fire risk) may be applied for an off-gas with a high VOC content. Post combustion as a "firewall" for bag filter protection has been reported in some cases for off-gas from the unpacking of drums. This technique is not applied in general; instead waste gas streams with high dust loads are mixed with gas streams with increased VOC contents to prevent the filter and the exhaust ducts from becoming sticky. A view of the inside and outside of a bag filter unit is given in Figure 4.10.

Figure 4.10: Bag filter units; inside (l.) and outside (m., r.) views
[237, HUT, 2003]

- *High temperature filter systems (using a ceramic filter medium):* These are available on the market but not currently applied in the foundry industry

- *Electrostatic precipitators (ESP):* These are not widely applied for foundry flue-gas dedusting. Due to their sensitivity to gas flow, gas temperature and humidity, they are only suitable for continuous melting regimes. They also incur a considerable explosion risk, due to the high gas volume they contain. The removal of dust to reduce this risk requires frequent cleaning, and therefore might incur economic problems. The main field of application for electrostatic precipitators in foundries is oil/mist removal from pressure die-casting exhaust gases.

Wet dedusting systems, such as venturi and disintegrators, are applied in melting flue-gas treatment. Scrubber towers are used for dedusting of non-melting off-gas. Compared to dry systems the wet systems have the following disadvantages: higher energy consumption, higher maintenance (corrosion, bacteria), and they result in waste water and a sludge for disposal.

Advantages are the capture of water-soluble compounds (such as SO_2, chlorides), quick cooling - which prevents dioxin reformation, low investment costs, and less restriction on input temperature.

- *Venturi scrubbers*: Water is sprayed into the gases as they pass through a venturi. The acceleration of the gas flow in the venturi throat causes an intensive mixing of both media. The dust particles are damped, making them heavier, so that they can be separated in a cyclone or other system placed downstream. If the gas flow drops, the venturi throat is adjusted to maintain the collection efficiency
- *Disintegrators*: These so-called dynamic scrubbers consist of concentric rotor and stator mounted pins through which the gas stream is driven by means of a fan placed downstream or by fan blades at the outer end of the rotor. Water injected into the centre of the rotor, is broken into fine droplets by the pins and dispersed in the gas stream. The wet particles impinge on the stator walls and are collected at the bottom of the disintegrator. The system works efficiently when the gas flow is reduced.

Post combustion systems and biofilters will be discussed in Sections 4.5.2 and 4.5.9, respectively.

Achieved environmental benefits
Reduction of emissions to the atmosphere.

Cross-media effects
Wet scrubber systems result in the production of a waste water flow, which then needs treatment. The cleaned water may be recirculated into the process. Sludge cakes, produced from the waste water treatment need to be disposed of.

If the foundry is located in a cold climate (heating season more than 6 months), all increases in air ventilation will also cause a growth in the energy consumption, since the workplace has to be heated more.

The use of all abatement systems require the use of energy to induce the draught of the gases through the abatement system.

Operational data
A comparison of the properties of wet and dry systems is given in Table 4.32. In the subsequent sections, techniques that are specific for the various melting furnaces and for the various process stages will be discussed.

Abatement techniques	Dry systems		Wet systems	
	Multi cyclone	Bag filter	Venturi	Disintegrator
Dust emission level*	100 – 200 mg/Nm³	<5 – 20 mg/Nm³	<20 – 150 mg/Nm³	<20 – 150 mg/Nm³
Investment cost	Low	High	Low	Medium
Energy consumption	Low	Low-medium	High	High
Advantages/reason for choice	Applicable for pre-cleaning of gases prior to other methods	Good performance for suitable dusts if well monitored. The potential to recycle dust to the process	Partial SO_2-capture Low risk of *de novo* synthesis	Compact installation Low risk of *de novo* synthesis
Disadvantages	Low efficiency when there is a disturbed flow pattern (dust blocking of distributor). limited efficiency for fine particles	Fire risk, large volume, blocking upon condensation	Wet sludge, waste water treatment, a loss of efficiency with wearing	Higher energy use, wearing, wet sludge, waste water treatment
* Values from operational practice, that can be maintained throughout the service life of the installation				

Table 4.32: Properties of wet and dry abatement systems for foundries [110, Vito, 2001], [155, European IPPC Bureau, 2001], [202, TWG, 2002]

Figure 4.11 gives a comparison of the operational conditions for hot blast cupola furnaces with a wet and dry dedusting system. The main differences are the temperature profile of the flue-gas and the energy consumption.

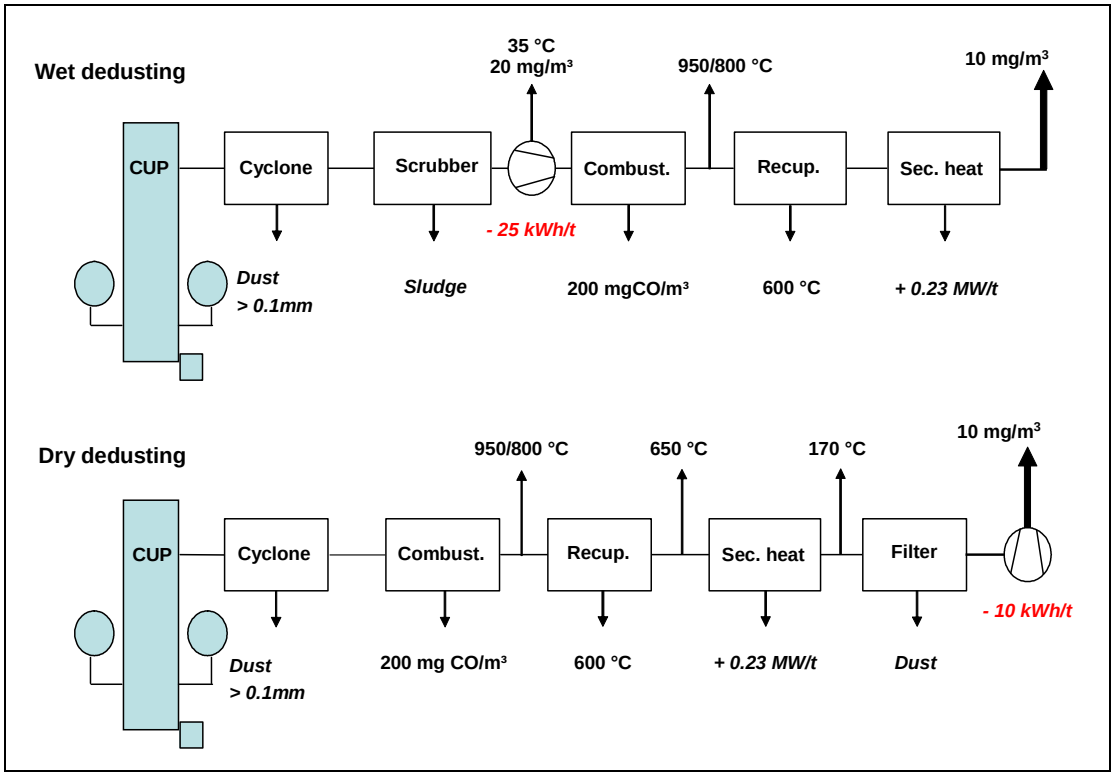

Figure 4.11: Operational conditions for wet and dry dedusting of hot blast cupola off-gas [230, CAEF, 2003]

Applicability
The applicability of the various abatement systems will be discussed in the following sections of this chapter.

Economics
Investment costs and energy usage for bag filters and wet separators are compared in Table 4.33.

Abatement technique	Investment cost* (EUR/Nm³)	Energy consumption (kW/1000 Nm³)
Bag filter	2.5 – 5	1 – 3
Wet separator	1.5 – 5	1 – 3
Biofilter	7.5 – 10	
* Excluding pipes and ducts, but including assembly		

Table 4.33: Investment and energy consumption data for various abatement systems [32, CAEF, 1997], [110, Vito, 2001], [202, TWG, 2002]

Driving force for implementation
Air emission regulations.

Example plants
This technique finds general application in European foundries.

Reference literature
[32, CAEF, 1997], [110, Vito, 2001], [155, European IPPC Bureau, 2001], [202, TWG, 2002]

4.5.1.4 Dioxin prevention and abatement

Description
Dioxins are relevant for thermal processes which have metals present. Dioxins or their precursors may be present in some raw materials and there is a possibility of *de-novo* synthesis in furnaces or abatement systems. Dioxins are easily adsorbed onto solid matter and may be collected by all environmental media as dust, scrubber solids and filter dust. Field tests have shown that the formation of dioxins in cupola furnaces cannot be correlated to one (or a few single) operational parameter(s). A combination of measures is needed to minimise the risk of dioxin formation.

In-process or primary measures to prevent dioxin emissions include:
- post combustion of the furnace off-gas in the CBC shaft or in a HBC combustion chamber. Combustion of cupola off-gas is fully described in Sections 4.5.2.2 and 4.5.2.3
- continuous temperature monitoring and control in the HBC combustion chamber (T >850 ºC) and maximising of the residence time (preferably >2s)
- maintaining the particulate matter concentration in the recuperator at a level <20 mg/m³, this is possible for HBC when using wet dedusting
- providing quick quenching of the dust laden off-gases, through the *de-novo* synthesis temperature range of 250 – 450 ºC
- preventing or minimising the build-up of dust along the cooling trajectory of the flue-gas, especially in the heat-exchanger, e.g. using vertical exchanger tubes, efficient internal cleaning, high temperature de-dusting
- melting clean scrap. This technique is described in Section 4.1.4
- using oxygen injection to ensure complete combustion. This technique is described in Section 4.2.1.6.

Although dioxins are destroyed at high temperature (i.e. above 850 ºC) in the presence of oxygen, the process of *de-novo* synthesis is still possible as the gases are cooled through the

reformation window (250 – 450 ºC). This window can be present in heat-exchangers or abatement systems and in cooler parts of the furnace, e.g. the feed area. Care must be taken in the design of cooling systems to minimise the residence time in the window and to avoid dust build-up, in order to prevent *de-novo* synthesis. An alternative is to dedust the off-gas by quick quenching using a wet system. Sufficient oxygen also needs to be present in the hot gases and for this oxygen injection can be used to ensure complete combustion. Nevertheless, excess oxygen should be prevented since this may support *de-novo* synthesis.

Sulphur has an inhibiting effect on the formation of dioxins, through depletion of molecular chlorine. The use of coal with a higher sulphur content in large combustion plants has been shown to provide lower PCDD/F concentrations. The reducing inhibiting effect is related to the S/Cl ratio, with a critical ratio of 0.64. A further increase does not result in less dioxins and furans. This effect has not been demonstrated in foundries, but may be studied. [231, UNEP, 2003]

The great spreading and big variability in the dioxin emission levels (even for the same installation) show that primary measures alone may not allow a stable and low dioxin emission value. Therefore, besides primary measures, the following abatement measures may be considered:

- *injection of additive powders* into the gas stream, such as activated carbon, open-hearth furnace coke or zeolite, so that dioxins are absorbed onto the surface. High efficiency dust filtration is then used to remove the dust and dioxins. The additive is injected into the off-gas stream before filtration. The adsorption process mainly takes place while the absorbents adhere to the filter bag. The filter dust may be recirculated back to the flue-gas to attain a higher efficiency. When using a carbon-based additive, special measures should be taken to prevent fire and explosion risk. The collected dusts may have high dioxin concentrations and will need to be disposed of or treated carefully
- *catalytic oxidation* systems are available for the destruction of dioxins. Fabric filters that incorporate a catalytic layer are used for the destruction of dioxins. In other sectors (e.g. steel, municipal waste incineration) this technique has been implemented successfully and implementation in the foundry industry is considered feasible. However, in order to prevent deactivation of the catalyst layer, a prior removal of coarse dust particles may be needed.

These are techniques to be considered depending on the application. They can all be incorporated into existing processes. The choice of the most effective and economically viable technique will depend on the specific site, safety aspects, and operational stability, as well as on economic factors.

Although the absence of one of the five dioxin building conditions mentioned above hinders dioxin synthesis, it is currently not possible to precisely foresee dioxin emissions by considering known operational parameters. The building of a new furnace therefore needs the careful consideration of primary measures as well as the option to add secondary measures in case of unexpectedly high values.

Achieved environmental benefits
Reduction of the emission of dioxins and furans to air.

Cross-media effects
The adsorption of dioxins and furans on activated carbon generates a PCDD/F-loaded dust stream. In order to prevent the explosion risk in the bag filter, mixing of the activated carbon with lime may be needed. This will increase the total amount of residue for disposal and will limit the possibility to re-use the filter dust.

Operational data
In-process measurements of dioxins in a hot blast cupola with dry dedusting have shown that high PCDD/F-levels (5 ngTEQ/Nm³) occur in the heat-exchanger. Other parts of the flue-gas system show much lower values. Reduction measures should therefore aim at minimising the

contact between dust and flue-gas in this zone, by minimsing dust or reducing the dust residence time.

A PCDD/F-emission level of 0.5 ng TEQ/Nm^3 can be achieved by using primary measures; and better than 0.5 ng TEQ/Nm³ can be achieved by using one or more of these techniques. A German survey concluded that without secondary measures the level of 0.1 ng TEQ/Nm³ is passed only in a limited number of installations and then only by a limited extent. The operational data as given in 3.8.2, however show that the level should be evaluated on a plant-by-plant basis.

Secondary measures in other sectors have been proven to allow a reduction to below 0.1 ng TEQ/Nm³.

For a flue-gas rate of 8000 m³/h at a blast rate of 3000m³/h, quick quenching of the cupola off-gas from 800 ºC to 150 ºC requires a water consumption of 4 m³/h.

Applicability
These techniques are applied in other industrial sectors, such as steel and non-ferrous metal production and waste incineration. Judging on a technical basis, they may be transposed to foundry furnace types that show a risk of dioxin formation: cupola, rotary and electric arc furnaces melting iron and steel (Section 3.8.2). For new and existing installations primary dioxin reduction measures, such as efficient combustion, furnace design modifications and scrap quality control have to be taken into consideration on a case-by-case basis, before turning to secondary measures.

The application of additive injection involves the installation of an additive silo, an injection system and, in the case of carbon injection control measures to prevent additive build-up. In order to prevent fire risks, activated carbon may be mixed with lime and may be injected, after the first filtration but before a dedicated secondary filter unit.

The application of catalytic filtration involves the least technical modification for existing plants, since only the filter bags need to be replaced by the catalytic type.

Economics
Primary measures do not involve additional investment costs. Operational costs are restricted to the use of oxygen or a higher price for cleaner scrap.

A cost estimation has been made for a hot blast cupola, as given in Table 4.34. Operational costs depend on the coke injection dose used and are given in Table 4.35. Costs for staff, maintenance, spare parts as well as possibly required early bag exchange or the installation of another type of bag quality have not been taken into consideration.

Parameter	Units	Value
Volume flow	Nm³/h	50000
Operating hours	h/yr	6250
Additive powder		Open-heart furnace coke
Additive price	EUR/t	400
Landfill price	EUR/t	300
Energy costs	EUR/kWh	0.09
Particle content		2 g/Nm³ - 100 kg/h
Investment cost: incl. silo, safety equipment, recirculation, integration - total cost - yearly cost	 EUR EUR/yr	 350000 52500
Energy consumption Cost of energy consumption	kW EUR/yr	10 6000

Table 4.34: Investment cost estimation for carbon injection installation, added to HBC [230, CAEF, 2003]

Parameter	Units	Values			
Coke content	g/Nm³ humid	0.2	0.3	0.4	0.5
Coke consumption	t/yr	63	94	126	156
Purchase cost	EUR/yr	25200	37600	50400	62400
Landfill cost	EUR/yr	18900	28200	37800	46800
Abated investment cost	EUR/yr	52500	52500	52500	52500
Energy cost	EUR/yr	6000	6000	6000	6000
Total cost	**EUR/yr**	**102600**	**124300**	**146700**	**167700**

Table 4.35: Total costs for carbon injection installation, added to HBC [230, CAEF, 2003]

Catalytic bag filter systems are used in the waste incinerator sector. Cost data from this application are transposed on basis of the flue-gas volume to be treated, but without taking into account operational parameters such as air-to-cloth ratio. For a depreciation time of 5 years, the investment and operational costs can be estimated at EUR 0.4 – 0.5/tonne molten metal for HBC and EUR 0.9 – 1.3/tonne molten metal for CBC. This price estimation was nor confirmed nor discarded by a catalytic bag filter supplier.

Driving force for implementation
Regulation limiting dioxin and furan emissions from the melting of metals.

Example plants
Reduction by installing oxygen injection: 3 example CBC plants in the Netherlands
Activated carbon injection: 1 example plant in Germany

Reference literature
[155, European IPPC Bureau, 2001], [161, UK Environment Agency, 2002], [202, TWG, 2002], [224, Helber, et al., 2000], [230, CAEF, 2003]

4.5.1.5 Odour abatement

Odour emissions are mainly associated with processes involving sand binders. The actual odorous products of pyrolysis may vary according to the type of system used, but generally the phenolic breakdown products, i.e. cresols and xylenols, are the most common source of odour complaint, due to their very low odour detection thresholds. The dispersion of odours during casting, cooling and shake-out involves mixing with large volumes of air, which makes collection and treatment difficult. The use of inorganic binders, such as sodium silicate, can substantially reduce emissions. No totally effective proven method of eliminating foundry generated smells is known to be currently available. A general approach is to ensure good ventilation and a rate of air change that ensures that emissions are quickly and efficiently dispersed to the atmosphere. Process-integrated measures include the substitution of binders or binder solvents (see Section 4.3.3.7). End-of-pipe techniques aim to abate pyrolysis products (see Section 4.5.8.5) and amines (see Section 4.5.8.4). These include adsorption techniques, post combustion, wet scrubbers and biofilters (see Section 4.5.8.6).

4.5.2 Cupola furnace

4.5.2.1 Gas collection, cleaning and cooling

Description
The design of the collection and gas cleaning system is based on the conditions occuring during blow-down, as these are often the most severe conditions experienced during the system operation. At the end of a melting campaign, the furnace is no longer filled with charge materials. Gas temperatures will increase gradually since they are no longer cooled by a cold charge in the stack. In contact with oxygen, CO will burn automatically. Temperatures can

therefore reach up to 1200 ºC, or even higher. The off-gas collection and treatment system has to be able to cope with these severe conditions.

Collection

Two systems are in use for top gas collection:

- *Above charge-hole offtake*: The exhaust gases are withdrawn at the end of the cupola stack by means of ductwork and a fan placed downstream. The opening above the charge-hole allows an important inflow of air, necessary to prevent cupola gases being emitted from the area. This volume of extra air may be many times the cupola gas flow. This increases the size and cost of the collection and cleaning system. Reducing charge-hole sizes may have some merit but this option may be limited because of the explosion hazard present when too little oxygen is mixed with the CO containing cupola gases (pulsating combustion)
- *Below charge-hole offtake*: The cupola top gases are collected through an annular ring below the charge-hole. No air inflow is required since the gases cannot be emitted out of the hole, provided the control system is sensitive enough to function properly during the variation of the blowing rate of the cupola. Too little offtake rate can result in the emission of uncleaned gases through the cupola stack, too great an offtake flow can result in air ingress, leading to combustion and overheating of the gases (i.e. an explosion hazard).

Cooling

Following collection, the gases may need cooling depending on the dust abatement system used. In the hot blast operation, the heat recovered from cooling may be used for preheating the blast air.

Several options are possible for cooling the collected gases, including:

- *Using tube coolers*: Running the collected gases through long ducts, decreases the temperature by natural convection and radiation. This system is simple but takes up a lot of space and does not offer controlled cooling (therefore there is a risk of condensation)
- *Using a forced air/gas heat-exchanger*: Cold ambient air is forced through an arrangement of tubes or plates to cool down the gases. Dust collection and the subsequent need for cleaning the heat-exchanging surfaces may lead to a complex and expensive design of the system. One advantage of this system is the possible use of the heated air for external heating purposes. Recuperative hot blast cupolas are equipped with a post combustion unit and a heat-exchanger (recuperator) to heat the blast air
- *Using an oil/gas heat-exchanger*: This is similar to the above system but more expensive because of the need for a secondary cooling system. The heat-exchanger is generally cooled with a circulation of mineral oil. Cooling with a water/gas heat-exchanger is not (or only very rarely) practised
- *Saturation with water*: Here the gases are cooled by the evaporation of the water sprayed into the gas stream. Wet scrubbers perform better if the gases are cooled in a saturation chamber prior to cleaning. When using fabric filters only, partial saturation is possible to prevent clogging of the fabric due to the condensation of water. A good control system is necessary to guarantee correct functioning of the system. Quenching the gases has the advantage that rapid cooling reduces the risk of dioxin formation.

Dedusting

Dust capture equipment of various types can be used to remove particulate matter from the waste gases. Generally wet scrubbers have low capital costs and maintenance, but require a high energy input to achieve acceptable collection efficiencies. The removal of the sludge is difficult and the scrubber water has to be treated prior to discharge. Dry collection systems have more expensive capital costs and need better control of the inlet gas conditions (temperature, condensation of water or organic vapours, $CO:O_2$ ratio, sparks) but usually use less energy than that needed for wet scrubbing. Furthermore, dry cupola dust can be recycled into the cupola (see 4.9.4.2).

Both venturi scrubbers and disintegrators are used with cupola systems. Descriptions of these systems are given in Section 4.5.1.3. A separator to remove small particles entrained in water droplets, is located after the wet scrubber.

With regard to dry systems, the following remarks can be made:

- *Multicyclones*: These are often used in conjunction with a fabric filter, acting as coarse dust arrestors. They help to prevent incandescent coke particles reaching the filter cloth. Provided refractory lining and high grade steel are used in the design of the cyclone, they can operate at high temperatures. Note, the collection efficiency from cyclones alone is not sufficient to meet today's regulations, hence they are usually used in combination with other dedustung systems
- *Bag filters*: These are ideal when the gases are burned prior to the dedusting. This avoids problems of the deposition of carbonaceous material or fire hazards. Bag filters can be designed to provide good efficiency for collecting metallurgical fume particles such as ZnO
- *Electrostatic precipitators*: These systems are less common in the European foundry industry. This system is best suited to more or less constant working conditions, such as in long campaign cupolas, because of its sensitivity to variations in gas temperature, flow and humidity. There is an explosion hazard when dedusting unburned gases mixed with air, due to the relatively large volume of the precipitator. The precipitator therefore needs to be flushed before applying electrical power.

A schematic representation of a cold blast cupola with heat recovery and a bag filter is given in Figure 4.12.

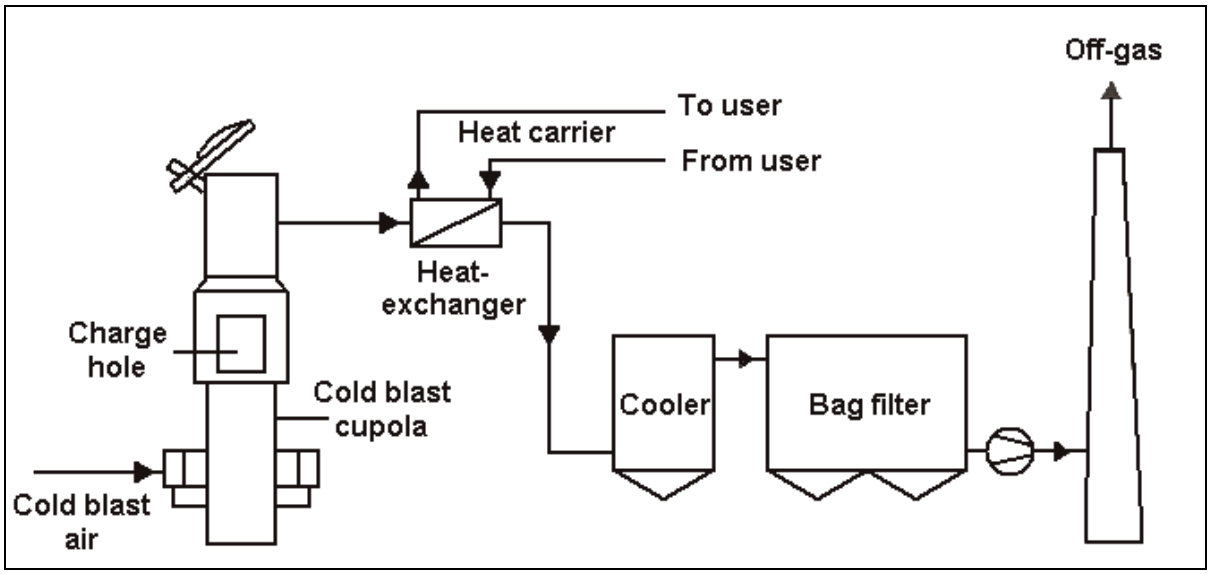

Figure 4.12: Flow sheet of cold blast cupola with heat recovery, cooling and a bag filter [29, Batz, 1986]

Post combustion

Post combustion of the waste gases is used to optimise heat recovery (chemically bonded as CO) and to provide cleaner exhaust gases. In burning CO, any residual carbonaceous material is simultaneously oxidised to CO_2 and H_2O. The generated heat can be recovered using a heat-exchanger and then transported to an internal user (e.g. blast air preheating).

Typical arrangements are:

- a post combustion chamber placed before (bag filter) or after (wet-filter) the dedusting unit (for below charge-hole offtake), this is discussed in Section 4.5.2.2
- (natural gas) burners or controlled air injection in the cupola shaft (for above charge-hole offtake), this is discussed in Section 4.5.2.3.

The design of the system needs to ensure that the waste gases remain at a temperature above 800 ºC and with a suitable residence time, i.e. 2 seconds, to guarantee the complete oxidation of the waste gases. The different systems are fully described and discussed below.

Achieved environmental benefits

Exhaust capture and cleaning is a necessary measure to reduce the emission products from coke combustion such as NO_x, SO_2, HF, PCDD/F, and dust.

The post combustion of CO allows (additional) heat recovery from the cupola off-gas. Additionally, it allows the melting of scrap contaminated with oil and grease without additional environmental effects and thus stimulates the recycling of metals. Post combustion without heat recovery shows a negative environmental balance (See cross-media effects).

Cross-media effects

Dedusting systems produce a residual dust for disposal. 5 – 13 kg of dust are produced per tonne of liquid iron. The dust may be re-circulated into the cupola. This is discussed in Section 4.9.4.2. The characteristics of the dust have already been given in Section 3.2.2.2.

The post combustion of CO without heat recovery has negative impacts on the environment, since powerful burners with a power of tens of kW need to be installed. The burners generate emissions of combustion gases and consume additional oxygen.

Operational data

Fabric filters have an efficiency of over 99 %. Daily average dust emission values stay well below 10 mg/Nm³. The sum of Pb, Zn, Cr, Cu, Mn,V, Sn, Cr, Ni, As, and Cd reaches about 20 % of the total dust content. The data represented in Table 4.36 were gathered within the framework of investigations of the Federal Environmental Agency in Germany of operational plants. Data for 3 example plants are given.

	Units	Plant D		Plant E	Plant F
		Initial	After rebuild		
Melting capacity					
- design value	t/h	7.5 – 8	12.0	6 – 7	4 – 5
- actual value	t/h	7.0	11.0	5.5	3.7
Exhaust gas stream					
- design value	Nm³/h	25000	30000	20000	n.d
- actual value	Nm³/h	19800	22300	17400	14300
Year of construction of the filter		1981	1995	1988	1985
Last filter cloth change		n.d	1995	1988	1993
Date of the measurements		07/1981	11/1997	03/1993	03/1993
Emissions	mg/Nm³				
- dust					
- raw gas		1623 - 2674		n.d	n.d
- clean gas					
• average[1]		21.5	<1	3	3
• min.		18.0	<1	1	2
• max.		25.4	<1	5	4
- gaseous [2]					
• SO_2		288	n.d	174	227
• NO_x		43	n.d	24	31
• C_{total}		n.d	n.d	22	7
• CO		700	n.d	11890	18980
• CO_2	%	7	n.d	4.9	3.9

	Units	Plant D			Plant E	Plant F
		Initial		After rebuild		
Heavy metal emissions - Cd - Cr - Pb - Zn - Ni - As - Mo	mg/Nm^3	Raw 0.0184 0.7287 29.895 16.464 0.2024 0.7665 0.2672	Clean 0.0019 0.0384 0.2952 0.2862 0.0077 0.0149 0.0420	Clean gas 0.00313 (ΣCu, Mn, Cr, V) 0.00057	n.d	n.d
PCDD/F-emissions - clean gas[3] - emission factor	ngTEQ/Nm^3 µg TEQ/t Fe			n.d	0.512 1.620	0.085 0.330
Filter dust - collected amount - PCDD/F-Gehalt	kg/t Fe µg TEQ/kg	6.5 disposal		8.2 re-use	4.850	0.960
Filter material		Polyester cloth with PA coating		Synthetic fibre	Polyester	Needle cloth
Filter cleaning		Pulse jet		Medium pressure counter flow	Pneumatical with pressure drop control	
Capital cost	EUR '000	385 (1981)		370 (1995/96)	n.d	350
Operating cost	EUR/tonne good casting	9.8 (1982) = 3 % of the casting costs		9.04 (1998) = 2.8 % of the casting costs	n.d	n.d

[1] Dust average is calculated on basis of 3 - 5 half-hour measurement data
[2] The concentrations of sulphur dioxide, nitrogen oxide, total carbon, carbon monoxide and carbon dioxide are calculated averages from continuous measurements over several hours during sampling for dust or PCDD/F
[3] Sampling time of 6 hours
n.d: no data

Table 4.36: Operational data of cold blast cupola furnaces with a bag filter for dust abatement data taken from [43, Batz, 1996] and [202, TWG, 2002], [225, TWG, 2003]

Data for hot blast cupolas are given in Section 4.5.2.2.

Applicability
This technique applies to all new and existing cupola furnaces.

Economics
Table 4.36 shows emission values and economic data. The most important operational cost factors are the electrical energy requirements for overcoming the pressure drop and for the filter material.

For a melting installation incorporating two cold blast cupolas with a melting rate of 4.5 t/h, a sales quotation was made with the following details:
- abatement equipment to treat up to 12400 m^3/h blast, with combustion chamber at a temperature of 820 ºC accepting up to:
  - VOC – 1 g/Nm^3
  - CO – 59100 g/Nm^3
- two burners to be used with methane – Power/burner 390 kW

Installation and start-up price: EUR 350000.
Foreseen running cost, considering a 4500 tonne casting production, five year payment period plus 10 % for energy and maintenance per year: EUR 23.3/t.

Driving force for implementation
Regulation of air emissions from foundries.

Example plants
The mentioned techniques are generally applied in European foundries with cupola furnaces.

Reference literature
[29, Batz, 1986], [32, CAEF, 1997], [110, Vito, 2001], [202, TWG, 2002], [225, TWG, 2003]

4.5.2.2 Post combustion in an HBC combustion chamber

Description
A post combustion chamber with a burner is installed after the cupola. Normally a separate post combustion unit has to be preheated with a natural gas burner. Once the cupola is up and running either a smaller burner sustains the combustion of the waste gases or the gases self-ignite.

The type and position of the chamber can vary according to the process composition. Both horizontal and vertical combustion chamber types exist.

- *Hot blast cupola with a recuperator and wet scrubber* (Figure 4.13): In this arrangement, the gases are dedusted prior to combustion. This reduces dust build-up in the recuperator, which improves the rate of heat transfer. One disadvantage is the higher energy consumption in the post combustion unit, caused because the gases are cooled down in the wet scrubber. Early cooling of the offtake gases is continuously carried out to reduce the size of the dedusting unit.

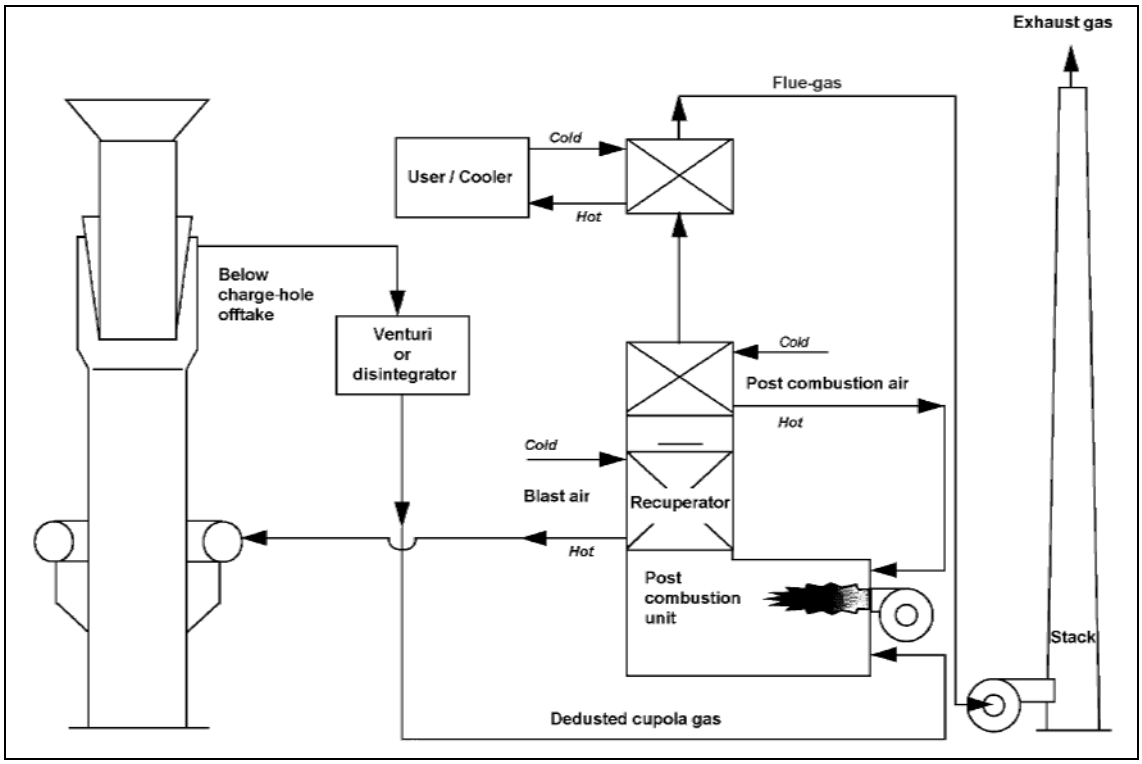

Figure 4.13: Hot blast cupola with a recuperator and wet scrubber
[32, CAEF, 1997]

- *Hot blast cupola with a recuperator and bag filter* (Figure 4.14): The hot, dust laden, top gases are fed directly into the post combustion unit. Close process control is necessary to prevent sintering of the dust particles to the walls of the recuperator, which need to be cleaned regularly. The gases need further cooling before entering the bag filter since they leave the recuperator at temperatures of 500 to 600 ºC.

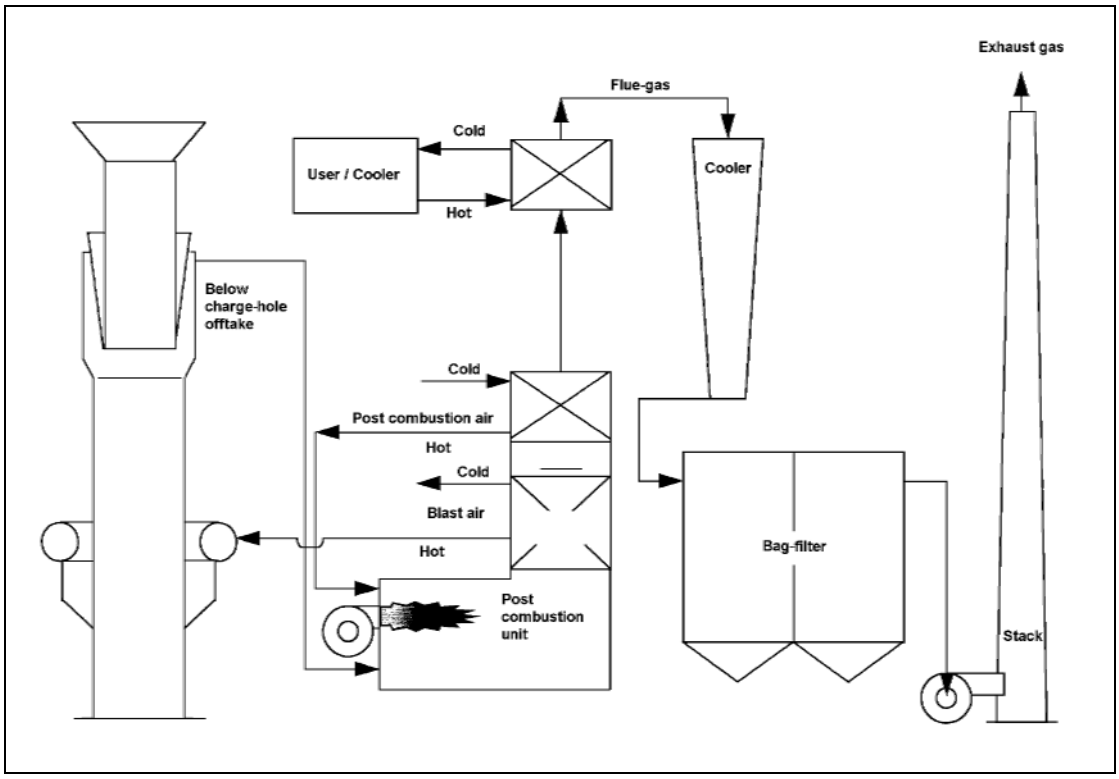

Figure 4.14: Hot blast cupola with a recuperator and bag filter
[32, CAEF, 1997]

Achieved environmental benefits
Post combustion limits the emissions of CO and eliminates the majority of organic compounds. If not combusted, these would be captured in the dust or emitted through the chimney. Furthermore, post combustion reduces the risk of fire in the filter.

Cross-media effects
Dry dedusting techniques produce dust for disposal (4 – 12 kg/t liquid iron). The dust may be re-circulated into the cupola. This is discussed in Section 4.9.4.2. Wet systems produce a sludge fraction.

Operational data
Operational data for hot blast cupolas are given in Table 4.37. Data for two example plants are given:

1. Foundry G is a 3 shifts/days and 5 days/week operated foundry with a melting capacity of 50 t/h. The off-gas is collected below the charge-hole and combusted in a recuperator. The waste gas is then separated: one part goes to hot blast production (T = 600 ºC), another part goes to a steam boiler. The steam is fed into a turbine, which powers a generator or compressor. The residual heat is used for preheating the combustion air of the recuperator. Waste gas is then cleaned in a bag filter. A concept drawing and further discussion of the installation is given in Section 4.7.3. Dust is recycled into the cupola, after mixing with petcokes. This is discussed in Section 4.9.4.2.

2. Foundry H is a 3 shifts/day and 5 days/week operated foundry with a melting capacity of 70 t/h. The off-gas is collected below the charge-hole and washed in a disintegrator, before post combustion in a recuperator. Heat is used for blast air preheating and goes to a further heat recovery, before leaving through the stack at a temperature of 220 ºC. Further discussion of the heat recovery installation is given in Section 4.7.3. Waste water is re-circulated after settling. The circulating water volume is 440 m³/h. The sludge from the settling tank is dried in a filter press to a 50 % DS content, before disposal. Some 80 m³/day of waste water are disposed to the municipal waste water treatment.

	Units	Plant G	Plant H
Melting capacity	tonne/h	50	50
Waste gas flow	Nm³/h	75000	55000
Hot blast temperature	°C	600	570
Exhaust gas temperature	°C	127	220
Year of construction of the flue-gas treatment		1989	1983
Date of the measurements		10/1990	Control measurement 09/1993
Emissions	mg/Nm³		
- Dust			
• Raw gas		1300 – 4300	8000 – 20000
• Clean gas: average[1]		1.1	6.1
maximum		1.8	7.3
- Gaseous[2]			
• SO_2		33	15.6
• NO_x		44	52.5
• C_{total}		<5	28.6 (FID)
• CO		32	<100
• O_2	%	12.2	6.4
Heavy metal emission	mg/Nm³	Clean gas[3]	Clean gas
- Cr		<0.001	<0.0022
- Cr_{total}		<0.001	n.d
- Pb		<0.001	0.11
- Zn		<0.011	0.36
- Ni		n.d	<0.004
PCDD/F-emissions[1]			
- Clean gas[4]	ng TEQ/Nm³	0.048	0.003
- Emission factor	µg TEQ/tonne Fe	0.089	0.004
Filter dust/sludge		Dust recycling	Filter cakes to disposal
- solitary quantity	kg/tonne Fe	4.5	5.5
- PCDD/F-content	µg TEQ/kg	0.176	1.4
Waste heat utilisation		Hot blast air, steam for electricity production up to 3 MW electric	Hot blast air, thermal oil for the conversion of the waste heat for heating and drying purposes up to 21 MW
Investment cost	DEM '000	26400	22700 in 1980/81
Operational cost	DEM/tonne good casting	See data in the text for foundry G	See data in the text for foundry H

[1] Dust average is calculated on basis of 5 - 6 half-hour measurement data and 2x2 hour values for PCDD/F
[2] The concentrations of sulphur dioxide, nitrogen oxide, total carbon, carbon monoxide and carbon dioxide are calculated averages from continuous measurements over several hours during sampling for dust or PCDD/F
[3] At the time of measurement, the dust recycling was not operational
[4] Sampling time of 2 hours
n.d: no data
note: Raw gas sampling was performed before the bag filter in G and before the disintegrator for H; clean gas sampling was performed after the bag filter for G and after the recuperator for H

Table 4.37: Operational data of hot blast cupola furnaces using a bag filter and a disintegrator for dust capture
[17, Strauß, 1983], [27, Kran, et al., 1995], [202, TWG, 2002]

Burning the fumes in the post combustion chamber does not consume much energy, providing there is sufficient carbon monoxide in the fumes, which is generally the case. But the whole system for treating the fumes (combustion chamber + heat-exchanger + filter or wet scrubber + fans) also needs electrical energy and regular maintenance. Table 4.38 gives some examples of energy consumption for hot blast cupolas.

Hourly rate of the cupola	Type of dedusting	Gas consumption for the combustion chamber (kWh/t charged)	Electricity consumption for the fume treatment system (kWh/t charged)
12	Filter	59	46
12	Filter	124	72
26	Filter	42	n.d
17	Electro filter (wet)	16	38

Table 4.38: Energy consumption of hot blast cupolas

Applicability
During the design stage, considerable care has to be taken to minimise the total flow of the gases to be treated. The combustion air intake has to be kept to a strict minimum. This is the reason why a separate combustion unit is always installed in conjunction with a below charge-hole offtake.
For economic reasons (see below) the post combustion chamber is only used on hot blast cupolas.

Economics
The high energy consumption of the post combustion is only economically reasonable if the released heat of the waste gases can be re-used, as it is in the recuperative hot blast cupola. However, switching from a cold blast to a hot blast cupola for the sole reason of gas combustion might encounter economical limitations in certain situations. Hot blast cupolas, preferably in a long campaign configuration, involve higher investment costs and are only used with production rates of 10 tonne Fe/h or more. In smaller foundries this production method might not be the right choice.

Table 4.37 gives economic data for the example plants. For foundry G, the investment costs for a hot blast cupola with bag filter and extensive heat recovery are given. The operational costs for 1994 (after refurbishment of the melting shop) were 25 % lower than those for 1985, i.e. with the old melting furnace. For foundry H, investment costs for 1980 - 1981 are given. After refurbishment, the operational costs went down by 2 %/tonne of liquid iron.

Driving force for implementation
Emission limit values and continuous monitoring of CO and emission limit values for organic compounds.

Example plants
The technique finds general application in HBCs around Europe.

Reference literature
[17, Strauß, 1983], [27, Kran, et al., 1995], [32, CAEF, 1997], [157, Godinot, et al., 1999], [202, TWG, 2002]

4.5.2.3 Post combustion in the cupola shaft

Description
The gases are combusted by an injection of air into the upper part of the charge or at a position above the charge top level. The airflow is adjusted so that the off-gases ignite spontaneously, due to their CO content and temperature. The injection nozzles can be placed on one or two levels. The partitioning of the airflow over the various levels, the choice of diameter and the

position of the nozzles is based on experience. The goal of the optimisation is to burn the CO without ignition of the coke. The draught will also suck in air from the charge door. This air excess allows a more complete burn-out of the CO.

A supporting burner may be provided to maintain the flame. When using very low coke charges (i.e. <6 – 8 %) the precautionary measure is reasonable.

Post combustion of the off-gas must be combined with a gas cooling, if a bag filter is used. For hot blast cupolas, the cooling is combined with a blast air preheating. In cold blast operation, a rapid cooling may be applied using water injection in the furnace shaft. Alternatively, an (off-gas – air) heat-exchanger may be used. This is illustrated in Figure 4.15.

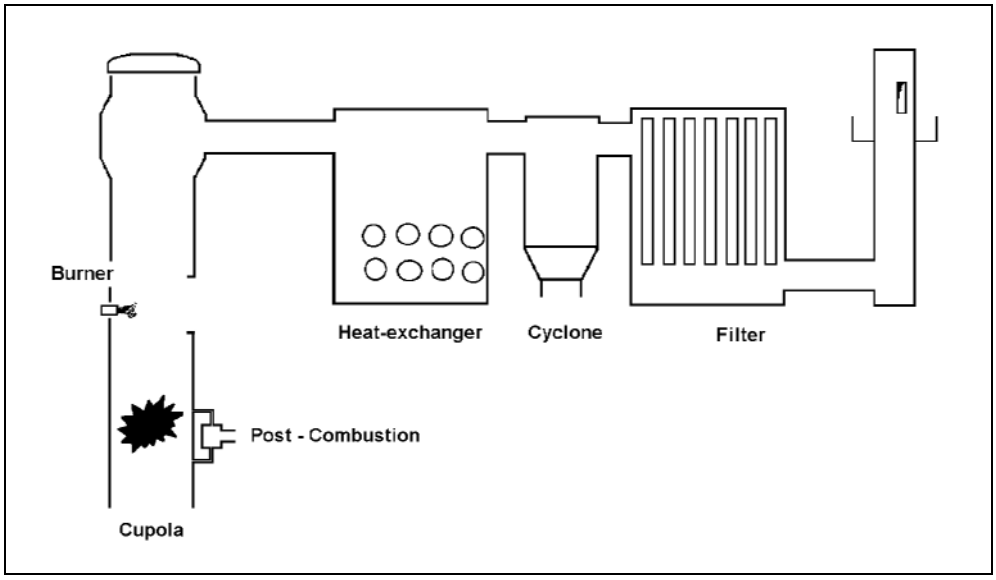

Figure 4.15: Principle of post combustion and off-gas cooling in cold blast cupolas [157, Godinot, et al., 1999]

Installing post combustion on cold blast cupolas can be combined with a full retrofit to hot blast operation. In general, this choice is based on operational considerations. The characteristics of hot blast and long campaign furnaces are discussed in Section 2.4.1.

Achieved environmental benefits

Post combustion limits the emissions of CO and eliminates the majority of organic compounds. If not combusted, these would be captured in the dust or emitted through the chimney. Furthermore, post combustion reduces the risk of fire in the filter.

This technique is known to avoid explosion risks under certain circumstances. The positive environmental effect is limited to those cases when the off-gas is burning autothermally most of the time. Otherwise, the energy consumption will counterbalance the CO reduction.

Cross-media effects

If the cupola off-gas does not ignite spontaneously, the installation of ignition or support burners is necessary. These incur a significant power use and increase the overall flue-gas volume.

Operational data

Two configurations of (in-shaft post combustion and) cooling on cold blast cupolas were studied on an industrial scale and compared by CTIF; cupola I was equipped with a water injection in the cupola shaft, a cyclone and a bag filter, cupola J was equipped with a gas-air heat-exchanger, a cyclone and a bag filter. Operational data are given in Table 4.39. Results of the measurement campaigns and reference to the applicable legislation are given in Table 4.40.

Parameter	Units	Foundry I	Foundry J
Melting capacity	tonne/h	10.3	9.2
Primary + secondary airflow	Nm³/h	7389	6484
Post combustion airflow	Nm³/h	2372	1549
Water flow	l/h	2678	
Flue-gas flow (chimney)	Nm³/h	26780	39179
Residence time combustion to bag filter	s	10.5	12.3
Residence time cooling stage	s	<1.7	6.01
Overall CO combustion efficiency	%	66	96.5

Table 4.39: Operational data of two example configurations using post combustion with water cooling (I), and air cooling (J)
[157, Godinot, et al., 1999]

	Foundry I		Foundry J		Arrêté du 02/02/98	
Compound	**analysis**	**flux**	**analysis**	**flux**	**limit value**	**limit for consideration***
Dust	1.7 – 2.8 mg/Nm³ 3 – 5 g/t	0.04 – 0.07 kg/h	1 mg/Nm³ 34 g/h		100 mg/Nm³ 200 g/t	<1 kg/h melt = 8 tonne/h
CO	450 Nm³/h	560 kg/h	35 Nm³/h	44 kg/h		50 kg/h
HCl	22 mg/Nm³	0.4 kg/h	9.2 mg/Nm³	0.35 kg/h	50 mg/Nm³	1 kg/h
HF	13 mg/Nm³	0.24 kg/h	4.8 mg/Nm³	0.18 kg/h	5 mg/Nm³	0.5 kg/h
HCN	<0.007 mg/Nm³	0.13 g/h	<0.01 mg/Nm³	0.38 kg/h	5 mg/Nm³	50 g/h
NH_3	0.61 mg/Nm³	12 g/h	0.10 mg/Nm³	3.8 g/h	50 mg/Nm³	100 g/h
NO_x	9 mg/Nm³	0.17 kg/h	15 mg/Nm³	0.57 kg/h	500 mg/Nm³	25 kg/h
VOC non-methane	13 mg/Nm³	0.25 kg/h	6 mg/Nm³	0.23 kg/h	110 mg/Nm³	2 kg/h
*: If the flux is below the limit of consideration, the measured value may exceed the limit value						

Table 4.40: Analytical results and applicable (French) legislation, for post combustion in a cold blast cupola with water cooling (I), and the air cooling (J) of flue-gases
[157, Godinot, et al., 1999]

The water spray cooling achieves a CO-destruction efficiency of 66 % and allows compliance with the applicable legislation. Flue-gas cooling over a heat-exchanger provides better efficiency (98 %). For discussion on cooling performance, see also 4.5.2.1.

Applicability

To change the offtake system of an existing cupola from above to below the charge-hole system is in most cases impossible. Post combustion of the waste gases in the furnace shaft therefore is a more viable solution for cupolas with an above charge-hole offtake.

For economic reasons, the application of post combustion has mainly been related to hot blast cupolas. However, recently, a post combustion system for cold blast furnaces, without the complexity of a hot blast installation, has also been developed. This system is currently in operation in France. 'In-shaft' post combustion therefore applies to both hot blast and cold blast cupola operation.

In the Czech Republic, the whole range of cold blast cupola installations was studied for applicability of in-shaft post combustion. The combustion was not spontaneous in any of the set-ups over the whole melting period. In each case, it was necessary to install ignition burners of significant power. The cupola emission volume also increased.

Economics

The high energy consumption of the post combustion needs to be evaluated against its benefits. In hot blast operation, the released heat of the waste gases can be re-used, which makes the investment more viable.

The high energy consumption of the post combustion is only economically reasonable if the released heat of the waste gases can be re-used, as it is in the recuperative hot blast cupola. However, switching from a cold blast to a hot blast cupola for the sole reason of gas combustion

is not possible. Hot blast cupolas, preferably in a long campaign configuration, involve higher investment costs and are only used with production rates of 10 tonne Fe/h or more. In smaller foundries, this production method might not be the right choice.

The investment cost for a twin cold blast cupola of 850 mm internal diameter, which produces 4.5 tonnes an hour, 10 hours a day, 5 days a week is in the order of EUR 300000.

Driving force for implementation
Emission limit values and continuous monitoring of CO and emission limit values for organic compounds.

Example plants
The technique is reported in 2 example foundries in France.

Reference literature
hot blast: [150, ETSU, 1998], [202, TWG, 2002]
cold blast: [157, Godinot, et al., 1999], [202, TWG, 2002]

4.5.3 EAF

4.5.3.1 Off-gas collection

Description
Particulate matter from an EAF is very fine and difficult to capture. The capture of smoke and dust is the most difficult problem to solve when installing a dust arrestment system on an electric arc furnace. There are several methods that offer different advantages and disadvantages. Figure 4.16 depicts the principle of roof mounted hoods, side-draught hoods and fourth-hole evacuation.

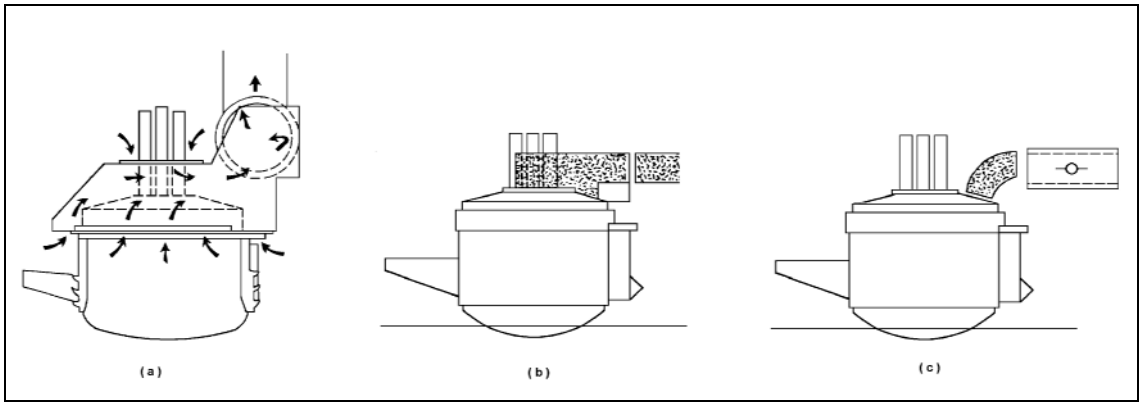

Figure 4.16: Principle drawings of (a) a roof mounted hood, (b) a side-draught hood, and (c) direct evacuation through a fourth-hole
[173, Huelsen, 1985]

- *Roof mounted hoods*: A hood is fixed on the furnace roof and collects fumes through a gap between the furnace shell and the roof. In addition, fumes arising from the working door and the tap-hole are also captured. Roof mounted hoods are heavy and subject to distortion from heat. If fitted to an existing EAF, problems may arise due to increased structural load of the roof lifting and rotating mechanism. Typical extraction rates for this system are 7500 to 15000 Nm^3/tonne
- *Side-draught hoods*: A hood is mounted on the furnace roof and collects the fumes emitted through the electrode ports. Vanes direct the airflow towards the hood. Additional hoods above the working door and the tapping-hole are used to capture emissions at these locations. Higher extraction rates are necessary here, compared to roof mounted hoods, as high air draught velocities are needed to capture the fumes. Some leakage of pollutants to the plant atmosphere can be expected, unless a tight seal is maintained. It has been reported that side-draught hoods increase electrode consumption

- *Canopy hoods*: A large exhaust hood is placed over the complete furnace, and above the charging system. This creates a large gap between the furnace and the extraction system, making it difficult to control the rising smoke and dust, even when using high extraction rates. Cross-draughts can seriously distort the collection efficiency. These disadvantages make the use of these collection systems unattractive
- *Direct furnace or "fourth-hole" evacuation*: The fumes are collected through a water-cooled or refractory-lined duct connected to a fourth-hole in the furnace roof. Ambient air is aspirated through a joint in the ductwork, thus providing oxygen to burn the CO gas in the undiluted and hot offtake gas. This prevents explosions in the dust collecting system. The dimensions of the combustion chamber are very critical in order to guarantee sufficient combustion at all stages of the melting cycle. The burnt gas (900 ºC) is cooled downstream by dilution with ambient air, water injection, heat-exchangers (water jackets) or by the use of long ducts. This cooling process is needed to protect the dust filter equipment. The use of a pressure control system in the furnace allows a relatively small extraction rate at the furnace at 2000 to 4000 Nm^3/tonne. Electrode consumption is generally higher due to the effect of oxidation
- *Partial furnace enclosure*: Mobile or fixed enclosures are mounted around the furnace and tapping area. The former are retracted in order to accommodate charging and tapping, while the latter are equipped with a mobile roof and side-walls for the same purpose. Exhaust gases are collected through a main exhaust duct at the top of the enclosure, assisted by fans inside the duct to guide the fumes to the exhaust. With these types of system collection, efficiencies of up to 98 % are possible
- *Total furnace enclosure*: This system consists of a large fixed evacuated room completely surrounding the melting furnace and ladle pit. The enclosure is equipped with a movable roof and/or with side panels to accommodate both charging and tapping operations. These may be equipped with air curtains to reduce gas losses. Disadvantages of the technique are the high temperatures and noise levels inside the enclosure. However, the advantages include low outside noise levels and low energy consumption. The energy consumption is estimated to be 30 to 50 % less than that required for a canopy hood.

Achieved environmental benefits

Flue-gas capture allows the controlled evacuation and treatment of the flue-gas stream, and results in a minimisation of both fugitive and guided emissions.

Cross-media effects

Capturing the exhaust increases the energy consumption. As it allows the cleaning of the exhaust gas, it will also generate dust for disposal or re-use.

Operational data

Table 4.41 provides typical exhaust flowrates and removal efficiencies for various capture systems.

	Exhaust flowrate for given furnace capacity			**Particulate removal efficiency (%)**	
	3.9 t/h	**9.1 t/h**	**22.7 t/h**	**Range**	**Typical max.**
Side-draught hood	12.9	19.8	50.00	90 – 100	99
Roof hood	7.7	11.9	30.00	95 – 100	99
Direct evacuation	3.2	5.0	12.5	90 – 100	99
Total enclosure			35 – 42		

Table 4.41: Typical exhaust flowrates (in m^3/s) and particulate removal efficiency of EAF exhaust capture systems
[173, Huelsen, 1985]

In a Polish foundry, the installation of a total enclosure over two EAFs with a capacity of 8.5 tonnes each, resulted in a reduction of the noise level from melting from 91 dBA to less than 85 dBA.

Applicability
The above-mentioned techniques are applicable to all new and existing EAF furnaces, with the following limitations:
- when installing a roof mounted hood on an existing furnace, problems may arise due to the increased structural load from the roof lifting and rotating mechanism
- direct furnace evacuation using a fourth-hole is limited to big electric arc furnaces, as the roof must be big enough to accommodate a fourth-hole without any structural weakening. The technique is not applicable for iron melting, because the in-flow of fresh air generates an excessive oxidation of carbon.

Economics
The construction and assembly of a doghouse over two EAFs with a capacity of 8.5 tonnes each, involved an investment of EUR 275000 (1996 prices), excluding costs for further refurbishment of the ducting and filtration system.

Driving force for implementation
Workers health-related prevention measures. It allows application of a gas cleaning technique by guiding the exhaust gas flow.

Example plants
doghouse: Metalodlew Foundry, Krakow (PL)
off-gas collection: Metso Lokomo Steels and Sulzer Pumps Karhula Foundry (FIN)

Reference literature
[29, Batz, 1986], [32, CAEF, 1997], [173, Huelsen, 1985], [199, Metalodlew s.a., 2002]

4.5.3.2 Exhaust gas cleaning

Description
Gas cleaning systems for EAF flue-gas need to be highly efficient since the particle size is small. Fabric filters are widely used to dedust the exhaust gases. Venturi scrubbers or disintegrators are applied less due to their higher energy consumption, the necessity for water treatment prior to discharge, and due to the need to dispose or recycle wet filter sludge. Fabric filters are widely used in favour of electrostatic filters, due to the wide fluctuations in gas temperature and the particulate concentration of the exhaust gases.

If a fabric filter is used, several precautions need to be taken in order to protect the filter medium as discussed in Section 4.5.1.3. These include:
- using a high temperature cyclone or multicyclone
- using gas cooling equipment. Here the exhaust gases are cooled by dilution with ambient air, water injection (quenching), heat-exchangers or by the use of long ducts. Water injection, in particular, has an additional advantage, in that the quick cooling down of the exhaust gases prevents the recombination of any partially burned organic substances, thereby leading to a cleaner emission. The cooling system needs an effective control system to prevent gases which are too hot from entering the fabric filters.

Achieved environmental benefits
Reduction of particulate emissions from EAF.

Cross-media effects
The application of wet dedusting techniques causes a higher energy consumption, the necessity for water treatment prior to discharge, and the need to dispose or recycle wet filter sludge.

Operational data
Operational data are given in Section 3.2.3.4. Current bag filters have air to cloth ratios between 2:1 and 3:1. The air to cloth ratio is the ratio of volumetric airflow through the filter to the

media area and is expressed in (m³/s)/m², which yields the same result as the air speed through the filter media.

Applicability
These techniques can be applied to all new and existing installations.

Economics
The costs for installing a new dust capture and filtration unit in an existing Polish EAF foundry using two 8.5 t/h melting furnaces are summarised in Table 4.42. Dust emissions have been reduced from 10 – 13 kg/h and 145 – 150 mg/Nm³ to 0.2 – 0.25 kg/h and 2.8 – 2.9 mg/Nm³. There has also been a major reduction of diffuse emissions from the melting shop.

Investment costs	**EUR***
Foundation and remodelling of old collector	115000
Construction and assembly of doghouse housings over 2 furnaces	275000
Purchase and assembly of filtration unit and electrical devices	560000
Research, implementation and supervision	80000
Operational costs	**EUR/year**
Depreciation cost	100000
Electric power	88000
Repairs and service	1500
* Prices converted from zlotys 1999	

Table 4.42: Cost data for EAF flue-gas capture and cleaning equipment [199, Metalodlew s.a., 2002]

Driving force for implementation
Regulation limiting the dust emissions from the melting of metals.

Example plants
doghouse with bag filter unit: Metalodlew Foundry, Krakow (PL)
Metso Lokomo Steels and Sulzer Pumps Karhula Foundry (FIN)

Reference literature
[173, Huelsen, 1985], [32, CAEF, 1997], [29, Batz, 1986], [199, Metalodlew s.a., 2002]

4.5.4 Induction furnace

4.5.4.1 Off-gas collection

Description
The capture of smoke and dust is the most difficult problem to solve when installing an off-gas collection system on a coreless induction furnace, since there is no exhaust shaft. Several methods have been developed in the past decade, each with advantages and disadvantages.

- *General ventilation of the workplace*: A combination of wall mounted louvres and roof mounted ventilators situated over the furnace platform are used to increase the natural convection of smoke and fumes and to direct them outside. Even with baffles suspended from the roof and using high extraction rates the efficiency is often poor and easily disturbed by draughts.
- *Canopy hood extraction*: Since lower placed hoods will interfere with crane charging systems, larger hoods have to be installed above the charger. This creates a large gap between the furnace and the extraction system, making it difficult to control the rising smoke and dust, even when using high extraction rates. Cross-draughts can seriously distort the collection efficiency of the system. These disadvantages make the use of these collection systems unattractive.

- *Swing aside hoods:* These hoods are more efficient when used in conjunction with vibrating feeders. Cut-outs in the hood can facilitate charging. During tapping, the hood is swung over the ladle, allowing efficient fume extraction.
- *Side-draught hoods*: Placing the extraction hood beside the furnace offers the advantage of good furnace accessibility and no interference with the charging systems. Due to the high buoyancy of the exhaust gases, large extraction rates are achieved, therefore giving good efficiency, especially when the hood is placed outside the furnace platform. In this case extraction control is poor during tapping. Attachment to the furnace platform overcomes this problem but may interfere with charging operations. The efficiency can be improved by installing airjets at the opposite side of the hood to blow the dust and fumes into the hood. Unfortunately, this facility does not work if there are any interferences in the airstream, which is the case during charging.
- *Lip extraction*: A suction ring is placed on top of the furnace and arranged so that it moves with the furnace during deslagging or tapping operations. This system does not interfere with the charging operations. With the lid closed, lip extraction offers very good control, since it is as near to the emission source as possible and involves the lowest extraction rates. The fumes do not pass through the breathing zone of the furnace operators. However, the extraction control decreases significantly when the furnace lid is opened, for instance during charging.
  The design of this extraction equipment has been subjected to many studies. Suppliers offer solutions to overcome some of the disadvantages.
- *Cover extraction*: The gas is exhausted through the furnace cover. This method is very effective. It is used by the majority of furnace producers. Exhaustion is managed according to furnace regime: melting, charging, pouring.

Attention has to be paid to the material used for hoods and ducts since the gases may be at high temperatures when the intake of the collection system is positioned close to the furnace. The heating required by radiation or convection from the molten metal bath needs to be taken into account in the design stage. Proper maintenance in combination with heat-sensors reduces the risk of fire.

Again scrap cleanliness plays an important role. When the scrap contains organic matter, collected gas temperatures may rise due to the combustion of the material, thus requiring the use of heat resistant steel or even refractory linings. Oily deposits, formed by condensation of oil vapour in the ductwork, accumulate dust and can present a fire hazard if not removed regularly. When using clean scrap, a mild steel construction is adequate and does not need accessibility for cleaning.

Achieved environmental benefits
Flue-gas capture allows controlled evacuation and treatment of the flue-gas stream, and results in a minimisation of both fugitive and guided emissions.

Cross-media effects
Applying exhaust capture increases the energy consumption. In addition, as it allows the cleaning of the exhaust gas, it will also generate dust for disposal or re-use.

Operational data
Through the use of specific capture systems, such as side-draught hoods, movable extraction hoods and partial housing of the furnace, a capture efficiency of more than 95 % is possible.

Operational experience in a German cast iron foundry showed that the furnace lid is open on average during 25 % of the working time of the furnace. During the opening periods, dust-generating process steps such as the feeding of additives, deslagging and pouring are performed. The lip extraction system installed on the furnace lid, does not allow extraction of the generated fumes. Installation of a telescopic canopy hood allowed an efficient exhaust capture during the opening of the furnace lid.

Applicability
The installation of exhaust capture equipment is applicable to all new and existing induction furnace installations, both in ferrous and non-ferrous foundries.

Driving force for implementation
Regulations concerning emissions to air.

Example plants
These techniques are commonly used on induction furnaces in Europe. A specific example is Walter Hundhausen GmbH & co KG (D)

Reference literature
[29, Batz, 1986], [18, Rademacher, 1993], [32, CAEF, 1997]

4.5.4.2 Exhaust gas cleaning

Description
Gas cleaning systems for induction furnace flue-gas need to be highly efficient as the particle sizes need to trap are small. Fabric filters are widely used to dedust the exhaust gases. Fabric filters are used in favour of electrostatic filters, as they are more suited to the wide fluctuations in gas temperature and particulate concentration of the exhaust gases.

When using fabric filters care has to be taken with respect to the presence of oil in the scrap, as oily vapour could condense on the filter cloth, where it could block the pores and make the removal of adhering dust impossible. There is also a possible fire hazard. The rapid increase in the pressure loss of the system when pores get blocked quickly reduces the extraction rate of the system. Therefore, in order to prevent workplace pollution the filter media have to be changed or regenerated (cleaned) much quicker than when using clean scrap. The use of coated fabrics or an injection of lime in the ductwork may be a solution to this problem. Furthermore, if the oil vapour is likely to burn in the ductwork, the process must allow enough time for combustion to be completed before the vapour enters the filter housing. The gas temperature may not exceed the design temperature of the fabric, in which case cooling of the gases may therefore be needed.

The wet scrubbers used generally need to be of the high energy type (venturi), because carbonaceous and metallurgical smoke consists of very small particles. These require considerable fan power to create sufficient turbulence in the scrubber to collect the particles. Exhaust flowrates are therefore kept to a minimum by using exhaust capture systems with the least entrainment of ambient air. Under normal conditions, corrosion is not a problem. If borings containing cutting fluids are charged into the furnace, it should be noted that some of these fluids might contain sulphur, which could lead to the formation of SO_2. This could cause problems in the equipment, as the absorption of SO_2 in the scrubber leads to an acidification of the water and eventually to corrosion of the equipment if water treatment is not applied.

Some aluminium foundries melt material recovered from the electrolysis of aluminium. In this instance, inorganic pollutants such as hydrogen fluoride may be formed. These can be cleaned from the flue-gas using a chemisorption step, which can be added onto the dust abatement system. In this treatment calcium hydrate or aluminium oxide can be used as the adsorbant.

Achieved environmental benefits
To reduce particulate and acidifying emissions from induction melting furnaces.

Cross-media effects
Exhaust gas cleaning increases the energy consumption. The dedusting of the exhaust gas, generates dust for disposal or re-use. The application of wet dedusting techniques lead to a

higher energy consumption, the necessity of water treatment prior to discharge, and the need to dispose of or recycle wet filter sludge.

Operational data
Cleaning of the captured gases is generally performed using filters. Daily average dust emission values stay well below 10 mg/Nm³. Operational data are given in Section 3.2.4.1.

Table 4.43 gives the operational data for a German cast iron foundry in which a centralised flue-gas capture system is installed, with dedusting carried out using a bag filter. The system collects exhaust gas from the various parts of the foundry, including: the four induction furnaces (each with lip extraction and canopy hood), the scrap storage and preheating, the metal treatment, the sand regeneration, and the casting areas. Data are given for the raw melting of the furnace off-gas, the raw combined gas flow and the cleaned gas flow.

Compound	Melting off-gas	Combined exhaust gas	Cleaned gas*
Dust	89.3	237	<1
NO_x	1.6	8.3	7.9
CO	2.2	4.2	3.8
SO_2	3.5	3.9	3.7
Total C	21.8	34.7	34.9
PCDD/-F		0.036×10^{-6}	0.0027×10^{-6}

* NO_x, CO, SO_2 and total C are not captured in the bag filter. The difference between raw and cleaned gases are due to the slightly changed gas mix after the ID fan
Melting capacity 14 tonne/h, total flue-gas flow 240000 m³/h
All data in mg/Nm³

Table 4.43: Emission data for a cast iron foundry, using induction melting and a centralised exhaust system with a bag filter
[18, Rademacher, 1993]

Applicability
This technique is applicable to all new and existing induction furnace installations, both in ferrous and non-ferrous foundries.

Economics
The cost and consumption data for a bag filter installation on a melting unit of crucible induction furnaces, melting 15 t/h, able to treat 120000 Nm^3/h are given in Table 4.44.

Dust emission level (mg/Nm³)	Investment cost (EUR)	Power consumption (kW)
<5	350000	250
<20	200000	150

Table 4.44: Investment cost and power consumption for a bag filter unit on induction furnaces, with varying final dust emission levels
data for Portugal 2003
[225, TWG, 2003]

Driving force for implementation
Regulation limiting the dust emissions from the melting of metals.

Example plants
Flue-gas cleaning is applied in most ferrous foundries using an induction furnace and in a limited number of non-ferrous foundries.

Reference literature
[18, Rademacher, 1993], [32, CAEF, 1997], [29, Batz, 1986]

4.5.5 Rotary furnace

4.5.5.1 Off-gas collection and waste gas cleaning

Description
In most cases, dedusting equipment is needed to meet the applicable regulations. Generally, bag filters are installed for this purpose, but it is also technically possible to use wet dedusting techniques.
In order to lower the temperature of the exhaust gases, they are diluted with ambient air. This is achieved by the intake of air through a gap between the furnace exhaust and the elbow shaped exhaust pipe. This gap is always present as it allows the furnace body to be able to rotate and tilt. Often the exhaust pipe is retractable. In general, dilution for emission reduction is unacceptable. If dilution is used (and is necessary) for cooling, the end-of-pipe technology should have the right dimension for the larger gas flow. Sometimes the diluted waste gases are then fed through an air-gas heat-exchanger for further cooling. This way the gas temperature is reduced from the initial 1500 ºC to 200 ºC, or lower. At this temperature, the gases can be introduced into a bag filter for dedusting.

The application of an afterburner allows the reduction of organic carbon emissions and combustible particles. This technique may also be effective in reducing the risk of dioxin formation upon cooling of the gases. The afterburner is installed after the furnace and before the heat-exchanger. One of the following afterburner types may be used:
- thermal incinerator: combustion in an open flame
- catalytic incinerator: combustion at lower temperatures through the use of a catalyst, resulting in a higher efficiency and lower NO_x emissions
- recuperative incinerator: combustion with a heat recovery for preheating the combustion air, resulting in a higher thermal efficiency and lower fuel consumption
- catalytic recuperative incinerator: a combination of the previous two types.

Achieved environmental benefits
Reduction of particulate emissions from rotary furnaces.

Cross-media effects
Exhaust gas cleaning increases the energy consumption. The dedusting of the exhaust gas generates a dust for disposal or re-use.

Operational data
Operational emission data are given in Section 3.2.5.3.

An afterburner can be expected to achieve between 80 % and 98 % efficiency for burning the combustible particulates emitted from the rotary furnace. Hot gases from the afterburner can be ducted through a recuperator and can assist in preheating the combustion air to the main furnace burner. Recuperators offer an energy saving of up to 15 %.

Applicability
This technique is applicable to all new and existing rotary furnace installations, both in ferrous and non-ferrous foundries.

Driving force for implementation
Regulations limiting the dust emissions from the melting of metals.

Example plants
This technique is commonly applied in foundries using a rotary furnace.

Reference literature
[23, Brettschneider and Vennebusch, 1992], [32, CAEF, 1997], [163, UK Environment Agency, 2002], [202, TWG, 2002]

4.5.6 Crucible, hearth type and radiant roof furnaces

4.5.6.1 Prevention of visible and fugitive emissions during melting and metal treatment

Description
Under normal operating conditions, melting processes using pure metal melts do not emit visible smoke. However, during charging of the furnace it is possible that a visible smoke may be produced. This can be either due to the burning of contaminants in the charge, such as oil or paint, or due to the burner flame being extinguished and unburned fuel being emitted, as may be the case with solid or liquid fuels. In these circumstances, an afterburner may be installed.

Hoods may also be installed to capture visible smoke and fugitive emissions. The melting of clean scrap prevents or minimises these types of emissions.

Achieved environmental benefits
A reduction of the emission to air of the products from incomplete combustion.

Cross-media effects
Smoke capture will involve a usage of electrical energy.

Applicability
This technique applies to new and existing crucible and hearth type furnaces.

For implementation, any constraints due to the current furnace design and operation need to be considered. These include physical constraints, for example due to crane tracks, the existing structural elements of the building, or due to the furnace itself. To be effective the extraction need to be fitted in such a way that it moves with the furnace body when it is tilted to pour, as tapping-out is one of the peak emission operations. This is not always easy to achieve with existing furnace bodies. There can also be physical problems related to the location of associated ducting. In some cases, major modifications to the furnace platform and surrounding area may be necessary to enable the ducting to be installed.

Economics
A cost estimate for an extreme (worst case) scenario, i.e. needing to capture all the dusts from charging and tapping, was made by CTI. Table 4.45 summarises this financial data for an 'average foundry' with the costs depreciated over a presumed 10 year lifespan of the extraction and abatement equipment. This estimation however, can broadly vary, depending on the foundry layout and the techniques used.

Extraction rate m^3/minute	Production rate tonnes/hr	Costs EUR		Power kW	Costs EUR/tonne of iron melted		
		Capital	Civil		Running	Financial	Total
142	0.5	117573	15676	40	15.24	18.81	34.05
	(1150 tonnes per year)						

Note:
- Civil costs are taken as 12 % of capital costs
- Running costs are based on maintenance and waste disposal costs and are equivalent to 10 % of the capital costs and power at EUR 0.06/kWh
- Financial costs are based on the plant being amortised over ten years with interest charges of 10 %

Table 4.45: A cost estimate for installation of an abatement system for visible fumes during charging and tapping
[161, UK Environment Agency, 2002]

In this example, under the pre-conditions used, the costs for abatement of these visible emissions would be about EUR 34.05 per tonne of metal melted.

Driving force for implementation
Regulations limiting the occurrence of visible emissions.

Example plants
This technique is commonly applied in foundries around Europe.

Reference literature
[161, UK Environment Agency, 2002]

4.5.7 Metal treatment

4.5.7.1 AOD Converter: exhaust gas capture and treatment

Description
Pollution control equipment need to be designed to be able to handle the peak effluent condition, even though the peak may only persist for a relatively short period.

Fume control hoods for AOD vessels come in a great variety of shapes and sizes. The alternative to the direct extraction hood is the roof canopy. Roof canopies are in use in several AOD plants and efficiently capture both AOD process fumes and smoke from other operations such as charging and tapping. These roof canopies may be used in conjunction with accelerator stacks over the AOD mouth. The accelerator stack performs several useful functions, including forming a more coherent plume out of the AOD, reducing the size of canopy required, and shielding the surrounding equipment and personnel from the sometimes intense radiation of the AOD flame. The main advantage of the roof canopy is the capture of both process and fugitive effluents in the same hood.

Achieved environmental benefits
Flue-gas capture allows controlled evacuation and treatment of the flue-gas stream, and results in a minimisation of both fugitive and guided emissions.

Cross-media effects
Exhaust gas cleaning increases the energy consumption. The dedusting of the exhaust gas generates dust for disposal or re-use.

Applicability
This technique is applicable to all new and existing AOD installations.

Driving force for implementation
Regulations limiting the dust emissions from the melting of metals.

Example plants
Example plants are reported in Italy and Finland.

Reference literature
[202, TWG, 2002]

4.5.7.2 Nodularisation: off-gas collection and dedusting

Description
The type of exhaust collection applied depends on the technique used for nodularisation (see 2.4.12.4). Depending on the technique, significant amounts of MgO can be released as a white smoke. Properties of the various nodularisation techniques are given in Table 3.20. In general techniques with a higher take-up efficiency result in lower emissions. This is the case for the ‘in-mould’ process, where the nodularisation takes place during pouring.

For ‘in-crucible’ nodularisation, techniques using a lid or cover result in a significant reduction of the emission.

If the nodularisation off-gas is not captured, this could result in the melting shop filling-up with a white smoke, and MgO dust drop out. Exhausting without filtration can result in a visible emission from the foundry. A large volume of visible particulate can be generated in a relatively short period of time, but usually only lasts for a short duration (5 to 10 minutes for each batch treated).

In-crucible nodularisation may be performed at a specific stand or location in the melting shop. The crucible with the molten metal is brought to this point after pouring, but before taking it to the casting furnace or station. This allows the installation of a fixed hood for exhaust capture.

The collection of the MgO fume is hampered by the fact that the gases are very hot and that the intensive Mg reaction causes sparks. Due to the high upward velocity and temperature large quantities of surrounding air need to be extracted as well. This requires a large sized, and high cost, installation.

Dry filtration (using bag filters) of the exhaust gas, results in a MgO powder that may be re-used in pigments or for refractory material production.

Achieved environmental benefits
Mg has no harmful effect on the environment and is an essential nutrient for animals and plants in small concentrations. UK occupational exposure limits give a long-term exposure limit (8-hour TWA) of 4 mg/m³ for MgO dust and respirable fume (expressed as Mg).

Cross-media effects
Capture of the magnesium oxide fume requires an increased energy use and therefore results in increased emissions from energy production. External re-use of the MgO powder leads to a reduced need for primary material.

Operational data
A typical addition rate for magnesium to the melt is around 0.1 % of the melt weight, measured as magnesium (the actual addition of magnesium containing alloy, such as magnesium ferrosilicon, could be up to 2 % of the melt weight according to the alloy used).

This addition provides about 0.05 % of the magnesium in the melt, most of the remainder oxidises and escapes to atmosphere as MgO, where it will agglomerate fairly rapidly in the air. Where there is no fume capture, the fumes can spread through the foundry and a proportion will drop out in the foundry as dust. There is no accurate information available on this amount but a reasonable figure may be 50 % of the fume released. Therefore, for each tonne of metal treated there would be around 500 g of magnesium released to air at the ladle as MgO (i.e. 833 g of MgO released per tonne of metal treated) and about 400 g of MgO released to the external atmosphere.

Applicability
The technique of exhaust capture and filtration applies for foundries using in-crucible nodularisation techniques. No information on applicability to the in-mould nor ductilator was provided.

Economics
In applying this technique, the extraction required to successfully capture most of the MgO emissions from the treatment ladle would be around 280 m³/min. The combined capital and installation costs per foundry would be around EUR 180000.

The table below summarises the financial data for an ‘average foundry’, with the costs amortised over the presumed 10 year lifespan of the extraction and abatement equipment.

Extraction rate m³/min	Production rate tonne/h	Costs EUR		Power kW	Costs EUR/tonne of iron treated		
		Capital	Civil		Running	Financial	Total
280	0.5	180280	23514	50	21.95	29.35	51.30
	(1000 tonnes per year)						
Note: Civil costs are taken as 15 % of capital costs. Running costs are based on maintenance and waste disposal costs and are equivalent to 10 % of capital costs and power at EUR 0.06/kWh. Financial costs are based on the plant being amortised over ten years with interest charges of 10 %							

Table 4.46: Cost calculation for MgO fume abatement
[161, UK Environment Agency, 2002]

The costs for abatement of the magnesium oxide fume emissions are estimated at about EUR 51.30 per tonne of metal treated.

Driving force for implementation
Regulations limiting visible emissions and workplace atmosphere quality measures.

Example plants
- Römheld & Moelle – Mainz (D)
- Fuchosa – Atxondo (E).

Reference literature
[161, UK Environment Agency, 2002], [110, Vito, 2001]

4.5.8 Mould and core-making

4.5.8.1 Exhaust capture of dust from green sand preparation (sand plant) and dedusting

Description
Only a few of the different green sand preparation stages cause significant dust generation, namely the vibrating screen, dedusting and cooling process stages. These stages are equipped with dust capture and treatment. The units are enclosed and connected to a centralised dedusting unit. The set-up of the dedusting system has to take account of the dew point of the exhaust air and the type of dust.

The exhaust air from the green sand preparation is saturated with water. Therefore, wet systems (often of the low pressure type) seem to be most suitable for exhaust capture. However, the wet system is widely being replaced by dry dust abatement. The latter has the advantage that part of the dust may be recirculated and that no waste water stream is generated. Additionally, the wet systems are prone to internal corrosion and the build-up of dust and oxidation products. The wet separation of exhausted air impurities can result in problems for the waste water cleaning. Dust contains bentonite which is difficult to dispose of due to its anti-sedimentable effects. [225, TWG, 2003]

When applying fabric filters, condensation problems need to be prevented. Condensation may cause a deposition of dust, clogging and/or a tearing of the filter. The addition of cooling water to the sand needs to be done in a controlled way in order to minimise steam formation. The dew point of the airflow may be increased through heating with gas burners.

One benefit is that the collected dust is dry and so can be easily transported. After size separation, the coarse fraction and part of the fine fraction may be recirculated into the sand mixing.

Achieved environmental benefits
Reduction of dust emissions to air.

Cross-media effects
The use of wet systems cause the production of a waste water flow. Which needs to be treated, a sludge fraction, which needs to be a disposed of. Some systems work without producing waste water. The sludge is thickened and, if it contains a sufficient amount of bentonite, is re-used in the moulding-sand cycle.

Operational data
Using fabric filter equipment, a residual concentration well below 10 mg dust/Nm^3 in the exhaust air can be achieved. For wet scrubbers, the efficiency is slightly less, normally resulting in emission levels of 50 – 100 mg dust/Nm^3, though lower values have also been reported (see also Table 4.47)

Equipment	Exhaust gas flow (m^3/h)	Abatement technique	Emission level (mg/m^3)
Sand preparation 160 tonne/hour	64000	Venturi	4
Sand preparation 11 tonne/hour	48080	Wet scrubber	7
Sand preparation	57400	Bag filter	6
Shake-out unit	51070	Wet scrubber	7
Shake-out unit	50000	Bag filter	2
Grinding	54000	Bag filter	5
Shot blasting	17000	Bag filter	4

Table 4.47: Dust emission values from moulding and post casting shops [29, Batz, 1986]

Continuous monitoring data for a large-scale automotive foundry are given in Annex 2. These data show dust monitoring for sand preparation, sand transport and shot blasting.

Applicability
This technique is applicable to new and existing green sand preparation plants.

Driving force for implementation
Regulation of dust emissions.

Example plants
Generally applied throughout Europe.

Reference literature
[29, Batz, 1986], [32, CAEF, 1997], [110, Vito, 2001], [225, TWG, 2003]

4.5.8.2 Exhaust capture of dust from the green sand moulding shop work area and from dedusting

4.5.8.3 Exhaust capture from core-making – general considerations

The type of binder and hardener used will determine the type of emissions that occur. The exhaust gas from core-making with chemical binders consists mainly of a mixture of organic solvents. Emissions of phenol, formaldehyde, or ammoniac etc. are much smaller and depend on the binder type. Mixing, core shooting and drying can be enclosed to varying degrees, depending on the emissions occurring. Various binder-specific techniques apply, and these are discussed in the subsequent sections. Volatile organic carbon emissions occur with all chemically-bonded sand types, except for water glass sands. For self-setting and cold-setting

binders, the emissions during mixing are low, given the low resin usage (1 – 2 % resin:sand ratio). The emissions during hardening, coating and drying can be considered for capture and treatment.

Upon regeneration of the chemically-bonded sand, dust generation occurs in the shake-out drum. Sand cooling and dedusting is generally performed in a dry unit, since there are no problems with water condensation. It is not possible to recirculate the dust. [110, Vito, 2001]

4.5.8.4 Cold-box: capture of amine vapour and exhaust treatment

Description
The gassing of cold-box cores produces off-gases that need cleaning before emission into the atmosphere. In order to safeguard the working atmosphere, the core shooting machines are enclosed and cores are flushed with air to remove all the gas residues before the machine is opened up to take out the freshly made core.

Exhaust capture systems may be installed to secure good working conditions during the checking, handling and storage of the freshly made cores. For this, hoods or evacuation systems are installed, for example at the checking table, above the handling area and above the temporary storage area (the waiting area for the tray of ready cores).

The exhausted amine vapour requires treatment to prevent an odour nuisance. One of the following methods may be used:
- *Adsorption on activated carbon*: This process is very efficient, but the operational costs are excessive, so it may only be feasible if the exhausted volume is small
- *Combustion*: For this process to be efficient, the afterburner chamber must be correctly designed, to ensure a temperature of at least 800 ºC, with a minimum dwell time of 2 seconds. Energy consumption is high and the process is therefore expensive to operate. In foundries operating a cupola furnace, the exhaust gas may be fed to the cupola for combustion
- *Chemical scrubbing*: Amines are strong bases, and react with sulphuric or phosphoric acid. The pH of the solution is normally controlled to below 3. As a consequence, the scrubbing solution is replaced from time to time to remove concentrated salts, which subsequently require disposal as a hazardous waste. It is technically possible to process the scrubbing solution to reclaim the amine for re-use. This is discussed in Section 4.6.5
- *Biofilter:* See Section 4.5.8.6.

In winter, it may be necessary to heat the exhaust air in order to prevent amine condensation inside the ductwork. This may be done using waste heat from compressors or from other nearby devices.

Achieved environmental benefits
Exhaust capture allowing a reduction in amine emissions and related odour emissions.

Cross-media effects
When using acid scrubbers, the amine is transferred to the scrubbing solution, which then needs further treatment. However, recovery of the amine from the solution is possible. This is discussed in Section 4.6.5.

Operational data
Whatever the treatment method applied, amine emissions can be kept lower than 5 mg/Nm^3.

Emission data for a cold-box core-making shop using an acid scrubber are given in Table 4.48. The scrubber uses a 75 % phospohoric acid solution. In normal operation, 15 kg amine is disposed per day through the scrubber solution. The solution is saturated and stored in a tank for external treatment or disposal. The installation operates at 35.5 kW power and for 2000 h/yr.

Compound	Emission level mg/m³
Dust	0.42
Amine	2.4
Phenol	0.53
Oxygen	21 %
Exhaust gas volume	25100 m³/h

Table 4.48: Emission data for a cold-box core-making shop, using an acid scrubber [29, Batz, 1986]

Applicability
The technique applies for all existing and new cold-box core-making shops.

Economics
Operational costs for the installation mentioned in the 'operational data' section are EUR 6.3/tonne good casting.

The investment cost for an example installation, using a wet scrubber is given in Table 4.49.

Property	Value
Exhaust airflow	30000 m^3/h
Crude gas amine concentration	150 mg amine/Nm^3
Cleaned gas amine concentration	<1 mg amine/Nm^3
Power supply	45 kW
Investment cost	EUR 187000

Table 4.49: Specification and investment cost for an amine scrubber on cold-box core-shop exhaust data for Portugal, 2003

Driving force for implementation
To ensure workers health and to prevent odour emissions.

Example plants
The technique is generally applied for foundries using cold-box binders.

Reference literature
[29, Batz, 1986], [32, CAEF, 1997], [15, Gwiasda, 1984]

4.5.8.5 VOC-collection and removal

Description
VOC emissions (mainly solvents, BTEX, and to a lesser extent phenol, formaldehyde, etc.) result from chemically-bonded sand preparation and also, further along the process, from pouring, cooling and shake-out (see Table 3.35 and Table 3.45). These compounds are noxious and generate odour emissions.

The abatement of VOCs is hindered by the fact that large volumes of ambient air are entrained by the collection systems (e.g. canopy hoods) used.

The following techniques are applicable for the removal of VOCs:
- adsorption to activated carbon
- post combustion
- biofilter.

For adsorption to activated carbon, the exhaust gas flows through a carbon bed. Upon saturation, the carbon is thermally regenerated. Activated carbon has a very high adsorption (and abatement) efficiency. For benzene, the efficiency is >99 %. Nevertheless, it has the following disadvantages:

- the high flue-gas volumes require large amounts of activated carbon
- dust and aerosols need to be filtered out of the off-gas before the carbon adsorption. Since very fine dust particles show a tendency to stick, the filtering is only possible using wet dedusting techniques and this thus generates a waste water flow.

To successfully exploit post combustion to eliminate VOCs from off-gases, specific minimum concentrations are necessary. These limit values are compound specific and depend on the chosen technique. Post combustion is possible for the exhaust gas from shell moulding. Generally, the exhaust gas from the casting shop does not have high enough VOC levels to operate post combustion. One alternative to post combustion is to use exhaust air from the core blowers as combustion air for the cupola.

The use of biofilters is discussed in detail in Section 4.5.8.6.

Achieved environmental benefits
Reduction of VOC-emissions to air.

Cross-media effects
Energy is consumed in the collection of the off-gas flow, which may also involve entraining large volumes of ambient air.

Driving force for implementation
Legislation on the emissions of VOC.

Reference literature
[20, Gapp, 1998], [110, Vito, 2001]

4.5.8.6 Exhaust gas cleaning using biofilter

Description
Biofiltration is based on the ability of microbes living in a fibre-peat filter bed to oxygenate malodorous gases and convert them into odourless compounds. The gas to be purified is blown by a fan through a bed of humid filter material, exiting odourless from the upper side. The odorous compounds are adsorbed in the water phase and are decomposed by micro-organisms living on the filter material. The good performance of the filter depends on the balance between the supply of nutrient (compounds for abatement/decomposition) and the number of micro-organisms.

In foundries, biofilters are applied for the removal of odorous gases, which mainly consist of amines from the off-gas from cold-box core-making processes and for the removal of VOCs (e.g. benzene) from casting shop exhaust gases.

Critical parameters for good functioning of the biofilter are:

- *Permeability of the filter layer*: Gases need to flow through the bed in good contact with the filter bed material. An excess of fine material in the filter bed may cause clogging, pressure build-up and blowout of bed material
- *Wetting of the filter medium*: A water dispersion system may be installed for continuous or intermittent wetting of the bed material
- *Conditioning of the exhaust gas*: The exhaust gases need to be moistened before entering the filter. For optimum operation, a constant temperature (30 ºC) has to be maintained. This may require preheating of the exhaust gas

- *Adequate water treatment*: The biofilter produces residual water, containing phenol and cresol. This is treated in a waste water system before disposal or re-circulation. Re-circulation requires an additional salt removal step.

Introduction of the biofilter technique into a German foundry required a long optimisation period, until it was able to function satisfactory. It was found that the following characteristics appear to be important:

- closure of the biofilter beds with a lid, in order to prevent CO- and condensation problems throughout the installation. The filtered air is evacuated through a centralised chimney
- close control of water quality (e.g. salt content), especially when applying a system not producing waste water
- the addition of nutrient salts to the sprinkling water, to maintain bed activity, and
- control of the pH-value of the bed material and the addition of lime to maintain a neutral pH-value.

Achieved environmental benefits

Reduction of odourous, amine and/or VOC emissions from the core shop and casting shop. The elimination of benzene and other VOCs takes place in biofilters but may not be regarded as reliable. The efficiency varies remarkably according to a wide spectrum of factors, such as weather conditions, age of substrates, etc. The use of biofílters alone is therefore not valid as a stand-alone technique for the reduction of VOCs. Their main purpose consists in the reduction of odour.

Cross-media effects

The biofilter produces a waste water flow. This may be re-circulated internally after treatment, yielding a sludge cake for disposal.

Energy is consumed during the transfer of the off-gas to and through the filter, as well as for the surrounding equipment.

It has been reported that emissions of N_2O, a greenhouse gas, may be a problem.

Operational data

Pilot scale data for amine removal have been provided by Finland. A biofilter unit (diameter 0.8 m, height 1 m) was installed in a core-making off-gas line, after an acid scrubber. The equipment included a fan and a dewing unit, with which the dampness of the biofiltration unit was adjusted to an optimum level. The odour removal was measured using an olfactometer. Results for the odour and total hydrocarbon levels are given in Table 4.50. Variations in the input analysis are due to process variations. The results show that filtration results in a significant odour and hydrocarbon reduction.

Compound	Units	Before biofilter	After biofilter
Odour	OU/m³	410 – 3000	150 – 310
Total hydrocarbons	mg C/m³	20 – 35	5 – 10
OU = Odour units			

Table 4.50: Operational data for the biofiltration of a cold-box core-making off-gas [112, Salminen and Salmi, 1999]

Industrial scale data for VOC removal have been provided by Germany. A biofilter unit (specification: surface 300 m³, height 1 m, in 5 rectangular beds, with a total throughput of 32330 Nm³/h dry gas) was installed for the treatment of exhaust gases from pouring and cooling in a green sand cast-iron foundry, using croning and cold-box cores. The emission data are given in Table 4.51. Olfactometric measurements showed an average reduction of odour emissions by a factor of 94.5 %.

Parameter	Units	Before biofilter	After biofilter	Reduction %
O_2	%	20.74		
CO_2	%	0.17		
NO_x	mg/m³	3.65		
CO	mg/m³	382	299	21.7
Benzene	mg/m³	15.80	1.44	90.9
Toluene	mg/m³	9.37	0.92	90.1
Ethylbenzene	mg/m³	3.00	0.46	84.7
Xylene	mg/m³	4.90	1.54	68.6
Formaldehyde	mg/m³	0.37	0.01	68.6
Dust	mg/m³	13.63	2.03	85.1
Ammonia	mg/m³	8.97	0.16	98.2
Phenol	mg/m³	4.67	<0.02	>99.6
Cresol	mg/m³	3.73	<0.02	>99.5
PCDD/F	ng/m³	0.0056	0.0041	26.8
Benzo(a)pyrene)	mg/m³	0.0001	0.00003	70.0

Table 4.51: Emission data for the biofiltration of exhaust from green sand pouring and a cooling line
[20, Gapp, 1998]

Applicability
This technique finds its application in green sand foundries and cold-box core-making shops. The applicability is limited to 3-shift large series casting foundries, as biofilters need very stable conditions throughout the year. It should be noted in each known case of application great individual efforts of research and development have been required to achieve an acceptable performance.

Economics
Investment costs for the biofilter unit in the German example (specification: surface 300 m³, height 1 m, in 5 rectangular beds, with a total throughput of 32330 Nm³/h dry gas), including a water treatment unit to allow operation without the production of waste water, have been estimated at EUR 3247000. This includes EUR 2333000 for the filter and surrounding equipment and EUR 914000 for the exhaust capture and ductwork. With a design load of 40000 Nm³/h, operational costs are estimated at EUR 170000/yr (costs based on DEM for 1998).

These estimated operational costs are much higher than generally stated investment and operational costs for biofilter units. This is probably due to the large throughput and the extent of the surrounding equipment. In a 1998 paper the cost for an open-bed biofilter, treating 17000 Nm³/h was estimated at USD 70000 – USD 100000 for investment and a yearly operating cost for water, labour and overheads of USD 15000 – USD 25000.

Driving force for implementation
Reduction of nuisance effects (mainly odour) on neighbouring locations.

Example plants
Halberg Guss, Saarbrücken-Brebach (D)

Reference literature
[20, Gapp, 1998], [112, Salminen and Salmi, 1999], [202, TWG, 2002], [208, Devinny, 1998]

4.5.8.7 Permanent moulding: collection of release agent emissions

Description
The spraying of a water-based release agent on HPDC dies generates a mist with low concentrations of decomposition products. The mist is collected using a suction hood and an EP.

Achieved environmental benefits
Reduction in the emission of release agent containing organic compounds. Prevention of diffuse emissions.

Cross-media effects
Capture and collection of the mist requires the consumption of energy.

Operational data
Operational data from an example plant are given in Table 4.52. The data refer to a water miscible release agent (1:40 dilution factor), based on synthetic polymer and polysiloxane. Each die-casting machine is equipped with a separate suction hood and an EP. The hot and cleaned air is blown back into the hall (i.e. for heat recovery).

Compound	Half hour measured values (mg/Nm^3)	Mass – flow (g/h)
Dust	1.5 – 4.3	5.5
Organic substances (values in total carbon) (mg/m^3)	4 -6	9

Table 4.52: Emission data from EP-cleaned HPDC off-gas [202, TWG, 2002]

Applicability
This technique applies to existing installations. It is an end-of-pipe measure, applied in cases where prevention or minimisation of the mist has failed. Prevention and minimisation measures are discussed in Section 4.3.5.1.

Driving force for implementation
Minimisation of diffuse emissions and legislation on the emission of oil mist (e.g. in Sweden).

Example plants
Reference plant: TCG Unitech, Kirchdorf/Krems (A)
General practice for older die-casting machines (D, F, B,...) and for all die-casting machines in Italy.

Reference literature
[202, TWG, 2002], [225, TWG, 2003]

4.5.9 Casting/Cooling/Shake-out

4.5.9.1 Introduction

The emissions during pouring, cooling and shake-out are diverse and differ broadly in quality and quantity from one foundry to another. Basically, dust emissions are produced, as well as inorganic and organic gaseous compounds. These are mainly reaction products, caused by the high temperature and the reducing atmosphere upon pouring and cooling. The composition of pouring fumes is complex. They consist mainly of CO, CO_2, H_2, and methane as the main representatives of the organic decomposition products. Polycyclic aromatic hydrocarbons and benzene occur, depending on the composition of the mould- and core-system.

The capture and treatment of the off-gases of these process stages is generally possible for automated moulding and pouring installations. [29, Batz, 1986]

Relative emissions (as kg/t of molten metal) increase over the pouring-cooling-shake-out sequence. Exhaust capture efforts will need to take this variation into consideration.

4.5.9.2 Pouring and cooling lines encapsulation

Description
The collection of emissions during pouring, cooling, and shake-out is as a rule more extensive as the plant becomes bigger.

The further the pouring process can be restricted to a fixed area or position, the smaller the amount of extracted air will be, and the easier it will be to capture emissions with ventilators and housings, and therefore air-treatment can be carried out more effectively.

In serial pouring, the emissions increase with increasing production capacity. Without extraction, the air at the pouring plant could at some point reach unacceptable concentration levels of noxious substances. To lessen the pollution in the work area, extractor ventilators or extractor surfaces are fitted as close to the moulds as possible, but without hindering the pouring process. The extractor elements are arranged in such a way that all emissions occurring during pouring, are moved away from the work area to the extracting equipment. The air-speed at the free extraction cross-section is kept between 0.5 and 1 m/s.

Achieved environmental benefits
Reduction of diffuse emissions of CO, PAHs and other organic decomposition products.

Cross-media effects
Extraction of exhaust air consumes electrical energy.

Applicability
This technique is applicable to new and existing installations utilising serial pouring and cooling.

Driving force for implementation
Reduction of diffuse emissions. Collection of emissions in order to allow treatment.

Example plants
The technique is commonly applied in large-series foundries.

Reference literature
[32, CAEF, 1997]

4.5.9.3 Exhaust capture and treatment from shake-out

Description
The technique used for the emission collection from shake-out depends on the degree of mechanisation, the emissions to be extracted and the size range of the castings, in particular the smallest and largest item cast on the same machine.

The system of reducing emissions most commonly used is a ventilator panel on the side of the shaker. Usually, panels are installed on both sides of the shaker, regardless of the shaker size. If possible the rear of the shaker is enclosed in this way too. Frequently an extraction point is provided under the shaker in the sand-box, operating through a projecting pipe. This presents the risk of sand being extracted if the box is filled with sand up to the pipe. Moreover the pipe's inlet is often obstructed by sand lumps or adhering steam and dust.

The best way of achieving good emission levels with relatively small ventilation rates is when shake-out is performed in enclosed units. Roof openings, possibly with a moving screen, doors and entry/exit chutes make it possible to use a crane or other means of transport. In addition, the closed cabins reduce the noise level.

In automatic moulding plants, the casting-mould package is often pressed out of the moulding box by a hydraulic jack with a mounted pressing plate. Afterwards the casting is separated from the sand firstly on a jig-shaker and then to a rotating shake-out drum or tube or a sand cooler. Extraction drums or tube drums, which are now increasingly being used, are much more suited to the collection of emissions than the usual shakers, but they have the disadvantage of possible odour emissions.

The quantity of extracted air is not only determined by the workplace limit values required, but also by processing requirements. Large air volumes may be required for cooling and for protection of the filter bags. This needs to be balanced against the demands of any pollution abatement techniques, that usually need highly charged waste gases with small air volume streams in order to be effective.

Appropriate techniques for dedusting are cyclones combined with wet scrubbers or dry filters. Biofilters are also used and are discussed in Section 4.5.8.6.

For gravity die-casting and centrifugal casting, post combustion, chemical washing and adsorption to activated carbon are used in order to reduce organic emissions and odour. These systems have already been described above.

Achieved environmental benefits
Reduction of the emissions of VOC and dust to air.

Cross-media effects
Dust collection produces a residue for disposal.

Operational data
With free-standing extraction shakers up to 2 m in width, for every m^2 of shaker surface 7000 to 9000 Nm^3/h of air is extracted in the case of a one-sided ventilation screen. With a two-sided screen, 5000 Nm^3/h per m^2 of shaker surface is installed.

If the extraction point is under the shaker in the sand-box, the amount of air extracted per m^2 of shaker surface is designed to be about 700 Nm^3/h.

In a Polish example foundry for large-size cast steel castings, a removable doghouse type cover was constructed over the shake-out grate. The doghouse consists of two sideways moving doors, which are opened and closed hydraulically, as shown in Figure 4.17. The cover reduces dust and noise emissions into the foundry hall. The exhaust is cleaned using dry de-dusting. The noise level for shake-out was reduced from 100 dBA to below 85 dBA.

Figure 4.17: Doghouse cover for a shake-out grate, for large-size batch castings [209, Metalodlew s.a., 2003]

Applicability
In plants where clay-bonded sand moulds are shaken out, the emission of steam is significant. The combination of dust and steam can lead to huge obstructions in the ductwork if the temperature drops below the dew point or worse, below freezing point. To overcome this problem, hot air must be injected into the ducts and the piping and filter-housing must be insulated, or water (free of dust) must be sprayed into the ventilator piping to prevent these obstructions.

Economics
For the doghouse in the Polish example foundry, as mentioned above, the investment cost was EUR 220000, including some additional equipment.

Driving force for implementation
Regulations on the emission of VOC and dust.

Example plants
Metalodlew s.a., Krakow (PL)

Reference literature
[16, Gerber and Gwiasda, 1981], [32, CAEF, 1997], [209, Metalodlew s.a., 2003]

4.5.9.4 Off-gas cleaning using biofilter

Description
Biofilters are used to treat emissions of VOC and benzene and are therefore used for the treatment of off-gas from pouring, cooling and shake-out. The full description and discussion of the technique is given in Section 4.5.8.6.

Example plants
Several examples in Germany.

Reference literature
[225, TWG, 2003]

4.5.10 Finishing/post-casting operations: off-gas collection and treatment

4.5.10.1 Finishing off-gas collection

Description
Considerable amounts of fume have to be captured and extracted when using thermal separation techniques. The work area may be as enclosed as much as possible, but ensuring the freedom of movement and that the inhaled air supply of the worker can be assisted. Dust collection techniques during abrasive cutting and grinding are differentiated between stationary machines and hand machines. Rigid hoods are customary at stationary machines, partly in connection with partial housings.

For stationary grinding machines, the tightly limited abrasive blast goes into an extracting funnel and is extracted. In the case of abrasive cutting-off stations, it is sensible to additionally extract emissions from the cabin in the interest of worker's health and safety. Handheld machine emissions are occasionally extracted via the splint protection hood. This is an effective but unpopular method, as it increases the weight of the machine and impairs its manageability. Normally hand grinding and hand cutting-off machines are housed in cabins (i.e. partial housings).

Collection of the dust takes place via extracting walls, roof domes, moveable hoods or extraction work benches. An effective aid when collecting emissions are hot-air curtains which direct additional air into the cabin. The additional air used may be cleaned recycled extraction air, in order to economise on heating energy. However, it should be noted, that a portion of fresh air will still always need to be provided from the outside.

Dust or pollutant collection is in most cases not needed for sawing, rapping, pressing, chiselling, stamping and milling. Screens may sometimes be used to protect the operator against rough particles. Welding is divided into processes with and without additional materials. Work protection regulations requiring extraction exist for most processes.

Achieved environmental benefits
Reduction of diffuse emissions of metallic particles and dust.

Cross-media effects
The collection and extraction of dust-laden off-gas consumes energy.

Operational data
Operational data have been given in Section 3.11 and show that emission from cutting, scarfing and welding (without off-gas cleaning) are low compared to those for fettling and shot blasting.

Applicability
As indicated in Table 4.53, some finishing techniques do not generate dust and consequently do not necessitate an off-gas collection system.

	Roof ventilation	Dome-shaped roof	Rigid hood	Adjustable hood	Housing
Abrasive cutting			x	x	x
Burning	x	x	x	x	x
Chiselling, needling	Off-gas collection seldom necessary				
Fettling		x	x	x	x
Milling	No off-gas collection necessary				
Rapping, pressing	No off-gas collection necessary				
Sawing	No off-gas collection necessary				
Slide grinding	x	x	x	x	x
Shot blasting					x
Stamping	No off-gas collection necessary				
Welding	x		x	x	x

Table 4.53: Applicability of dust capture techniques for various finishing operations [32, CAEF, 1997], [225, TWG, 2003]

Driving force for implementation
Regulations on dust emissions and occupational health and safety.

Example plants
The technique is applied in the vast majority of the European foundries.

Reference literature
[32, CAEF, 1997]

4.5.10.2 Exhaust air cleaning techniques

Description
- *Blasting:* Blasting generates a lot of dust. Off-gas capture is unproblematic due to the total enclosure of the blasting process in a closed cabin. Customary exhaust air decontamination processes are wet washing and dry filters, usually with a cyclone as a pre-filter
- *Slide grinding, drumming:* Both processes do not require emission reduction in normal conditions. Aerosols that can form in quickly moving drums can be neglected
- *Cutting:* All thermal separation processes generate emissions. Exhaust capture is achieved through enclosing the work place and carrying out an intensive extraction of the arising fume. It is important to place the capture elements as close as possible to the emission source, but without hindering the operating process. In some cases it has proven beneficial to combine a mobile arm for direct extraction and additional cabin extraction. By carefully arranging the extraction elements, the dust-filled air can be guided away from the breathing area of the worker. The usual exhaust air decontamination processes are wet washing and dry filters. It should be noted that the systems are set up for the smaller grain sizes of the emitted fumes. Inertia force separators are applied as pre-separators
- *Abrasive cutting*: Stationary abrasive cutting installations are extracted. Customary exhaust air decontamination processes are cyclones, wet washing and dry filters
- *Sawing, rapping, pressing*: These handling processes cause few emissions and do not require reduction measures in normal conditions
- *Chiselling, needling*: In these processes mainly coarse particles are produced which are difficult to remove through extraction. The work is mainly carried out in cabins for safety reasons. In special cases, e.g. when removing burnt-on sand, the generated dust may be extracted by an extraction arm. The exhaust air is decontaminated in cyclones, wet washing and dry filters

- *Grinding*: Emission capture when grinding on stationary machines takes place in a similar way as with abrasive cutting, i.e. via fixed funnels into which the abrasive blast is directed. An enclosed work place is used for manual grinding and abrasive cutting. Extraction walls can then be applied in the housing. Air decontamination processes are cyclones, wet washing and dry filters
- *Stamping, milling*: These handling processes cause few emissions and do not require reduction measures in normal conditions
- *Welding*: More or less emissions occur according to the type of the selected welding process, which is usually be best collected by extraction arms. For exhaust air cleaning, wet washing and dry filters and occasionally electrostatic filters are used.

Achieved environmental benefits
Reduction of dust emissions.

Cross-media effects
The extraction and cleaning of dust-laden off-gas consumes energy.

Operational data
Wet scrubbers and fabric filters have been installed and operated successfully for many years. Fettling cabins with high-efficient dust arrestment units can be run stackless, as their output is cleaner than the usual fettling shop air. They also help to improve workplace conditions.

Operational data is given in Section 3.11 and show that emission factors for cutting, scarfing and welding (without off-gas cleaning) are low, as compared to those for fettling and shot blasting.

Using fabric filter equipment, emission levels below 10 mg dust/Nm^3 can be achieved.
Using wet dust removal systems, emission levels below 20 mg dust/Nm^3 can be achieved.

Applicability
These techniques apply to new and existing foundries. In general, non-ferrous foundries do not apply intensive (dust generating) finishing operations.

Driving force for implementation
Regulations on dust emissions and occupational health and safety.

Example plants
The technique is applied in the vast majority of the European foundries.

Reference literature
[32, CAEF, 1997], [180, Assofond, 2002]

4.5.11 Heat treatment waste gas collection and cleaning

4.5.11.1 Use of clean fuels in burner-heated heat treatment furnaces

Description
A basic process-integrated measure for emission reduction in burner-heated heat treatment furnaces is the use of clean fuels i.e. natural gas or low-level sulphur content fuel.

Additionally, automated furnace operation allows close control of the working regime and temperature and minimises excessive energy consumption.

Achieved environmental benefits
Reduction of combustion-based pollutants, such as CO, SO_2, NO_x.

Cross-media effects
No cross-media effects apply.

Operational data
In an example foundry in Poland, up to 1998 the heat treatment was performed in 3 coal gas furnaces with manually controlled burners. The coal gas came direct from the coke oven and was of a variable quality (e.g. CO-content up to 15%). This resulted in high emissions and the risk of intoxication, together with a poor control of the temperature profile.

In 1998, 2 of the 3 furnaces were newly equipped with computer controlled natural gas burners. Additionally the furnace lining was renewed. The results of these changes on the operation were:
- automated control of the temperature profile
- 40 % reduction of gas consumption (volume)
- reduction in cost due to the use of cheaper natural gas
- reduction of emissions of SO_2, NO_x, CO and aromatics (see Table 4.54).

Compound	Coke oven gas burners		Natural gas burners	
	Concentration (g/Nm³)	Emission (kg/h)	Concentration (g/Nm³)	Emission (kg/h)
CO	0.006	0.074	0.000	0.000
SO_2	0.011	0.136	0.003	0.064
NO_x	0.016	0.197	0.004	0.085
Aromatics	0.001	0.012	0.00025	0.0054

Table 4.54: Emission levels from a heat treatment furnace before and after conversion to natural gas burners system

Applicability
This technique applies to burner-fired heat treatment furnaces.

Driving force for implementation
Regulation of emissions of SO_2, NO_x, CO.

Example plants
Metalodlew, Krakow (PL)

Reference literature
[32, CAEF, 1997]

4.5.11.2 Quenching baths

Description
Here, emission capture and reduction essentially involves the capture of fume at the quenching baths, especially at the oil quenching baths. Roof ventilation, extraction domes and edge extractors are used. Here similar difficulties arise as with shake-out grids. The baths must be frequently loaded by a crane, so the extraction hoods need to be installed high above the hall floor.

Abatement systems are not widely applied at this pointin general, but if any abatement is performed, electrostatic filters are mostly used.

Achieved environmental benefits
Reduction of diffuse emissions of oil-mists.

Cross-media effects
Exhaust extraction consumes energy.

Applicability
The applicable techniques for different types of baths are characterised in Table 4.55.

	Roof ventilation	Dome-shaped roof	Dome, rigid	Dome, adjustable	Edge extraction
Water	x				
Emulsion	x	x	x	x	x
Hardening oil	x	x	x	x	x
Note: x : applicable					

Table 4.55: Applicability of fume collection techniques for quenching baths [32, CAEF, 1997]

Edge extractors are only effective up to a certain size and lose their effectiveness almost completely at the time of the highest emissions, i.e. when a hot workpiece is submerged in the bath. In spite of this, edge extraction is the most sensible capture measure, utilising big baths combined with a blast veil and a roof dome.

Driving force for implementation
Regulations on emissions and occupational health and safety.

Example plants
The technique is used in several foundries around Europe.

Reference literature
[32, CAEF, 1997]

4.6 Waste water prevention and treatment

4.6.1 Measures to prevent the generation of waste water

Description
The following measures result in a marked reduction in waste water:

- *Use of dry dedusting systems:* Dry dedusting systems can be used for most foundry exhaust gas flows. However, in exceptional cases, it may be necessary to use a wet scrubber for removal of iron-containing ultra-fine dust fractions. The applicabilities of dry and wet exhaust cleaning techniques are discussed in Section 4.5
- *Biological waste gas scrubbers or compost filters:* The use of a biological waste gas scrubber can be considered if the gases to be treated contain readily biodegradable substances such as phenols, etc. Biological scrubbers generate less waste water than conventional wet scrubbers because biologically treated waste water can be recirculated more often.
  Note: Compost filters (biofilters) do not generate any waste water, although the compost material must be sufficiently moist. The technique of biofiltration is discussed in Section 4.5.8.6
- *Internal recycling of process water:* An extensive recycling of scrubbing water requires the use of treatment facilities. These include sedimentation tanks, possibly with an integrated flocculation stage, and filtration equipment. Depending on the process, cooling may be necessary. Evaporation losses and substance inputs from gas scrubbing lead to an accumulation of salt in the circulating water. Depending on the salt concentration and the applicable discharge limit values (in the case of indirect discharge), circulating water may have to be drawn off. It may be economically favourable to evaporate this waste water and to use the condensate to make up evaporation losses

- *Multiple use of treated waste water:* Multiple use of treated waste water needs to be considered, e.g. using process water from sand preparation in the moulding sand cycle or in slag granulation. The use of cooling water in wet scrubbing may also be considered
- *Use of waste heat for the evaporation of waste water:* This technique can only be applied when waste heat is available on a continuous basis. A case-by-case evaluation is needed to evaluate its applicability and economic viability
- *Prevention of waste water from scrap storage:* The generation of waste water from the storage of contaminated scrap can be prevented by roofing the storage area. The run-off water is collected as uncontaminated rainwater. All techniques for storage are discussed in Section 4.1
- *Avoidance of AOX formation in waste water:* Careful selection of scrap types can prevent the uptake of chlorinated compounds in the production cycle. Analyses for AOX compounds prior to scrap purchase are a helpful measure. AOX may also be contained in auxiliaries used in waste water treatment, e.g. commercial-grade hydrochloric acid, iron chloride or aluminium chloride
- *Keep water types separate:*Various water flows with distinct pollutant levels are kept separate, in order to minimise the need for waste water treatment and to optimise the water use.

Achieved environmental benefits
Prevention of the production of waste water.

Cross-media effects
Cross-media effects may apply, depending on the chosen technique. Information is given in the specified sections.

Operational data
Operational data are given in the description of the example plant in Section 4.6.3.

The waste water system of an example aluminium foundry consists of 4 separate flows:
- surface run-off: this joins to the central rainwater channel, through an oil separator (2xNG80), and onto a nearby river
- used water = process water (open cooling baths) and sanitary water: this goes through an open air channel on site, into a public channel and then onto the public sewage works of the town
- cooling water: this is initially taken from the nearby river, over a sand filter, and goes through the installation in a closed percolation cooling circuit, and then back to the river, with a temperature limited to 28 ºC. Roof water also enters the cooling water circuit
- water from off-gas scrubbers (green sand, post casting): this is partially evaporated, so that only the remaining sludge leaves the installation.

Applicability
This technique applies to all new and existing installations.

Economics
Economic data are given in the specified sections for alternative techniques and in the ‘Example plants’ section of Section 4.6.3.

Driving force for implementation
Minimisation of waste water production.

Example plants
Honsel, Meschede (D)

Reference literature
[195, UBA, 2003]

4.6.2 Treatment of scrubbing water and other waste water flows

Description
For furnace gas cleaning, dry filtration systems eliminate potential waste water streams, however with a wet cleaning system there is no need for an aqueous discharge if appropriate measures are taken to clean the water and recycle it. As long as solids are removed to a level acceptable to the scrubbing device, soluble compounds can normally be allowed to reach saturation without any adverse effects. There are a variety of techniques, or combinations thereof, which could adequately separate the solids.

The following treatment techniques are applied:
- sedimentation
- hydroxide precipitation
- multi-stage precipitation
- wet oxidation
- filtration procedures.

The waste water can contain undissolved and dissolved heavy metals, phenols and cyanides. The treatment needs to be adapted to the type of pollutants.

Undissolved heavy metals have to be removed from waste water by physical methods (sedimentation, filtration, possibly flotation). Concentrations well below 0.5 mg/l can be achieved by the use of these methods.

Dissolved heavy metals must first be transformed into poorly soluble compounds using suitable precipitants. Especially strong bases (lime milk, caustic soda solution, soda) are used as precipitants for hydroxide precipitation. If this is not sufficient, sulphide precipitation with organic sulphides or alkali sulphides must be carried out.

Phenols and **cyanides** can be biologically degraded or removed by physical-chemical treatment. Normally they are present in such low concentrations that there is no need for targeted pretreatment. Combined treatment in a sufficiently large biological waste water treatment plant is sufficient.

Achieved environmental benefits
Reduction of the pollutant load in discharged waste water.

Cross-media effects
Waste water treatment generates a sludge fraction for disposal.

Operational data
Waste water from foundries mainly contains zinc, in addition to iron. Hydroxide precipitation in a pH range of 8.5 to 11 can reduce the zinc concentration to values below 2 mg/l. This pH range must be respected, because at a pH in excess of this range amphoteric zinc is re-dissolved, in the form of zincates.

By way of example, Figure 4.18 shows the combined conditioning and precipitation reaction of non-dewatered sludge from wet scrubbers of cupola furnaces. Following removal from the wet scrubber's water treatment system, the sludge is conditioned in a separate treatment stage using caustic lime. This results in an increase in the pH value and the precipitation of heavy metals. Organic pollutants are also adsorbed. The sludge is subsequently dewatered in a chamber filter press. Following turbidity measurements, the filtrate is passed to a storage tank incorporating a monitoring of pH and conductivity. Depending on its condition and actual needs, the filtrate is returned to the sludge silo, sent to slag granulation or sent for dry dust humidification via equalising tanks, or discharged to drain as surplus (following the requirements for discharge to a municipal waste water treatment plant).

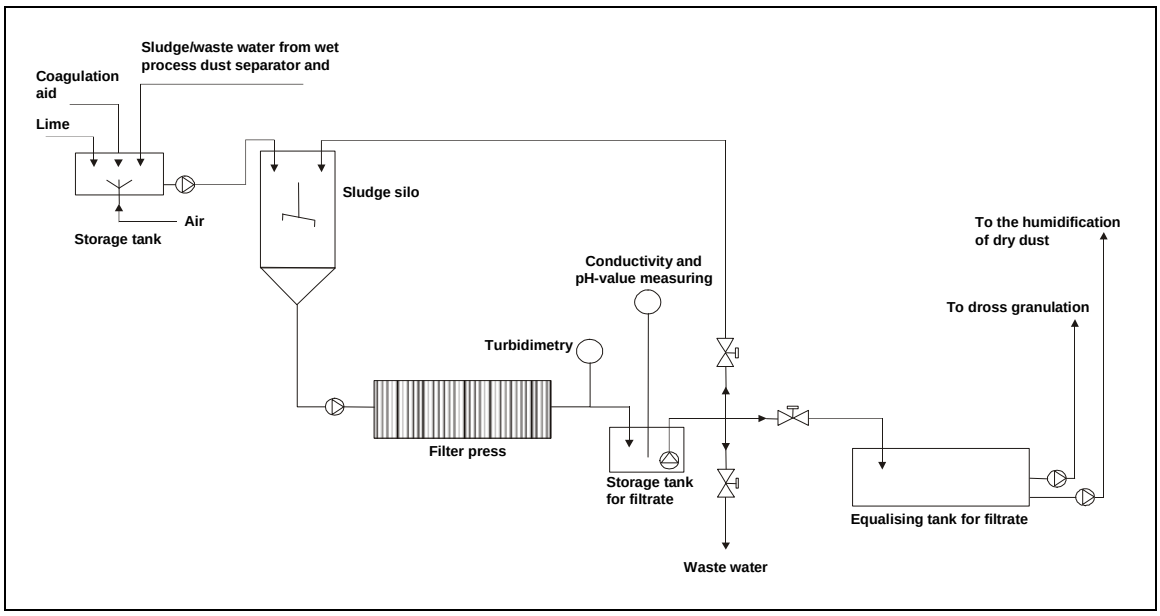

Figure 4.18: Treatment of waste water and sludge from the wet de-dusting system of a cupola furnace
[195, UBA, 2003]

Additional operational data are given in the description of the example plant in Section 4.6.3.

Applicability
The type of waste water treatment to be applied needs to be selected on the basis of the waste water composition and the local conditions for disposal of water from the plant into the receiving water medium.

Economics
Economic data are given in the description of the example plant in Section 4.6.3.

Driving force for implementation
Regulations for pollutants discharge into water.

Example plants
See Section 4.6.3

Reference literature
[195, UBA, 2003], [160, UK Environment Agency, 2002]

4.6.3 Example plant for waste water prevention and reduction

Description
A German example plant produces parts from cast iron (grey and nodular cast iron) and die-cast aluminium.
The following operations are carried out:
- *Melting:* Gas-fired melting furnaces and flue-gas treatment plant (dry filter)
- *Manufacture of diecast parts:* Automated casting-punching cells for aluminium diecasting
- *Sand casting:* Manufacture of special alloys
- *Iron casting (core production):* For core production, the cold-box and Croning processes are used. Scrubbing concentrates are generated in amine scrubbing
- *Iron casting (melting):* The melting shop consists of a mixing plant, a hot blast cupola furnace, several electric furnaces, a converter and a holding furnace
- *Iron casting (moulding):* Use of lost moulds made of bentonite-bonded sand.

Production data and water consumption are given in Table 4.56.

Production	
Good iron castings, total	46710 t
Good non-ferrous metal castings, total	2355 t
Water consumption	
Drinking water (town water)	59630 m^3
Surface water/groundwater	64998 m^3

Table 4.56: Production and water consumption data (on yearly basis) for example foundry [195, UBA, 2003]

Wet scrubbers are applied where large volumes of waste gas containing relatively high concentrations of organic substances are generated (waste gas from core-making) or where high flue-gas temperatures occur (flue-gas from hot-blast cupola furnaces).

A schematic representation of the water circuit of the wet dedusting system is given in Figure 4.19. The waste gas from under-charge cupola flue-gas extraction is fed to a cyclone separator and a venturi scrubber for dedusting. The subsequent removal of gaseous pollutants is achieved in a packed bed scrubber. The waste water from the venturi scrubber is pretreated in a float and sink separator and then passed to a settling tank for secondary treatment. The scrubbing liquid from the packed tower is fed directly into the settling tank. The settled sludge from the settling tank can be pumped discontinuously to the float and sink separator. The sludge from the float and sink separator is pumped to a scraper conveyor, agglomerated by the addition of flocculants, and passed into a storage tank. From there, the sludge is fed to the sludge silo and is subsequently solidified in a mixing plant by the addition of dry dust.

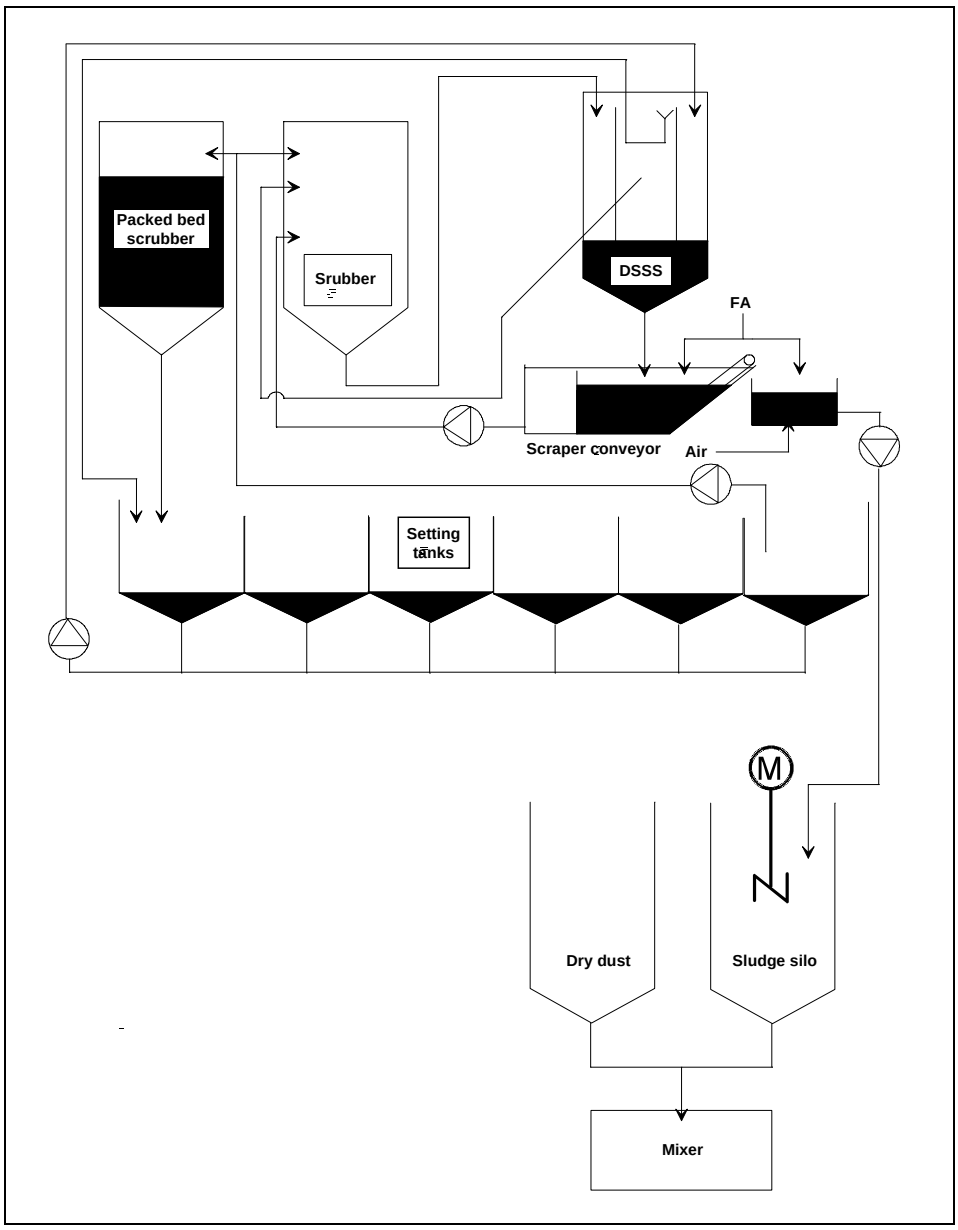

Figure 4.19: Water circuit for the wet dedusting system of a cupola furnace
DSSS: double shell sinking separator; FA: flocculant, M: motor
[195, UBA, 2003]

In this basic layout, the plant experienced some operational problems, due to salt accumulation and the low final water quality. An extension was made to the plant, with the aims of:

- increasing the settling velocity, by the use of other flocculants
- reducing the pollutant content in the scrubbing medium
- improving sludge dewatering
- re-using the scrubbing medium from the gas scrubbing cycle.

For this purpose, a chamber filter press with a volume of 2 m^3 and a sludge collection tank (30 m^3 in volume) with an agitator were installed. The sludge was passed from the scraper conveyor directly into the storage tank and preconditioned with lime.

During the trial phase, which lasted several months, it was found that approximately 25 kg of lime per batch were needed to achieve the best result in terms of dewatering and heavy metal removal. The average dry matter content was 70%. Analysis of the filtrate for heavy metals showed values in the range of detection limits. However, the relatively high sulphate concentrations of about 1 g/l posed a problem for re-use of the filtrate in the scrubbing cycle.

As a practicable alternative, the sludge treatment was further extended with other compounds as shown in Figure 4.20. The water/solids mixtures from wet scrubbing were pre-conditioned by the addition of flocculant and the resulting sludge was fed to a mixing tank by a scraper. Lime is added to the mixing tank in a quantity which needs to be determined previously through tests, and the sludge is fed to the sludge silo by a pump (pump P1 in Figure 4.20). Pump P2 pumps it to the filter press.

The filtrate is passed via a turbidity meter into a storage tank in which pH and conductivity are monitored. There are three possibilities for where it goes from there:
- via an equalising tank to slag granulation or dry dust humidification
- back to the sludge silo (if the turbidity limit is exceeded)
- to drain (emergency measure only).

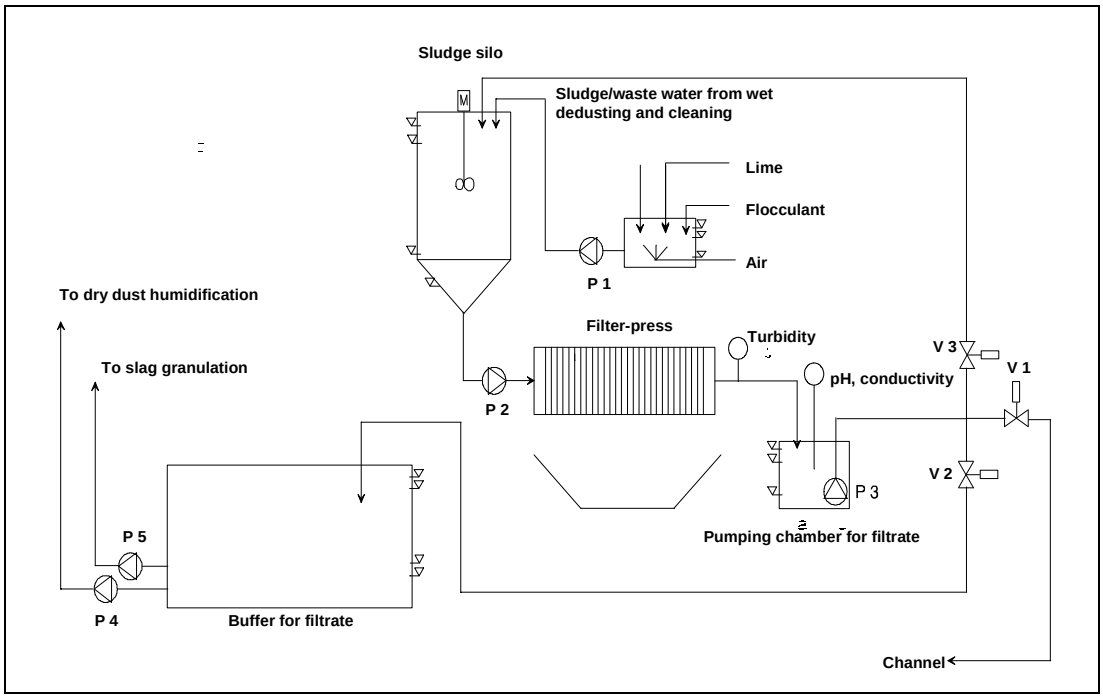

Figure 4.20: Treatment system for sludge from the wet dedusting of cupola flue-gas [195, UBA, 2003]

Economics

Economic data concerning the extension of the system with the sludge treatment are given in Table 4.57.

Before extension		After extension	
Generated sludge with a dry matter content of 30%	2000 t/yr	Generated sludge with a dry matter content of 70%	850 t/yr
Dry dust for sludge solidication	1100 t/yr	Dry dust for sludge solidication	0 t/yr
Landfill price	EUR 100/t	Landfill price	EUR 100/t
Disposal costs per year	**EUR 310000**		**EUR 85000**

Table 4.57: Disposal costs for the extension of a waste water system with sludge treatment [195, UBA, 2003]

The sludge with 70 % dry matter content does not need further stabilisation before disposal. For the wet sludge, a solidification with dry dust is needed. The saving in disposal costs is EUR 310000 – EUR 85000 = EUR 225000. This compares to an investment cost for the extension totalling EUR 175000 and an additional annual operating costs of about EUR 50000. The total cost saving therefore amounts to EUR 175000/yr, giving a 1-year payback period. The calculation does not include the cost savings from the re-use of the filtrate.

Example plants
Sach Giesserei GmbH, Kitzingen (D).

Reference literature
[195, UBA, 2003]

4.6.4 Oil interceptors

Description
Run-off from all open areas, but particularly from raw materials stocking areas, contain suspended solids, which can be removed by settlement or other techniques. Oil interceptors are used in draining scrap handling areas. Drainage sumps are designed with a sufficient size to handle storm-water and to accommodate any storm surge, in order to prevent carry-over of unsettled material.

Oil interceptors are used on waste water from permanent mould casting foundries. The hydraulic systems of die casting automates can potentially leak oil. The water collection system is thus designed in such a way that any oil from leakage is collected and the resulting waste water flow is treated using an oil interceptor.

Achieved environmental benefits
Prevention of water pollution.

Cross-media effects
Oil interception generates a residue for disposal.

Applicability
This technique applies to new and existing die-casting (permanent mould) foundries and to all other foundries with a waste water discharge directly to surface water.

Driving force for implementation
Regulations for pollutants discharge into water.

Example plants
Honsel, Meschede (D).

Reference literature
[160, UK Environment Agency, 2002]

4.6.5 Recovery of amine from scrubbing water

Description
When acid washing the cold-box exhaust gas, amine sulphate is formed (see Section 4.5.8.4). This amine may be recovered through neutralisation with sodium hydroxide, followed by distillation.

As shown in Figure 4.21, the salt that is formed from tertiary amine (e.g. DMEA, DMIA and triethanolamine (TEA)) in the acid scrubber, and the scrubbing acid (e.g. sulphuric acid) are retransformed by reaction with a strong base (e.g. caustic soda solution), thereby forming free amine and e.g. sodium sulphate. The amine is expelled with water vapour and is then cleaned and concentrated in a column, to an extent that allows it to be re-used. The sodium sulphate solution (together with polluted scrubbing solution) can be recovered or may be disposed of.
If the amine is not recycled, the scrubbing concentrates can be treated in a biological waste water treatment plant with nitrogen elimination.

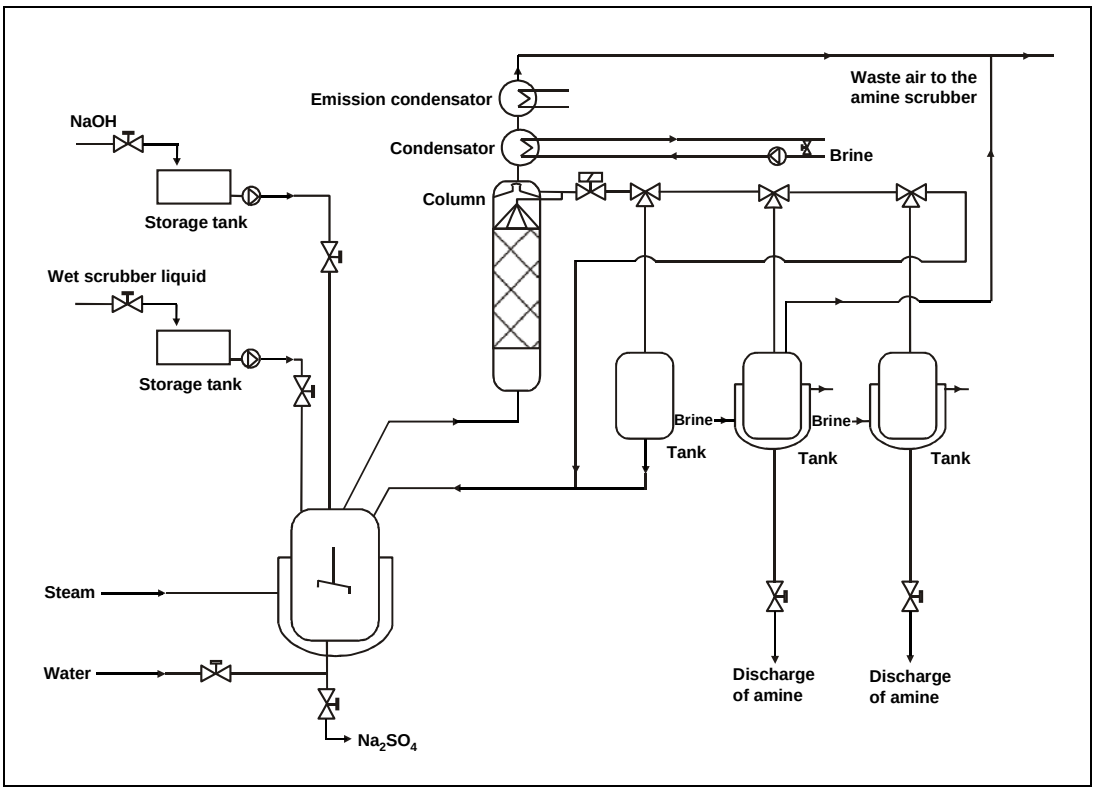

Figure 4.21: Amine recycling plant
[195, UBA, 2003]

Achieved environmental benefits
Recovery of a chemical compound, which may be re-used.

Cross-media effects
If the operation is performed in a centralised plant, it involves transport of the scrubber liquid to the treatment unit.

Applicability
This technique is applicable to all amine-containing scrubber liquors from core-making exhaust. The implementation is limited by economic factors (e.g. transport costs), since sufficient quantities of amine scrubber liquid need to be available. In general, the treatment is applied in a centralised location, treating the effluents of several foundries. Since the operation is subject to an explosion hazard, any necessary measures to prevent explosion risks should be taken.

Driving force for implementation
Recovery of chemical compounds. Disposal costs for industrial waste.

Example plants
- Centralised recycling plants Voerde (D)
- Centralised plant for group of automotive foundries: Poitou (F).

Reference literature
[195, UBA, 2003]

4.6.6 Reduction of glycols in die-casting waste water streams

Description
Hydraulic systems for die-casting use water-glycol mixtures, such as hydraulic liquid. Leaks in the hydraulic system and consequent transport of the leaked liquid into the water system could lead to the presence of glycols in the foundry waste water. Removal of the glycol is not possible using filtration or flotation techniques.

The applicable treatment techniques are:
- distillation or vacuum evaporation
- biological degradation.

The cleaned waste water may be re-used as a solvent for the release agent.

Achieved environmental benefits
Reduction of water pollution.

Cross-media effects
In the waste water treatment, a sludge cake is produced and needs disposal.

Operational data
In an example Belgian foundry, process water is treated in a vacuum evaporation unit (capacity 3 m^3/day). Three sources feed the unit: excess release agent (collected under the HPDC units), leakage hydraulic fluid from casting automates (water + glycol), and water from E-filter cleaning. The vacuum evaporation produces a sludge cake for disposal and an effluent. The effluent has a high COD and a low hardness (alkalinity). This makes it well suited for re-use as a solvent for the release agent.

Applicability
This technique applies to all new and existing die-casting foundries.

Driving force for implementation
Regulation for pollutant discharge into water.

Example plants
Metaalgieterij Giessen, Hoboken (B): aluminium foundry using HPDC and gravity die-casting.

Reference literature
[202, TWG, 2002]

4.7 Energy efficiency

4.7.1 Introduction

Metal melting and the holding of molten metal in the molten state generally take up a significant part of a foundry's energy consumption. In many foundries more energy is used in holding the metal in the molten state than in the actual melting process. Furthermore, considerable energy is expended in areas other than that of metal supply. For example, foundries are generally large users of compressed air. Other large users of energy are likely to be items such as high-pressure die-casting machines, whose mainly hydraulic power units are also driven by electricity. Sand and gravity die foundries may employ hot core-making processes, such as shell or hot-box, using gas or electricity to heat the boxes. The heating of dies and ladle and furnace linings can amount to an appreciable fraction of the total energy used. The typical relative distribution of energy use in two foundry types is given in Table 4.58.
[64, ETSU, 1997]

Activity	Non-ferrous foundry (%)	EAF steel foundry (10000 t/yr good casting) (%)
Melting	30	44
Holding	30	
Plant actuation	15	
Air compression	14	10
Tool heating	3	
Heat treatment (gas)		7
Others *	8	39
(*) Includes all activities for which no values are given in the same column and activities which are not mentioned		

Table 4.58: Typical energy use in a non-ferrous and EAF steel foundry [64, ETSU, 1997], [202, TWG, 2002]

These data show that foundry services (i.e. all but melting and holding) are responsible for up to half of foundry energy consumption. This includes activities using items such as motors and drives, compressed air, lighting, space heating and boiler plant. Energy efficiency measures should have regards to both the melting and the services field. [46, ETSU, 1995]

Energy efficient operation is brought about by applying good practice measures to reduce energy use in all of the mentioned steps. Improved energy efficiency is one of the main environmental benefits mentioned throughout the techniques discussions this chapter. The following sections focus on specific techniques aimed at heat recovery and heat transfer to other parts of the foundry.

4.7.2 Induction furnace: waste heat utilisation

Description

A significant proportion of the electrical energy which is supplied to an induction-melting furnace is converted into waste heat. About 20 to 30 % of the total energy input to the plant is dissipated through the cooling system. The furnace cooling circuit not only deals with the electrical losses in the induction coil, but also protects the coil from heat conducted through the furnace lining from the hot metal in the crucible. The heat in the furnace cooling system is used in some installations for space-heating, the heating of shower water and for drying raw materials.

- *Drying of raw materials:* Where metallic charge materials are added to a molten heel in an induction-melting furnace, the presence of water in the scrap can potentially be very dangerous. Although scrap may be stored under cover at the foundry, it is possible that it may be wet when delivered by the scrap dealer. The heat in the furnace cooling water can be extracted in an air/water heat-exchanger and a fan can be used to convey the warmed air to the bases of the stockyard bunkers. A diagrammatic layout of such an installation is shown in Figure 4.22.

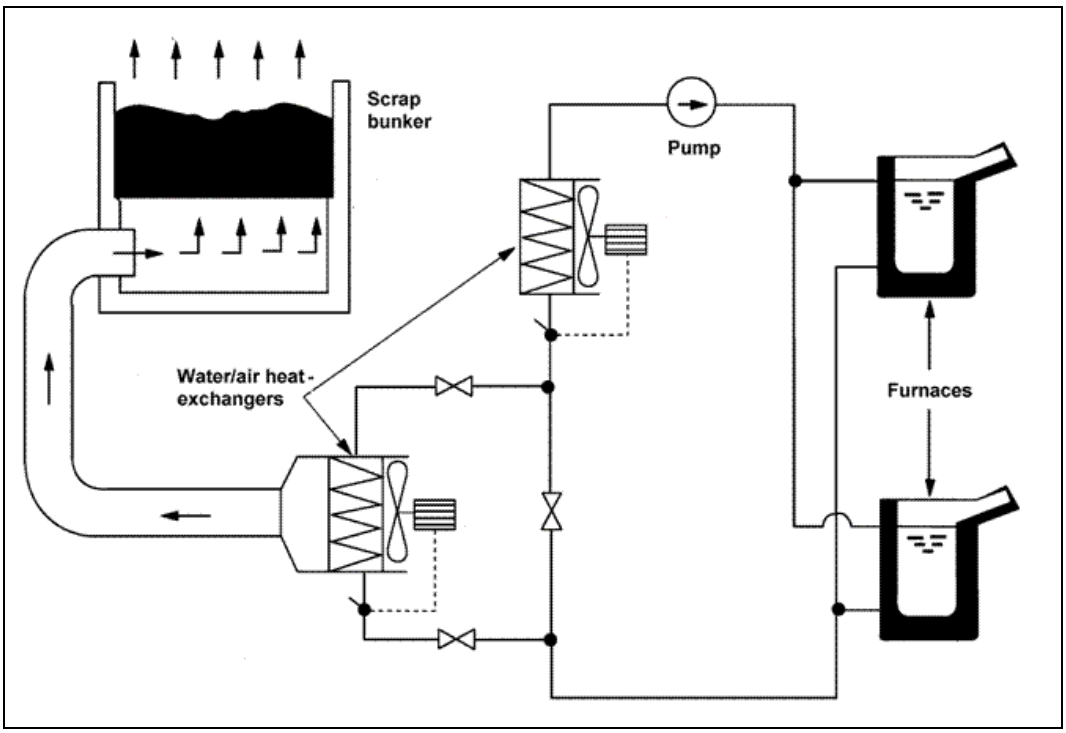

Figure 4.22: Use of waste heat for scrap drying
[47, ETSU, 1992]

- *Space heating and hot water supply:* A similar system to the one discussed above may be used to blow hot air into the foundry hall for space heating. Alternatively, a water-water heat-exchange is used to heat a water circuit for radiators or for hot water supply.

  Since the temperature of the cooling water in an unpressurised system is normally unlikely to exceed 60 – 70 ºC, radiators will need extra large surface areas are necessary in order to transfer heat efficiently. Alternatively, the temperature of the water can be boosted by some other heat source, such as supplementary gas or oil burners or an electrical heater. Some alternative heating system may be necessary to take over when the furnaces are not operating; for example, early in the morning, to raise the temperature of the work areas to a comfortable level.

  The normal furnace cooling facilities must be kept operating during the summer period and at other times when the space-heating facilities are not extracting an appropriate quantity of heat from the furnace cooling system. It is essential to ensure the integrity of the furnace cooling system. The whole installation must be designed to be fail-safe, to protect the integrity of the furnaces at all times. Also water returning to the furnaces must not be too cold (i.e. not below 30 ºC). Temperature operated alarms should be provided and emergency bypass pipework with easily accessible manual control valves, should be installed, to ensure that the heat recovery facilities can be isolated quickly from the primary cooling circuit in the event of any problems.

Achieved environmental benefits
Increased energy efficiency.

Cross-media effects
No cross-media effects have been reported.

Operational data
A heat recovery system using the cooling oil of induction furnaces was installed in a Belgian foundry. The foundry operates two induction holding furnaces in duplex with a cupola furnace.

The inductors of the electrical furnaces are cooled using thermal oil. The thermal oil gets heated up to 200 – 300 ºC and looses its heat over an outside oil-air heat-exchanger. Before installation of the heat recovery system, 1 MW of heat was dissipated into the air. An alternative system was installed to use the waste heat for space heating. The heated air is introduced into the core shop. This allows the recuperation of 1/3 of the dissipated heat and replaces the original gas-fired heating system. The implementation was possible at low cost because the oil-air heat-exchanger is installed next to the core shop. Space heating in other parts of the foundry may be considered later, but will require more piping (and will subsequent thus involve further losses).

Applicability
Before heat recovery can be applied, a number of criteria must be met:

- a worthwhile application for the waste heat must be reasonably nearby and the times at which this recovered heat can be utilised must match the times at which the furnace is operating. However, typically the heat available is fairly low grade. The temperature for the cooling water must not exceed 70 ºC
- the relatively low temperatures involved mean that heat-exchangers need to be much larger than those which are normally encountered
- the furnace water must not be returned to the furnaces at a temperature lower than about 30 ºC, otherwise this may give rise to condensation problems
- maintaining the integrity of the cooling circuits is absolutely essential. The cooling circuit is provided to protect the coil - if it fails in its task the results can be disastrous.

The above aspects, particularly the question of furnace integrity, discourage most furnace operators from even contemplating the utilisation of heat from the cooling circuit.

Economics
A foundry attempting to make use of the heat from the cooling circuit needs to fully evaluate the benefits and then compare them with the cost of the additional equipment and the safety of the furnace and operators.

Driving force for implementation
Increasing energy efficiency at the foundry.

Example plants
Space heating using hot air: Proferro, Oudenaarde (B).
Metso Paper Jyväskylä Foundry (F).

Reference literature
[47, ETSU, 1992]

4.7.3 Cupola furnace: waste heat utilisation

Description
The need to cool cupola off-gases before they enter the bag filter leads to the possibility of attaching to a secondary user and applying waste heat utilisation. The secondary user may be e.g.:
- a steam boiler
- a thermal oil circuit
- a heating circuit
- a hot water circuit.

Achieved environmental benefits
Recovery of waste heat, which otherwise would be lost to the outside, allowing a reduction in fuel (or other sources of energy) consumption.

Cross-media effects
No cross-media effects apply.

Operational data
The two example plants described in Section 4.5.2.2, are equipped with a waste heat utilisation system. Plant data have been given in Table 4.37.

Plant G uses cupola waste heat for electricity production. Part of the off-gas flow is fed to a steam boiler, which drives a turbine, coupled to a generator or compressor. A schematic representation of the installation is given in Figure 4.23. In total 29 % of the introduced cokes heat is converted into additional utilisation. Around 2.9 MW of electrical energy are generated. This means that the plant generates an electrical power of 75 kWh/tonne liquid iron.

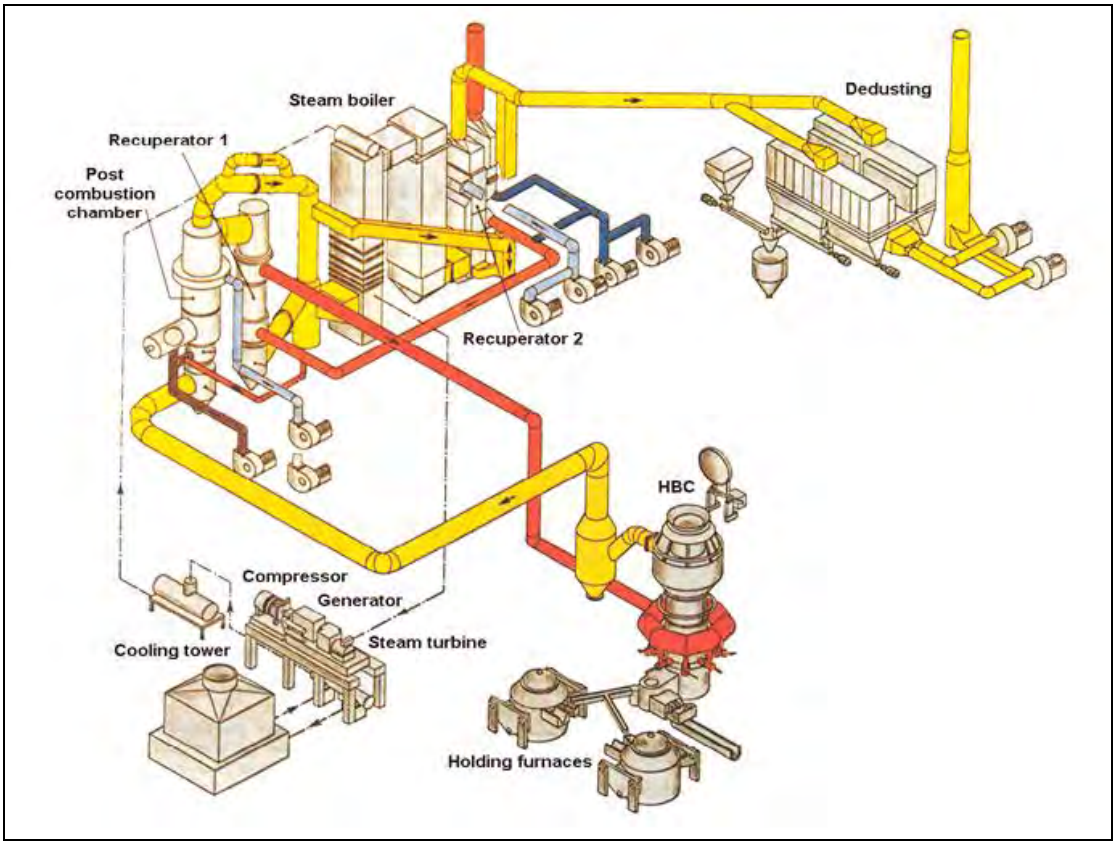

Figure 4.23: Schematic representation of a hot blast cupola with a steam boiler, turbine and generator
[27, Kran, et al., 1995]

Plant H uses cupola waste heat in a thermal oil circuit. After heat exchange for blast preheating, the off-gas passes a gasoil heat-exchanger. The heated oil is used for core drying. A maximum heat recovery of 21 MW can be attained. A process flow diagram is given in Figure 4.24.

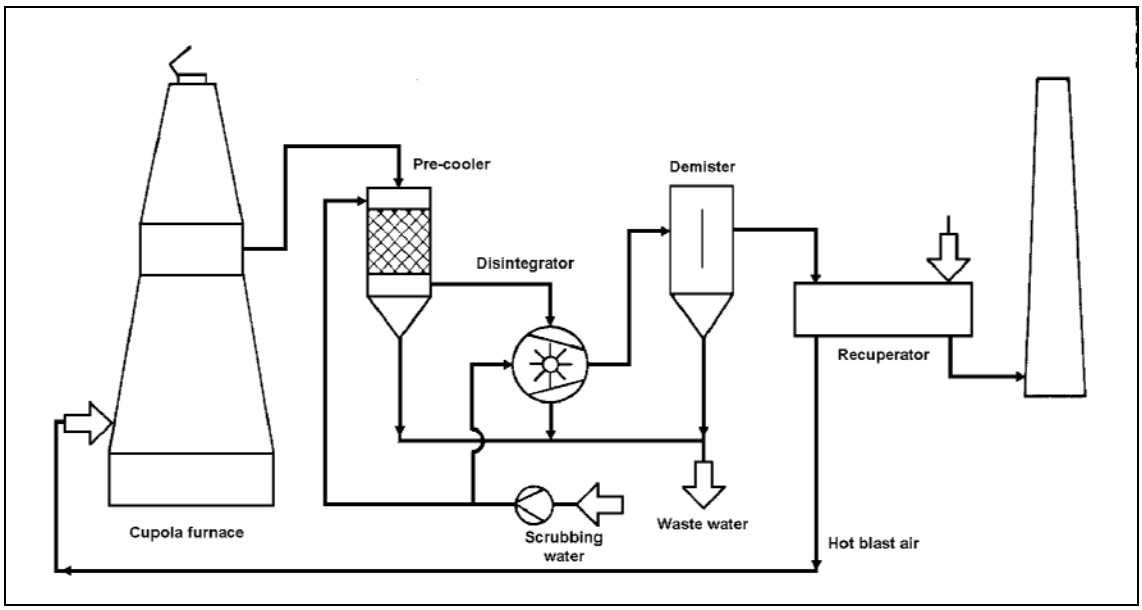

Figure 4.24: Process flow diagram of a hot blast cupola with heat recovery [17, Strauß, 1983]

Applicability
This technique applies to new installations and should be taken into account when designing the process. For existing plants, the technique can be applied during major refurbishment of the plant, however, small add-on units can generally be accomodated in existing plants.

Economics
The stated examples were installed as part of a major rebuilding of the considered installation. It is therefore not possible to extract specific cost data.

Driving force for implementation
Increasing energy efficiency of industrial processes.

Example plants
The two mentioned example plants are located in Germany.

Reference literature
[17, Strauß, 1983], [27, Kran, et al., 1995], [202, TWG, 2002]

4.7.4 Reduce energy loss/improve preheating practice of ladles

Description
Energy is wasted if the molten metal transfer system allows an excessive loss of metal temperature between furnace tapping and mould pouring. Losses can be prevented by using good practice measures. These imply the following:

- the utilisation of clean ladles, preheated to bright red heat
- the utilisation of distribution and pouring ladles, which are as large as is practicable and are fitted with heat-retaining covers
- keeping the covers on ladles which are standing empty or putting ladles upside down when not in use
- minimising the need to transfer metal from one ladle to another
- always conveying the metal as quickly as possible, while still complying with safety requirements.

Achieved environmental benefits
To reduce energy losses.

Cross-media effects
No cross-media effects occur.

Applicability
Since this technique involves measures related to good practice, it is applicable to all new and existing foundries.

Economics
No economic data can be given.

Driving force for implementation
Energy efficient foundry management.

Example plants
These measures are used to a varying extent in European foundries.

Reference literature
[44, ETSU, 1993]

4.8 Sand: regeneration, recycling, re-use and disposal

4.8.1 Introduction

Since foundries make intensive use of sand as an inert primary material, the regeneration of this sand is a major point of consideration as part of its environmental performance. A clear distinction must be made between green sand and chemically-bonded sand. Green sand can be easily reconditioned after use. Indeed, recirculated green sand shows a better technical quality than new sand. Most green sand foundries perform primary regeneration.

Primary regeneration, also known as attrition or particulation, involves breaking down the sand from moulds or cores back to its original grain size. This includes screening the sand, removing tramp metal, and separating and removing fines and over-sized agglomerates. The sand is then cooled before being sent for storage, returned to the sand system or blended with new sand. At this stage, the sand grains are likely to retain a partial coating of spent binder. This affects the amount of reclaimed sand that can be used to make moulds and, more particularly, cores. New sand therefore has to be added to ensure that the sand mix produces adequate mould and core strength and subsequenty aids good casting quality. Primary reclaimed sand is not generally of sufficient quality to be used for core-making, without further processing to remove residual binder materials, and is therefore used principally for moulds. The main primary regeneration techniques are vibration, rotating drum or shot blasting.

Secondary regeneration involves the further processing of the previously particulated sand to remove residual binder. The sand is returned to a quality similar to, or better than, that of new sand. Foundries using secondary regeneration have, in some cases, virtually eliminated the need for new sand. To remove residual binder, more aggressive techniques are needed than for primary regeneration. The main secondary regeneration techniques are:

- cold mechanical treatment:
  - low energy attrition: friction, impact (for cold-setting resins)
  - high energy attrition: pneumatic chafing, grinding, centrifugal friction
- thermal treatment (usually in a fluidised bed)
- wet scrubbing.

Sands bonded with cold-setting resins may be regenerated using simple treatment techniques, due to the fragility of the binder layer. Mechanical regeneration systems (e.g. fluidised bed systems) are based on interparticle friction or impact.

Sands bonded with gas-hardened and thermosetting resins need more intensive treatment to remove the binder layer. These include grinding, pneumatical chafing and centrifugal friction. Silicate sands can only be regenerated mechanically using pneumatical treatment.

Thermal treatment involves the burning of the organic binder. Bentonite is inactivated by the high treatment temperature. For sand flows containing green sand, any thermal treatment should therefore be combined with a mechanical treatment.

Wet regeneration involves binder removal through interparticle grinding. This technique applies only for green sand and silicate or CO_2-bonded sands and is not widely applied.

Secondary regeneration of green sand as a monosand flow finds limited implementation. For chemically-bonded sands, mechanical regeneration is most widely applied (>200 units in Germany in 1999) [80, ERM Lahmeyer International GmbH, 1999]. The applicability of the various regeneration techniques and of the regenerated sand are summarised in Table 4.59 (monosands) and Table 4.60 (mixed sand). Each of the presented techniques will be discussed in more detail in the sections below.

The most important **monosand** flows for secondary regeneration are the core sands in non-ferrous foundries. Due to the low thermal load they are easily separated from the green sand. Furthermore monosands are produced from mould and core-making with purely organic systems such as croning, furan resin and urethane cold-box. A smaller monosand stream is non-cured core sand, arising from broken or rejected cores in the core-making shop and the residual sand of core-making machines.

Mixed sands generally contain bentonite-bonded sand as well as chemically-bonded sand. They are mainly generated in iron foundries and represent some 75 % of the total waste sand production.

Type of sand	Regeneration technique	Regeneration equipment	Utilisation	Borderline conditions	Minimal quantity (tonne/h)
Organic monosystems					
Cold-setting resins	Mechanical or thermal	Mechanical: friction, impact, pneumatic chafing Thermal: turbulent bed, fluidised bed or rotary furnace	- for mould-making using cold-setting resins - 20 – 25 % substitution of new sand for cold-setting core-making	- mechanical: only if binder shells have become fragile enough upon pouring - the target values for regenerate quality must be met	1.5
Cold-Box, SO_2, Hot-Box and Croning sand	Mechanical or thermal	Mechanical: pneumatic chafing, centrifugal friction, fluidised bed chafing Thermal: turbulent bed, fluidised bed or rotary furnace	In core-making, as new sand substitute	- mechanical: only if binder shells have become fragile enough upon pouring - the orientative values for regenerate quality must be met - re-use of fines	0.75
Resol- ester methyl formate hardened sand	Mechanical	Mechanical: friction, impact, pneumatic chafing	With limitations, in mould-making with methyl formate sands	- regeneration as resol-ester cold setting but with lower yield - embrittlement of binder components	
Inorganic monosystems					
Green sand	Mechanical	pneumatic chafing, grinding	Renewal sand for green sand circuit	- requires predrying - re-use of fines	0.75
Sodium silicate sand	Mechanical		Only for making moulds and cores using sodium silicate sand	Embrittlement of binder components at 200 ºC	0.5

Table 4.59: Fields of application of different regeneration systems for monosands [128, IHOBE, 1998], [225, TWG, 2003]

Type of sand	Regeneration technique	Regeneration equipment	Utilisation	Borderline conditions	Minimal quantity (tonne/h)
Mixed organic systems	Mechanical or thermal	Mechanical: pneumatic chafing, centrifugal friction, fluidised bed chafing Thermal: turbulent bed, fluidised bed or rotary furnace	- core-making substituting new sand	- mechanical: only if binder shells have become fragile enough upon pouring - the orientative values for regenerate quality must be met - re-use of fines	0.75
Mixed sands containing bentonite	Mechanical or mechanical-thermal-mechanical	Mechanical: grinding, pneumatic chafing, fluidised bed chafing Thermal: turbulent bed, fluidised bed or rotary furnace	- core-making substituting new sand - renewal sand for the green sand circuit	- require pre-drying - combined thermal regeneration requires efficient mechanical regeneration to remove active bentonite - re-use of fines	0.75

Table 4.60: Fields of application of different regeneration systems for mixed sands [128, IHOBE, 1998]

The applicability of the various treatment systems is summarised in Table 4.61 and will be discussed further in the specific applicability sections.

	Simple mechanical systems	Cold mechanical			Wet regeneration	Thermal	Mechanical – thermal – mechanical
		Grinding	Impact drum	Pneumatic chafing			
Monosands							
Cold setting	x	x	x	x	x	x	0
Cold-box, SO_2, Hot-box, Croning	0	x	x	x	0	x	0
Silicate (CO_2 or ester)	0	0	0	x	x	0	0
Green sand (primary)	x	0	0	0	0	0	0
Green sand (secondary)	0	x	0	x	x	0	0
Mixed sands							
Mixed organic	0	x	x	x	0	x	0
Mixed green + organic	0	x	0	x	x	0	x
x: Applicable; 0: Not applicable							

Table 4.61: Applicability of various sand regeneration techniques to various sand types

The application of both primary and secondary regeneration in a mixed sand foundry in order to achieve a total regeneration of 92 % is shown in Figure 4.25. This simplified scheme does not take into account the various losses in the processing steps. The addition of new sand can be reduced to a minimum by integrating (the coarse fraction of) the filter dust sands (from the exhaust of hand forming lines, de-coring lines, storage silos, etc).

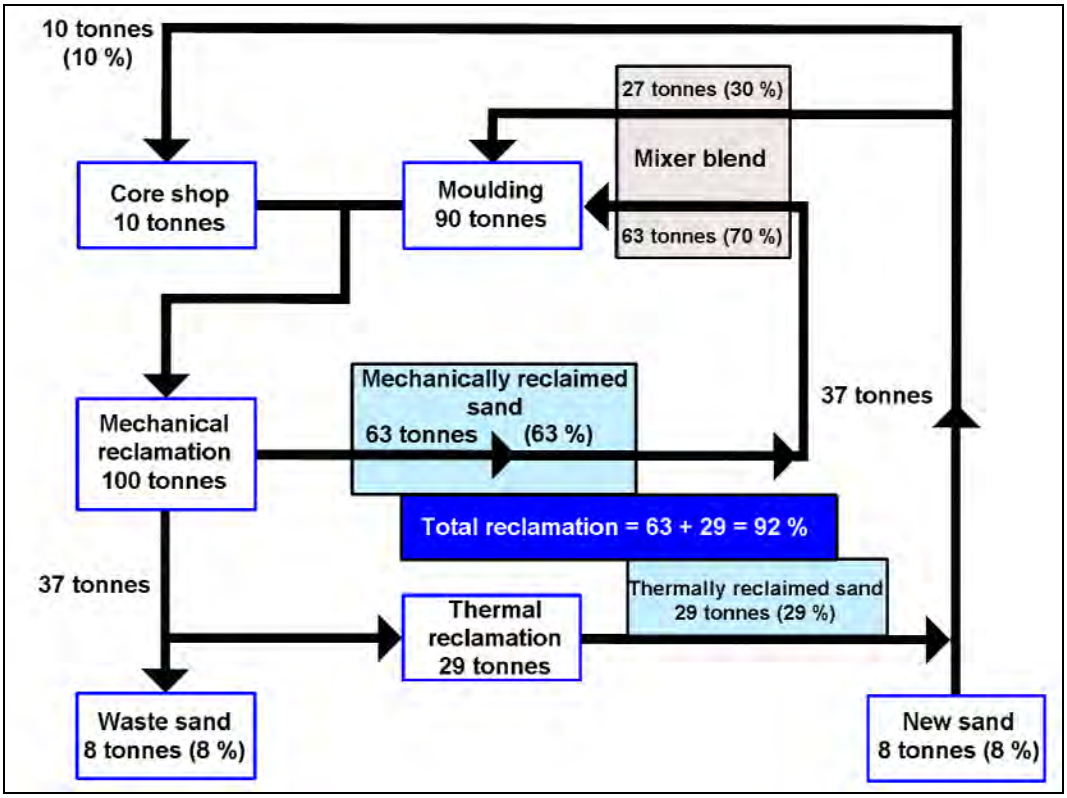

Figure 4.25: Sand balance diagram for a thermal/mechanical regeneration system [70, ETSU, 1998]

An overall reclamation ratio of 92 %, as given above, is a normal value for mixed green sand – chemically bonded sand systems. Regeneration ratios of up to 98 % have been reported. The actual ratio depends on the volume and chemical composition of the used cores. For furan cold setting monosands, values around 78 % are reported.

Generally the mixing of different types of sands has a negative effect on the strength of the cores and subsequently the moulds made with the regenerated sand, although there are a few exceptions to this general principle. In order to produce a good quality regenerated sand it is therefore of great importance to keep non-compatible sand types separate. Optimisation of the regeneration potential may therefore imply changing to compatible binder systems, if mixed sands are used, or the application of (shake-out) techniques that allow the separation of various sand types. Table 4.62 provides a cross-compatibility table.

Source system \ Goal system		Bentonite	Silicate	Cold-setting	Hot-box	Croning	Cold-box		
							Methyl-formate	Amine	SO_2
Bentonite		+	0	0	-	0	0	0	0
Silicate		0	+	-	-	-	-	-	-
Cold-setting		+	-	+	-	0	-	0	+
Hot-box		0	-	+	+	+	-	0	+
Croning		+	+	+	+	+	+	+	+
Cold-box	Methyl-formate	0	+	0/-	-	-	0	0	-
	Amine	+	+	+	+	+	0	+	+
	SO_2	+	-	+	-	0	0	+	+
+: Compatible, 0: Limited compatibility, -: Incompatible									

Table 4.62: Compatibility of regenerated sources sands with various binders [37, Winterhalter, et al., 1992], [225, TWG, 2003]

[37, Winterhalter, et al., 1992], [70, ETSU, 1998], [128, IHOBE, 1998], [138, Metaalgieterij Giesen B.V., 1996], [153, Umweltbundesamt, 2002], [202, TWG, 2002], [225, TWG, 2003]

4.8.2 Regeneration of green sand under optimised conditions (primary regeneration)

Description

One of the major advantages in using green sand moulding is that the sand from the moulds can be reconditioned after pouring for multiple re-use. The addition of a minimum percentage of new sand is performed in order to maintain the quality of the moulding-sand. The amount of new sand added is determined by the input of core sand and the losses in the process. For coreless moulding, the average sand renewal ratio is 2 – 5 %. In casting processes using cores, sand renewal occurs through the introduction of the core sand into the loop. In any case, surplus sand is removed from the sand circuit after the shake-out screen or from the storage silos. The general treatment is depicted in Figure 2.28. This internal recirculation of green sand with minimal treatment is referred to as primary regeneration. This regeneration basically has three aims: (1) to break the sand into its original grain size or small particles, (2) to remove the fines, and (3) to cool the sand before blending with new sand.

Various techniques are applied for the breaking and separation:

- *Vibration*: The vibratory grid, or screen equipment, is the most widely used technique for primary reclamation purposes. The sieved sand is removed for subsequent treatment, e.g. for cooling, size classification, and thermal reclamation, and the residual material is collected for disposal

- *Drum*: Sand from the knock-out operation is loaded into a rotating drum fitted with both lifting and travelling bars. As the sand travels along the drum, the rotating and lifting action causes the sand particles to grind against each other and break down to individual grains. The sand grains fall through screens at the end of the drum, while oversize and tramp materials are removed for landfill disposal
- *Shot blast*: The mould and casting is loaded directly into the shot blast machine. The action of the shot blast results in the complete disintegration of the mould and also cleans the surface of the casting. The sand and shot are subsequently separated. However, this technique is not very common.

During cooling of the castings, the sand gets heated-up. In order to reach good sand mixing conditions, the sand needs to be cooled down to 40 – 45 ºC. Evaporative coolers are used with turbulent and fluidised beds, as well as heat-exchangers. If shake-out is done using the vibrating transporters of revolving drums, the cooling can occur at the same time.

If a fluidised bed cooler is used, the drying air may be heated using gas or electricity. The average treatment time in the bed is 10 minutes. In general, the sand enters the fluidised bed with a humidity of 2 – 3 % and a temperature of 250 – 300 ºC. Temperature and humidity control may be performed before the fluidised bed cooler with a subsequent addition of controlled amounts of water. This allows minimisation of the amount of fines that are removed during the fluidised bed drying. The fines contain bentonite that may be re-activated. The level of humidity of the return sand needs to be kept between 2 and 2.2 % at 35 ºC. Consequently, during storage, the bentonite contained in the cooled and wet sand starts to activate and, during the mixing, the water and bentonite that need to be added are reduced, as is the cycle time.

A good homogenisation of the sand allows a constant sand quality and better and easier sand preparation. Homogenisation systems consist of the use of a few small silos instead of one big one, or in the re-circulation of the sand in the silo.

In systems using chemically-bonded cores, the mixing of the core sand may have a negative effect on the sand quality, depending on the binder type and the amount of core sand mixed. The negative effects are more significant with acidic and alkaline cores, than compared to neutral systems (SO_2-epoxy, PUR-cold-box). During shake-out, core sand and moulding sand will inevitably get mixed. Uncured cores and non-broken cores, however, may be left out or taken out of the sand before feeding back to the primary regeneration.

Achieved environmental benefits
Reduced usage of primary materials (sand and bentonite), reduced amount of material for disposal.

Cross-media effects
Sand regeneration uses electricity, therefore it increases the overall electric energy consumption of the installation. Since mechanical techniques are mainly applied, this increase is low.
Sand cooling and the separation of fines leads to dust-laden exhaust gas. The exhaust needs to be filtered to prevent dust emissions. The collected dust is sent to disposal or re-used (see Section 4.8.12).

Operational data
While the level of new sand addition is governed by a number of factors, the usual range is 10 - 20 % of the poured metal weight. However, it is more convenient to consider new sand additions as a percentage of sand throughput. For most foundry processes, a 5 % addition is considered sufficient, but many foundries work at lower rates.

For a green sand monosystem, regeneration ratios of 98 % may be achieved. Systems with a high degree of incompatible cores, may achieve a regeneration ratio of 90 – 94 %.

Applicability
This technique is applicable to all green sand foundries, in new and existing installations.

Economics
The potential cost benefit of reclamation for a foundry that does not currently reclaim its sand is summarised in Table 4.63.

Description	Cost (EUR/tonne of sand)
Average price of silica sand	32.64
Average cost of waste sand disposal	14.56
Total cost of sand purchase and disposal	**47.2**
Estimated depreciation cost to recoup equipment expenditure in one year	18.24
Average operating cost	7.76
Anticipated cost saving in first year	**21.2**
Anticipated cost saving in subsequent years	**39.44**

Table 4.63: Cost benefits from primary reclamation (UK estimation 1995)

The investment for a mixer, dosing unit and process control unit is in the range of EUR 0.05 - 1 million. The investment for the size reduction of core-breaks is EUR 0.1 million, although this is only applied if the size reduction cannot be done in an available mechanical or pneumatic regeneration unit. Operational costs (on a yearly basis) can be estimated at 5 – 10 % of the investment cost.

Driving force for implementation
Many foundry operators state the reduction in costs as the sole reason for starting various sand reclamation programmes. Regulations encourage a reduction in the amount of dumped material, through an increase in disposal costs.

Example plants
Primary reclamation is used by virtually all green sand foundries, though the degree of sophistication of the reclamation plant varies widely; from a simple manual operation to one fully automated with computer-controlled equipment.

Reference literature
[72, ETSU, 1995], [73, ETSU, 1995], [108, FEAF, 1999], [110, Vito, 2001], [128, IHOBE, 1998], [140, EU Thematic Network Foundry Wastes, 2001], [143, Inasmet and CTIF, 2002]

4.8.3 Simple mechanical regeneration of cold-setting sand

Description
Simple mechanical techniques are used for the regeneration of cold setting monosands (e.g. furan sand) and uncured core sand. These techniques include the breaking of lumps, segregation of the sand grains and cleaning by intergranular friction, with consequent dedusting and cooling down to operational temperature. Various types of crushers and mills are used, e.g. impact crusher, jaw crusher, ball mill.

Achieved environmental benefits
A reduction of the amount of sand for disposal and of the consumption of new primary sand.

Cross-media effects
The regeneration of sand requires additional energy and causes additional dust emissions and residual dust for disposal.

Operational data
For furan cold setting monosands regeneration ratios around 78 % are reported.

Applicability
The technique can be used for all cold-setting sand, excluding silicate sand. The regenerated sand can be re-used in the same moulding cycle, with small additions of new sand to level-off quality losses.

The technique can be used for uncured coresand with organic binders. The regenerated sand may be re-used for core-making using the same binder type, after mixing with new sand. It may also be used, within certain limits, for the renewal of moulding-sand.

Driving force for implementation
Legislation using high disposal fees to reduce the amount of residues for disposal.

Example plants
Simple mechanical regeneration of furan sand is applied in many foundries around Europe, and is specifically widespread in Germany and Finland.

Reference literature
[153, Umweltbundesamt, 2002], [202, TWG, 2002]

4.8.4 Cold mechanical regeneration using a grinding wheel unit

Description
This is a widely applied commercial grinding system (see Figure 4.26). The system was originally developed to regenerate mixed bentonite-organic sands. In this system, a horizontally rotating grinding wheel is used to remove the hard oolitic bentonite layer from the sand. The grinding can also remove chemical binders from sand grains. Around the grinding wheel is a slowly rotating paddle wheel, which continuously moves the sand onto the grinding wheel. Above this, a dedusting unit extracts the dusts and the fines. To be fit for processing, the sand must be dry. A pre-drying step, using a fluid bed or other dryer, is required to bring the moisture content down to below 0.2 %.

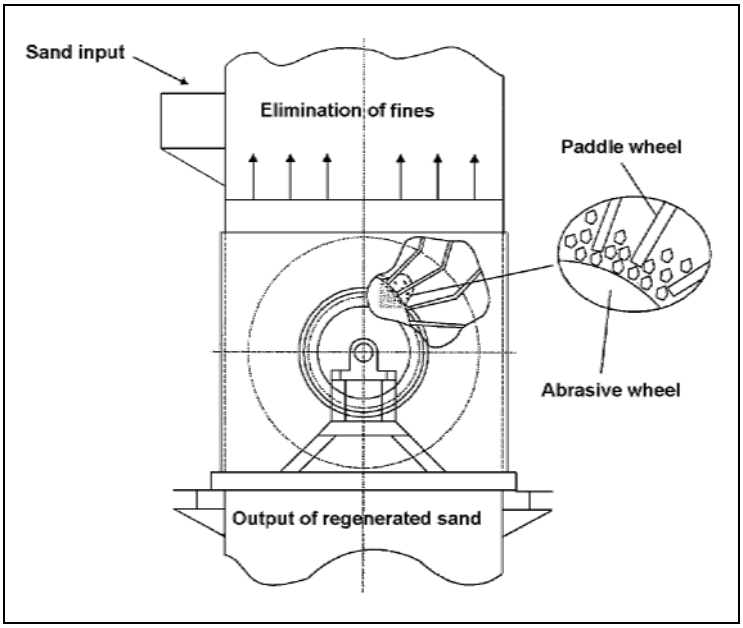

Figure 4.26: Cold mechanical regeneration using grinding
[128, IHOBE, 1998]

The off-gas stream of the regenerator is dedusted using a cyclone and a bag filter. The filter dust contains residual active bentonite and coal dust. It may be recirculated into the core-making, thereby allowing a reduction in the use of lustrous carbon. Furthermore, the moulds demonstrate better technical quality (wet tensile strength, flowability), due to the remaining bentonite content, which furthermore leads to a reduction in the amount of scrap moulds and a reduction in finning on the castings.

Achieved environmental benefits

A reduction of the amount of sand for disposal and of the consumption of new primary sand.
A reduction in the consumption of lustrous carbon, in the case of green sand.
An increase in moulding sand properties, resulting in a reduction in the number of scrap moulds and in the number of rejects in finished castings.

Cross-media effects

The regeneration of sand requires additional energy and causes additional dust emissions and residual dust for disposal. However, the use of regenerated sand in the moulding process allows a reduction in the amounts of lustrous carbon used.

Operational data

For clay-bonded sand, the maximum regeneration rate is 65 - 75 %. This corresponds to the quartz grain content of the material. For a chemically-bonded sand, the amount of recyclable quartz sand is 90 – 95 %.

The total sand circuit flow and the need for new sand depends on the amount of cores (and core sand) used. Therefore, data on the sand circuit are very process-specific. Figure 4.27 gives data for a plant in the Netherlands.

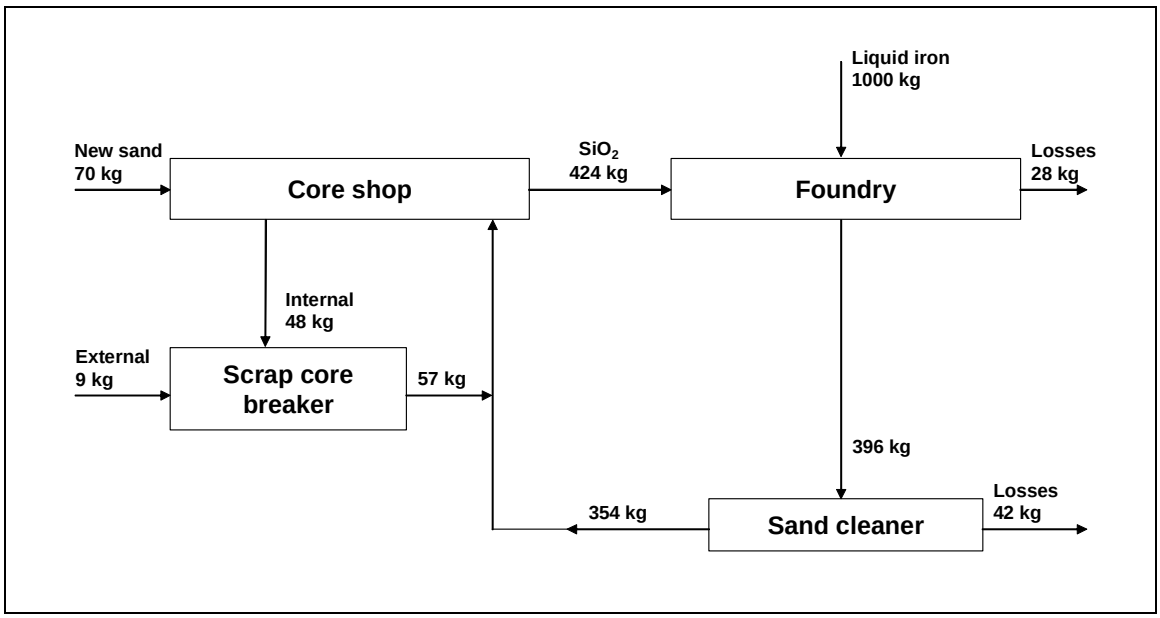

Figure 4.27: Operational data on the sand circuit of a Dutch green sand foundry [140, EU Thematic Network Foundry Wastes, 2001]

In general, waste green sand consists of about 80 % quartz sand grains and about 20 % fines (bentonite, coal dust, etc,). Out of 100 % waste sand, about 70 % is transferred back to the core-making as reclaimed sand. The degree of efficiency with regard to quartz is about 88 %.

The filter dust contains approximately 40 % active bentonite, which has a loss of ignition (LOI) of 17 % and contains 43 % fines. Re-use of the dust in the sand plant results in a reduced requirement for lustrous carbon by up to 30 %. Results of the improved sand quality at the example foundry show the amount of scrap moulds were practically halved.

The cyclone dust (20 % of regenerated green sand weight) contains 25 – 30 % bentonite and high levels of organics, but its chemical composition falls outside the required specification to allow its re-use as a secondary construction material. In the Netherlands, a specific application in cover layers on disposal sites is allowed. In other regions, this fraction will need disposal of. However, legislation limiting the organic content of material for disposal, may limit the disposal options.

The grinding of the sand causes accelerated wearing of the sand grains. This and the recirculation of the filter dust cause shifts in the grain size distribution of the sand. The overall sand composition therefore needs good control and follow-up.

Applicability
Cold mechanical regeneration is mainly applied for removing bentonite layers from green sand and for removing chemical binders in no-bake systems. The grinding technique is the most widely applied cold mechanical treatment. Vibration- and impact systems are also used for chemically-bonded sands but produce sand of only low or average quality. These techniques are more appropriate for the conventional sand loop (primary regeneration). The secondary regeneration of green sand has limited implementation.

Economics
The investment cost for a 50 tonne/day unit, including drying, cooling, regeneration unit, cyclone and bag filter is around EUR 1135000. Data from Germany, state an investment cost of EUR 600000 for a 1.5 tonne/h unit.

The consumption levels are as follows (based on yearly average figures):

Electricity:	39	kWh/tonne
Natural gas:	3	Nm^3/tonne (depending on the moist input of the sand)
Compressed air:	36	Nm^3/tonne
Wear parts:	1.18	EUR/tonne
Manning level:	0 %	
Maintenance:	routine.	

Cost curves for the mechanical regeneration of organic bounded sand are given in Figure 4.28. Fixed costs vary according to the total capacity and investment. Variable costs can be up to around EUR 11/tonne, although the actual costs depend on the specific installation and local conditions. The total costs (fixed plus variables) range from EUR 12 - 40/tonne of regenerated sand, depending on the size and type of equipment.

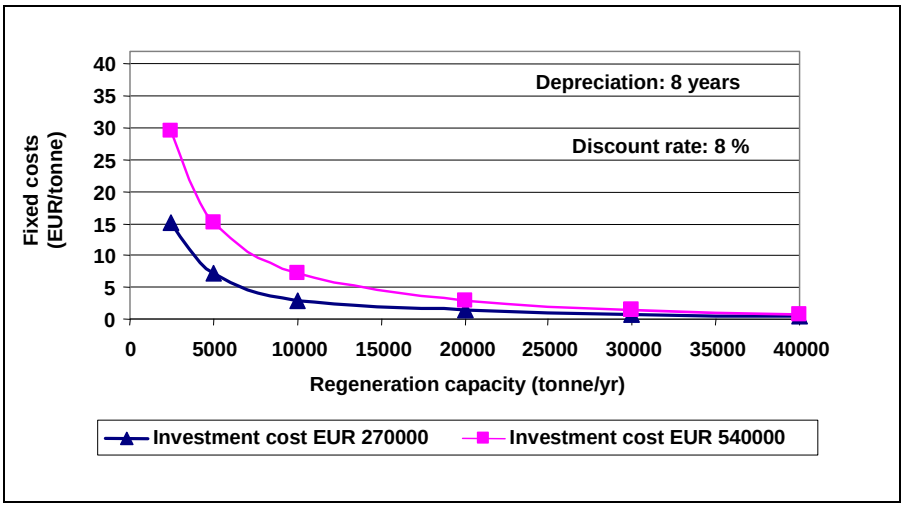

Figure 4.28: Fixed costs in euros per tonne of regenerated sand, for the mechanical regeneration of sand with cold-setting binders
[82, IfG - Institut für Gießereitechnik, 1996]

Driving force for implementation
Legislation using high disposal fees to reduce the amount of residues for disposal.

Example plants
- De Globe, Weert, the Netherlands, 60 tonnes per day plant using two lines, in operation since 1995
- Eisenwerk Brühl, Brühl; D (1.5 tonne/h), 1999
- Giesserei Fritz Winter GmbH & Co KG, Stadtallendorf, D (9.5 tonne/h)
- Mercedez-Benz AG, Mannheim, D (9 tonne/h).

Reference literature
[82, IfG - Institut für Gießereitechnik, 1996], [110, Vito, 2001], [128, IHOBE, 1998], [133, De Globe B.V., 1999], [140, EU Thematic Network Foundry Wastes, 2001], [151, Gemco, 1999]

4.8.5 Cold mechanical regeneration using an impact drum

Description
This mechanical regeneration technique is based on intergranular grinding of the sand and gives the best results for chemically bonded monosand. The sand is fed into a drum with a spinning internal axis, equipped with small blades. Sand grains are impacted against the drum wall and against each other. This impact produces a mechanical abrasive cleaning action. Fines are removed with the exhaust gas. The impact drum operates in a batch wise regime. The installation of two units allows continuous operation.

When applied on a mixed bentonite-organic sand, the regeneration is preceded by a magnetic separator, to remove green sand. Due to the presence of unreacted bentonite, the green sand shows a very weak magnetism, which allows a magnetic separation to be carried out. The regeneration system allows the introduction of a limited amount (15 %) of uncured core sand (core breaks from production). The combination of magnetic separation and impact drum cleaning allows an optimised chemically bonded sand regeneration from a mixed sand flow, with re-use of the regenerated sand in core-making.

Achieved environmental benefits
Internal re-use of core sand, therefore limiting the amount of material for disposal and the need for raw materials.

Cross-media effects
The regeneration of sand requires additional energy, and causes additional dust emissions and residual dust for disposal.

Operational data
The regeneration drum has a batch wise regime, with a 20 minute treatment time for each 1.5 tonne sand charge. The energy consumption of the full installation (including magnetic separation, exhaust treatment, sand transport) is 55 kWh/tonne of treated sand, of which 35 % may be attributed to sand transport and feeding. The installation uses compressed air at 48 Nm^3/tonne sand.

The regenerated sand is of the following quality:
- average grain size: 0.30 – 0.33 mm
- share of fines: 0.4 – 1 %
- pH: 8.7
- loss on ignition: 0.25 – 0.5 %.

Cores made with 100 % regenerated sand have acceptable properties. In practice, 10 – 70 % of regenerated sand is used for new cores, the actual amount depending on the core type.

Dust generation in the installation is 10 % of the regenerator input. This dust is collected using a cyclone (90 %) and a bag filter (10 %).

Applicability
The combined separation-regeneration technique can be applied for the treatment of mixed green sand and chemically bonded sand. Regeneration is performed on the chemically-bonded sand flow and may include uncured core sand. The technique may be applied in new and existing installations.

Economics
Investment costs for a 3 tonne/h unit with 1 impact drum, magnetic separation, exhaust gas dedusting and transport and a feeding system are EUR 1.3 million. Operational costs for this unit are EUR 10/tonne. These include energy consumption, wear and tear of parts, maintenance and disposal of residues. This represents a net benefit of EUR 37/tonne, compared to the costs of new sand purchase and used sand disposal (both incl. transport).

For a 380 tonne/day unit in France, an operational cost of EUR 15/tonne was quoted. For this plant this represents a net benefit of EUR 18/tonne, compared to the costs of new sand purchase and used sand disposal (both incl. transport).

Driving force for implementation
Legislation using high disposal fees to reduce the amount of residues for disposal.

Example plants
This technique is used in the following plants:
- PSA, Sept-Fons (F): 6 magnetic separators and 2 grinders, working alternatively
- GF, Leipzig (D): 2 magnetic separators and 1 grinder
- Döktas – Turkey: 5 magnetic separators and 2 grinders.

Reference literature
[185, Spitz, 2002], [122, Kirst, 1999], [153, Umweltbundesamt, 2002]

4.8.6 Cold regeneration using a pneumatic system

Description
In a pneumatic system, binders are removed from the sand grains using abrasion and impact. The kinetic energy is provided by a compressed air stream. This results in a simultaneous dedusting. The advantage of this type of system is that the direction and velocity of the sand can be controlled. Due to the low energetic efficiency of air compression, the energy consumption is higher compared to the purely mechanical treatment. The principle of the reactor is depicted in Figure 4.29.

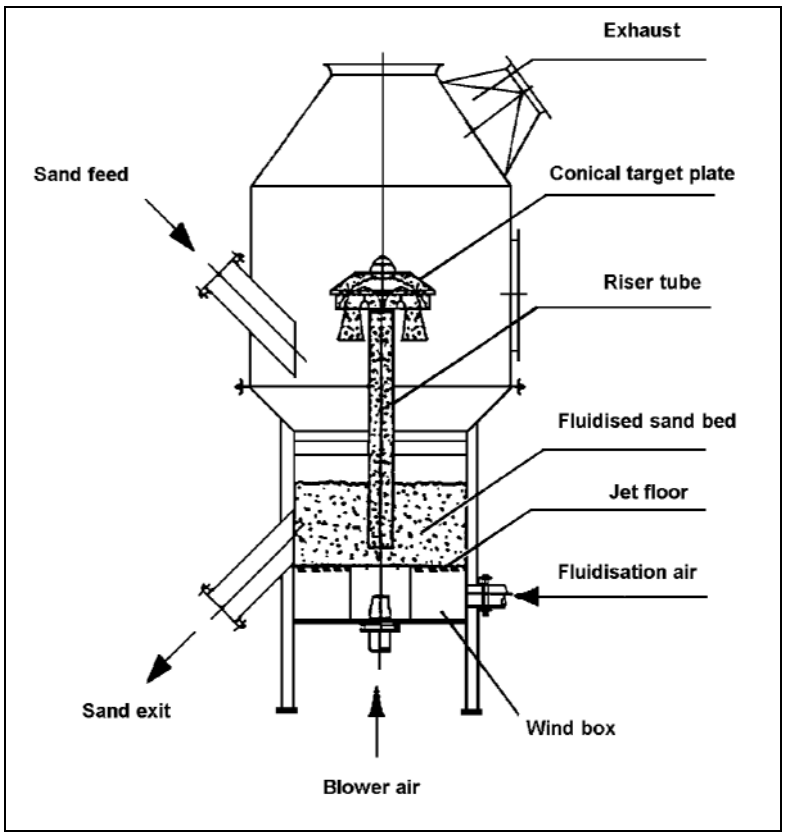

Figure 4.29: Cold mechanical regeneration using a pneumatic system [122, Kirst, 1999]

The reactor uses a fluidised bed with a central raiser tube. The sand is blown into the tube using compressed air and impacts on either a rubber deflector plate or a conical target plate. From there, the sand falls down again and the cycle starts over again. The cleaning happens through intergranular abrasion, abrasion against the impact plate and through 'pure' impact. The shape of the plate determines the main cleaning mechanism: impact (bell-shape) or abrasion (conus). The generated dust is removed with the airflow over a bag filter. Treatment is performed as a batch system or through a series of coupled pneumatic units. In this case, the cleaned sand is sucked out of the reactor through a deflector below the impact plate.

Achieved environmental benefits
Reduction of the amount of sand for disposal and of the consumption of new primary sand.

Cross-media effects
The regeneration of sand requires additional energy and causes additional dust emissions and residual dust for disposal.
The general evaluation of internal regeneration versus external re-use and the corresponding cross-media effects are discussed separately below.

Operational data
A waste sand mix of green sand with chemically-bound core sand having the following characteristics: 8 – 12 % fines content, 3 – 5 % LOI, <2 % humidity; produces a regenerate with the following characteristics:

- regenerate yield, based on SiO_2 content of waste sand: 70 – 80 %
- ultra fines content (<0.063 mm): max. 2 %
- fines content: <2 %
- loss on ignition: <0.5 %
- average grain size: unaltered.

The technique uses a modular installation build-up, using 0.8 – 1.2 t/h basic units. The supplier mentions an electric energy consumption of 15 – 20 kWh/t (excluding dedusting equipment). German operational data give an electric energy consumption of 41 kWh/t for a 8 t/h unit and 62 kWh/t for a 0.75 t/h unit. Reported sand regeneration efficiencies based on sand input range from 65 % to 85 %. Spanish data give a total energy consumption of 120 kWh/t of regenerated sand for a 1.2 t/h unit.

Applicability
The pneumatic system can be used for the regeneration of organic mixed and monosands and mixed sand containing bentonite. It also finds application as a pre- or post-treatment in combined mechanical-thermal-mechanical treatment Here, the main use is the removal of residual dust from the sand grains and cooling. The regenerated sand from simple mechanical regeneration may be used in mould making (using 100 % regenerated sand) or mixed with new sand in core-making (using 40 - 60 % regenerated sand).

Furthermore, the technique may be applied for the regeneration of core sand of the CO_2-water glass type from aluminium foundries. This is discussed separately below.

Economics
Investment costs for a single 0.8 – 1.2 tonne/h unit are EUR 330000. Operational costs are estimated at EUR 22/tonne, which gives a total regeneration cost of EUR 36.5/tonne of sand.

Driving force for implementation
Legislation using high disposal fees to reduce the amount of residues for disposal.

Example plants
This type of equipment is built by various suppliers: e.g. KGT Jet Reclaimer, Künkel-Wagner GmbH Turbo Dry, Kernfest Webac AB. The technique is used in several plants in Western Europe and China.

Reference literature
[32, CAEF, 1997], [82, IfG - Institut für Gießereitechnik, 1996], [108, FEAF, 1999], [110, Vito, 2001], [122, Kirst, 1999], [128, IHOBE, 1998]

4.8.7 Thermal regeneration

Description
Thermal regeneration uses heat to combust binders and contaminants. All thermal processes need an initial mechanical step in order to bring the sand to the correct grain size and to screen out any metallic contaminants. This pretreatment may also involve a (partial) abrasion of bentonite and dust removal. The heating of the sand is usually achieved by means of a fluidised bed furnace, operating at temperatures mostly between 700 to 800 ºC. Rotary kilns or multiple-hearth furnaces are also used. Heat may be provided by gas combustion, electric heaters or by short wave infra-red emitters. The throughput of these systems ranges from 250 kg/h to more than 5 t/h.

The emerging gases are combusted in order to eliminate carbon monoxide and any VOCs that may be present. This may be done in the freeboard of the furnace, if it is large enough, by adding complementary air or by gas-fired afterburners. If the temperature of the combustion gases is not high enough or if the time during which the gases are at a high temperature is not sufficient, a separate afterburning device is added. In all cases, emissions can be considered as insignificant.

The exhaust gases are filtered, mostly by means of fabric filters. Therefore cooling is needed, which may be done using water injection, heat exchange/recovery or by mixing with air naturally entering through openings/slits etc. The cooling may incorporate a preheating of the fluidisation air.

Achieved environmental benefits
Reduction of the amount of sand for disposal and a reduction in the consumption of new primary sand.

Cross-media effects
Thermal regeneration requires fuel and generates emissions of dust and combustion related compounds (NO_x, CO; and in the case of oil:SO_2).
The high energy consumption and complexity of the installation are balanced by a low wearing of the sand grains and the recovery of the dust in a thermally inert form.

Thermal regeneration of furan bonded sand with paratoluenesulphonic acid as a hardener, requires flue-gas cleaning: i.e. a, post-combustion of CO and the adsorption of SO_2.

Operational data
The sand is usually heated to temperatures of 700 – 850 ºC. Theoretically, this requires 200 kWh/t. In practice, energy uses of 150 – 350 kWh/t are reported, depending on the energy recuperation and the calorific value of the sand.

Operational data from 3 thermal regeneration plants, treating various types of sand and of various capacities are given in Table 4.64.

Property	Units	Plant		
Reference plants		**Foundry K**	**Foundry L**	**Foundry M**
Type of sand		Cold-box core units	Green sand moulding, Cold-box cores	Handforming in furan bonded sand
Regeneration unit supplier		CEC/VAW	Richards	Siempelkamp
Technique		Multiple hearth furnace (500 ºC) with sieving and classification	Fluidised bed furnace (780 ºC), mechanical size reduction and dedusting	Fluidising combustion chamber with magnetic pre-separation, simultaneous processing of sand and dust from mechanical furan sand regeneration
Sand throughput	t/h	12 – 16	1.0	2.0 used sand, 0.5 dust
Capacity	t/yr	28600	3840	5000
Regeneration ratio, based on used sand throughput	%	95	95 (99 (1))	95
Application of regenerated sand		Core-making	Core-making	Mould and core-making
Quality criteria for regenerated sand		Dust <1 % AFS 60 – 70 LOI <0.1 %	Identical to new sand F33	LOI <0.5 % pH 6.0 – 6.5 Mould strength upon addition of 1 % binder and 0.3 % harder: 350 N/cm² after 24 h
Consumption of electrical energy	kWh/t	119	65	
Consumption of natural gas	m³/t	24.5	38	
Residue production	t/year	660	Dust: 10 Bentonite sand: 1700	200
Final destination of residues		Mining cavities	Cement production	Construction industry/disposal site
Waste gas flow	Nm³/h	7000	16509	6560
Waste gas temperature	ºC	75	60	35
Type of filter		Post combustion and fabric filter	Fabric filter	Lime injection + fabric filter
Emission levels (2)				
- dust	mg/Nm³	0.1	4.9	0.4
- C_{total}		2.2	5.7	10
- CO		2.3	1.6	0
- O_2	%	14	n.d	20.95
- PCDD/F	ng TEQ/Nm³	0.006	n.d	n.d.

(1) The higher recuperation rate (99%) is reached if only in-house core sand is regenerated. A rate of 95 % applies for mixed internal and external core sand
(2) Emission levels are calculated average values from continuous monitoring data over a period of several hours, during sampling for dust or PCDD/F

Table 4.64: Operational data of 3 German reference foundries applying thermal sand regeneration [153, Umweltbundesamt, 2002]

The performance of the regeneration technique and the quality requirements for the regenerated sand are evaluated on a location-specific basis. Specific data may be found in the references: [186, Stephan, 1996], [187, Stephan, 1997], [188, Stephan, 2000].

Applicability

Thermal systems are normally used for chemically bonded sand systems and mixed sand systems, providing the share of chemically bonded sands (cores) is high enough. Nevertheless, a distinction can be made:

- some binders may leave inorganic salt residues at the grain surface. When the temperature increases above the melting point, these spread out over the sand surface and may cause the sintering of the sand grains upon cooling. Known examples are resol resin and silicate resin-bonded sands
- the thermal recycling of furan resins causes the emission of SO_2 if sulphonic acids are used as a hardening agent. The temperature of the exhaust system must be sufficiently high enough to prevent sulphuric acid condensation. If the emission is high, a wet flue-gas cleaning may be needed. Phosphor (from the phosphoric acid used as a hardener) does not evaporate but remains on the surface in salt form. This may lead to P accumulation upon recycling. If the P-concentration rises above 0.5 – 0.7 %, a metallurgical reaction may occur, causing the rejection of the casting.

The degree of implementation of thermal regeneration is low compared to mechanical regeneration. In Germany, only 10 installations were reported to apply this technique in 1999 (compared to 200 mechanical units).

The Siempelkamp thermal regeneration unit in Krefeld has the ability to treat foundry dust along with the waste sand. Tests have been run on other mineral waste types as well.

Economics

Investment costs vary according to the size and type of equipment and are given in Figure 4.30. The data relate to thermal systems with a mechanical pre- or post-treatment step, as well as for intensive mechanical regeneration (e.g. grinding units). Small scale installations have a capacity of 0.75 t/h or 1500 t/yr. A medium size foundry will be between 2500 and 5000 t/yr. For a small scale unit, the capital cost (with 8 years amortisation and 8 % interest rate) would be EUR 55/t. These costs do not include expenses for energy, personnel nor for the disposal of residues.

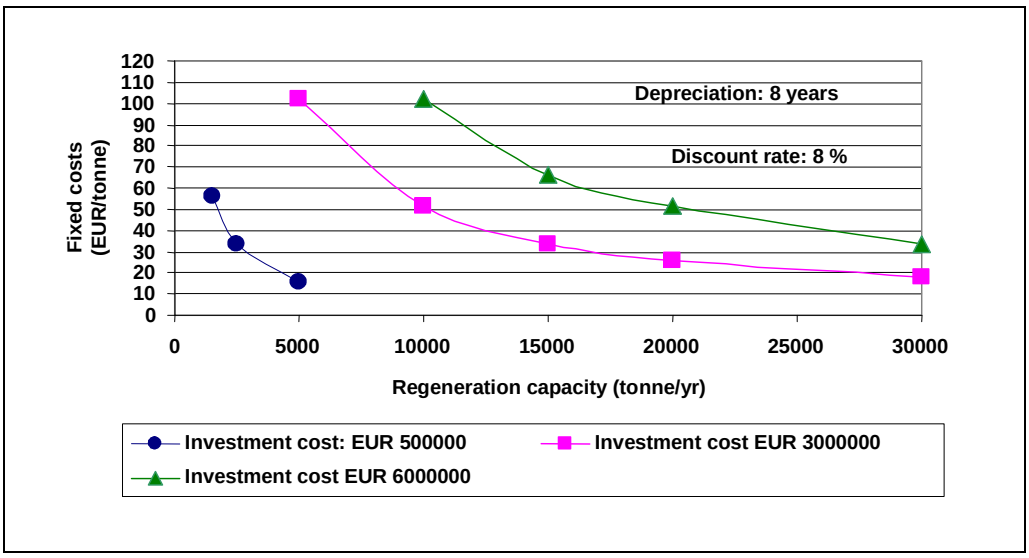

Figure 4.30: Fixed costs in euros per tonne of regenerated sand for thermal regeneration and high level mechanical regeneration of mixed sands
[82, IfG - Institut für Gießereitechnik, 1996]

Driving force for implementation

Legislation using high disposal fees to reduce the amount of residues for disposal.

Example plants
- Fluidised bed, Metaalgieterij Giesen, the Netherlands
- Fluidised bed centralised regeneration plant, Bielefeld, Germany
- VAW Alucast GmbH, Dilingen, Germany, system CEC/VAW
- Werner Rietschle GmbH, Schopfheim, Germany, system Richards
- Siempelkamp Giesserei gmbH & Co, Krefeld, Germany, system Siempelkamp
- Sofogir, Ronchamp (F) system Regetherm 500
- Duranton Sicfond, Vénissieux (F), system Richards
- FOAM, Leumann (I), system Eco-rec
- Fonderie Bréa, Montluçon (F).

Reference literature
[9, Schneider, 1993], [32, CAEF, 1997], [80, ERM Lahmeyer International GmbH, 1999], [128, IHOBE, 1998], [138, Metaalgieterij Giesen B.V., 1996], [186, Stephan, 1996], [187, Stephan, 1997], [188, Stephan, 2000]

4.8.8 Combined regeneration (mechanical–thermal-mechanical) for mixed organic-bentonite sands

Description
In mixed organic-bentonite sands, cured bentonite and organic binders are present on the sand grains. The dust is composed of active and cured bentonite, coal dust (only for iron foundries), quartz fines and organic binder residues. Mixed sands occur mainly in iron foundries and represent some 75 % of the total used sand production. The regeneration can be performed using mechanical, pneumatic, thermal or combined systems.

The sand is pretreated (sieving, magnetic separation) and dried, in order to reduce the water content to <1 %. After this, the sand is mechanically or pneumatically cleaned in order to remove part of the binder. In the thermal step, organic constituents are burned, and inorganic constituents are transferred to the dust or burned onto the grains. In a final mechanical treatment, these layers are removed mechanically or pneumatically and discarded as dust. A typical layout for a system using pneumatic treatment and fluidised bed thermal treatment is depicted in Figure 4.31.

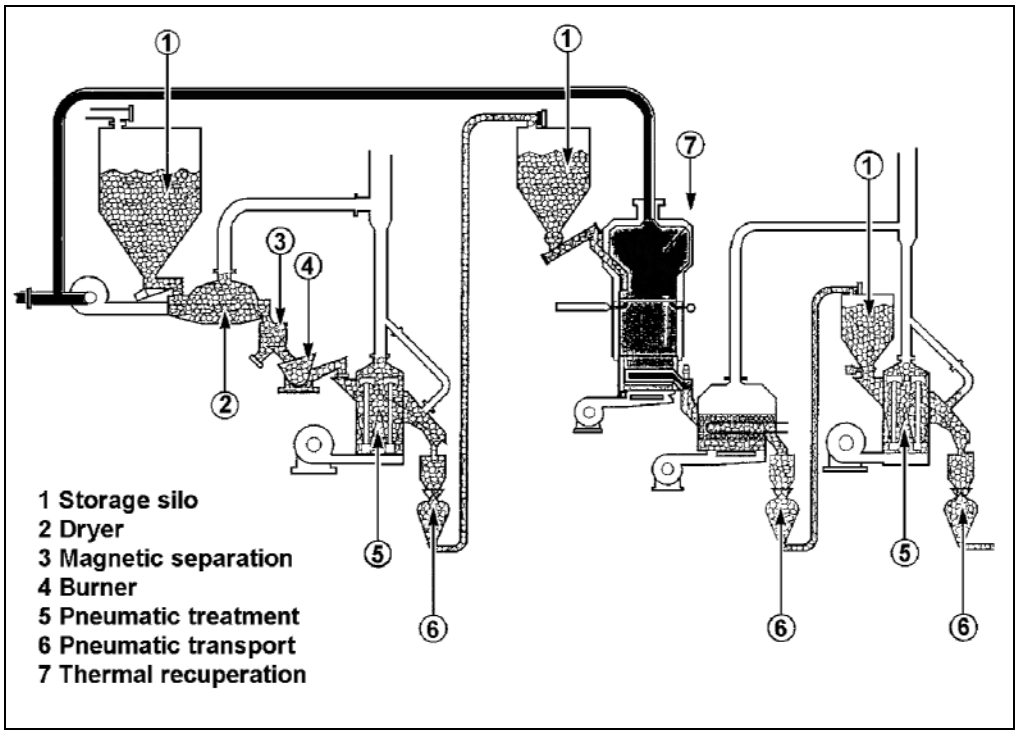

Figure 4.31: Mechanical-thermal-mechanical sand regeneration unit [108, FEAF, 1999]

Achieved environmental benefits
Reduction of the amount of sand for disposal and of the consumption of new primary sand.

Cross-media effects
The regeneration of sand requires additional energy and causes additional dust emissions and residual dust for disposal.
The general evaluation of internal regeneration versus external re-use, and the corresponding cross-media effects, are discussed separately below.

Operational data
Operational data for a mechanical-thermal-mechanical treatment are given in Table 4.65.

Parameter	Units	Foundry N	Foundry O	Foundry P
Sand flow	(tonne/h)	1	2	3
Maximum humidity of the sand input	(%)	1	1	1
Total installed electric power	(kW)	150	215	400
Natural gas	(Nm^3/h)	31	62	155
Thermal treatment - average airflow (fluidisation + combustion)	(Nm^3/h)	700	1200	3000
Treatment temperature	(ºC)	800	800	800
Average treatment time	(min)	20	20	20
Flue-gas flow	(Nm^3/h)	200	300	500
Cooling - type - water flow in the circuit	(m^3/h)	Fluidised bed with water circulation 15	30	75
Sand temperature at exit	(ºC)	30 – 40		
Total energy consumption: - electric - gas		100 260	90 260	70 260
Compressed airflow	(Nm^3/h)	150	210	330
Efficiency of the installation		70 – 80 %		
Regenerate sand quality: - granulometry - loss on ignition		Unchanged ≤0.1 %		
Re-use of the regenerated sand: - mould making - core-making		100 % 70 – 80 %		

Table 4.65: Operational data of a mechanical-thermal-mechanical treatment system (pneumatic - fluid bed - pneumatic)
[108, FEAF, 1999]

German data for a 85000 tonne/yr (13 – 15 tonne/h) installation provide the following off-gas composition:

- SO_2: 118 mg/Nm³
- NO_x: 150 mg/Nm³
- total C: 10 mg/Nm³
- CO: 30 mg/Nm³

Applicability
This regeneration technique is used for mixed sands containing bentonite. The economical and technical success of the regeneration depends on the selection of the sand to be regenerated. It is not suitable to regenerate the whole sand volume. Sand which is not thermally damaged can be re-used directly for new sand preparation. Its regeneration is not suitable, because active binders and additives would be removed. A selection and separation has to be made during shake-out, before homogenisation. The technique cannot be applied for core sands which disrupt bentonite characteristics (binders of acid nature) or which change green sand characteristics (e.g. water glass sand).

The regenerated sand can be used for core-making in the original process, for cores with low or medium geometrical demands. The applicability for core-making is related to the initial amount of chemically-bonded sand. The applicability in other binder systems must be tested in each case. Furthermore, these sands may be applied without restrictions for the replacement of losses in green sand moulding cycles. Restrictions may apply in processes that use water glass or methyl formate bonded sands.

In recent years, various types of installations have been developed for the treatment of mixed sands, but they have not yet found broad implementation in the sector. Some only work on a pilot scale. Others have been developed for a specific foundry and produce a regenerated sand suitable for re-use only in the same process, and results cannot be transposed to other foundries.

Economics
Costs for a 3-step installation (mechanical-thermal-mechanical) using pneumatic cleaning as the mechanical step (3 tubes in 1 chamber, KGT type Jet Reclaimer) with a capacity of 2.5 tonne/h are as follows: operational costs (consumption, personnel, maintenance) - EUR 21/t, investment costs (8 year amortisation) - EUR 30/t, thus yielding a total regeneration cost of EUR 51/tonne.

The consumption levels are as follows:

- Electricity: 50 kWh/t
- Natural gas: 18 Nm^3/t (depending on the moisture content of the sand)
- Compressed air: 60 Nm^3/t
- Wear parts: 5 EUR/t

Driving force for implementation
Legislation using high disposal fees to reduce the amount of residues for disposal.

Example plants
Halberg Guss GmbH, Saarbrucken (D), thermal-mechanical system. This plant treats 13 – 15 t/h of mixed 30 % organic, 70 % inorganic bonded sand. The organic bounded sand is a 50/50 mixture of Croning and cold-box sand. The regeneration yield on the basis of the amount of used sand treated is 78 %. The regenerated sand is applied for core-making (100 % Croning; 70 – 100 % cold-box).

The mechanical primary regeneration + separation of chromite (from cores) and quartz sand (both chemically-bonded) + thermal/mechanical treatment of quartz sand was demonstrated on a pilot scale in Germany (1993). Separation of both sand types was needed because sintering and eutectics formation occurred in the mixed sand. The plant later closed down due to other economic reasons.

Reference literature
[11, Schachtner and Müller-Späth, 1993], [37, Winterhalter, et al., 1992], [108, FEAF, 1999], [122, Kirst, 1999], [128, IHOBE, 1998], [153, Umweltbundesamt, 2002], [225, TWG, 2003]

4.8.9 Wet sand regeneration

Description
After metal removal, the sand is mixed with water to produce a sludge for easily separating the binder and to allow subsequent wet screening (1.6 mm). The removal of grain-bound binder residues is performed in the wet regeneration unit, through intensive interparticle rubbing of the sand grains. The binders are released into the wash-water. The washed sand is dried to a final moisture content of max. 0.3 %, dry screened (at 1.2 mm), and then cooled. This may be followed by an additional magnetic iron extraction and a final dust collection. The binder residue is separated from the suspension and treated to allow its safe, disposal.

The main advantage of the process over mechanical and thermal processes is that it allows real time process monitoring. Through pH control, continuous follow-up of the process is possible, allowing corrective real-time action if needed and producing a continuous quality regenerated sand. The technique allows removal of the binder layer through wet mechanical action, combined with chemical action when needed, without wearing the sand grains.

The process mainly aims to lower both the oolitisation degree of used sand (LOI max. 1 %) and the acid content.

Achieved environmental benefits
Reduction of the amount of sand for disposal and of the consumption of new primary sand.

Cross-media effects
The wet process generates a sludge for disposal and a waste water stream. A serious problem of this waste water flow is the bad sedimentation of bentonite, and its difficult removal out of waste water. Waste water from water glass sands regeneration shows the presence of alkaline ions. These ions are difficult to separate from the waste water.

Applicability
The wet regeneration system can only be applied to green sand and silicate- or CO_2-bonded sands. Regeneration from these types of processes allows full re-use of the regenerated sand in both moulds and cores. Tests on regenerated green sand showed the possibility of producing good quality cold-box cores with an acceptable binder quantity (1.8 % in total).

Economics
Within the Italian foundry market, a centralised wet regeneration plant can offer regenerated sand at a price lower than that of new sand.

Driving force for implementation
This system is reported to be able to cope with changes in used sand quality better than mechanical or thermal processes. This makes it suitable when considering a centralised sand regeneration plant.

Example plants
Safond centralised green sand wet reclamation plant, which since 1981 has been treating 230000 tonnes/yr of used sand.

One Polish foundry (Odlewnia Zeliwa Srem s.a., Srem (PL)) operates a wet regeneration of furan bonded sand. The operation is governed by site-specific factors and the technique cannot be considered for transposing to other sites.

Reference literature
[37, Winterhalter, et al., 1992], [140, EU Thematic Network Foundry Wastes, 2001], [225, TWG, 2003]

4.8.10 Regeneration of water glass sand using pneumatic systems

Description
Water glass sand has been traditionally difficult to regenerate. The use of a pneumatic system has allowed the setting up of regeneration plants operating of a 60 % regeneration ratio. The system works along the same principle as mentioned above (see Section 4.8.6). For this type of binder however, the sand needs to be heated to 220 ºC before the regeneration, in order to make the silicate layer brittle. The sand should have a humidity below 0.3 % before regeneration. The regenerated sand may be re-used in the same system. In order for the ester to work properly, the regenerated sand must be cooled to below 20 ºC, before feeding back into the moulding cycle.
Water glass sand regeneration systems comprise the following process steps: breaking – drying/heating – (pneumatical) reclamation – cooling - filtration.

This technique has a lower performance than the thermal regeneration of organically bound sands. The following limitations occur:
- lower immediate compressive strength
- shorter applicability times of the core sand mixtures
- stability loss upon storage of cores
- loss of retained compressive strength, especially with the use of binders with high collapsibility.

In order to compensate for these problems, changes to the processing scheme or the binder mixes are needed.

Achieved environmental benefits
The application of water glass sand as a binder has a low environmental impact, compared to the application of organic binders. This technique allows the (partial) regeneration of the water glass bonded sand and thus reduces the need for used sand disposal and primary raw material use.

Cross-media effects
In order to heat up the sand, natural gas is combusted. The corresponding CO_2-emission is estimated to be 18 kg/tonne of used sand. NO_x emissions will also occur.

Operational data
A German example plant operates a pneumatical unit in a step-wise cycle. The sand is first dried by the introduction of heated air (5 min/220 ºC). After this, the pneumatic cleaning is started by injecting of shots of compressed air (70 min.). This is followed by a final dedusting phase, during which only fluidising air is introduced (2 min). There is no need for further cooling, since the sand cools down to a workable temperature.

The yield of regenerated sand for one cycle operation is reported to be 85 % of the initial weight (on the basis of SiO_2). In order to produce stable cores, and taking into account the further reduction of sand quality upon a second regeneration cycle, a maximum regeneration ratio of 62 % may be achieved (leaving 38 % new sand addition).

Specific consumption levels are as follows (for a 1500 tonne/yr; 0.5 tonne/h unit):
- natural gas consumption: 104.4 kWh/t used sand
- electricity consumption: 74.5 kWh/t used sand.

A Polish example plant (in a cast steel foundry) consists of the followig units: vibratory crusher – drier – impact plate regenerator – cascade dedustor – electromagnetic separator. The technical details of the installation are given in Table 4.66. The regenerated sand is re-used in the preparation of silicate-bonded moulding-sand. The silicate-sand is used as backing sand in mould making, with alkaline sand used as contact sand. The total sand balance (on a yearly basis) shows a use of 45 - 47 % regenerated sand.

Characteristic	Value
Capacity	10 tonne/h
Recovery ratio	90 %
Content of regenerated sand in the moulding-sand	50 – 60 %
Working power	76 kW
De-dusting system efficiency (2 bag filters)	99.4 %
Installation area for regeneration site	220 m²

Table 4.66: Operational data of a silicate sand regeneration unit [200, Metalodlew s.a., 2002]

A Spanish example plant (cast steel foundry) reported a re-use of 80 - 88 % (with a yearly average figure of 12.5 % new sand addition) of regenerated silicate-ester sand in a manual moulding line, used for the casting of big pieces. The regeneration system consists of: vibratory crusher – heating in an indirectly heated reactor ('quemador' with gas burner in a side chamber) – cooling in a water-cooled heat-exchange tower – impact cleaning in a rotary mixing chamber.

Italian example plants also use special equipment for heating sand to temperatures of 140 ºC to 150 ºC, to enable the removal of defects and the embritlement of the water glass coating. This is followed by mechanical treatment in a rotary wiper, dedusting and finally cooling. A schematical drawing of the rotary regeneration unit is given in Figure 4.32.

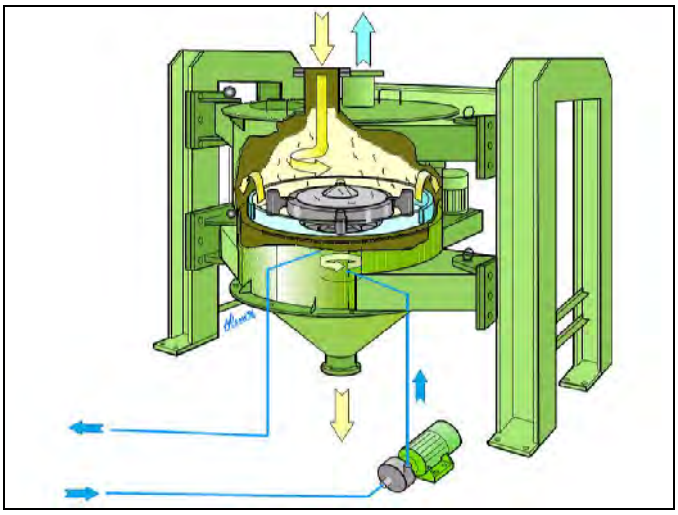

Figure 4.32: Rotary mechanical regeneration unit [225, TWG, 2003]

The equipment has an energy consumption of 35 kW/tonne of regenerated sand. The operational loss of sand is about 5 %. For moulding and core making mixtures, over 90 % of regenerated sand can be used. The achievable regeneration ratio depends on the intensity and time of regeneration and the operational sand loss. Sand losses occur during each part of the whole cycle of mixing, preparation, transportation, mould production and regeneration.

Applicability

The applicability of regeneration for water glass sands depends on the catalyst used. With classic polyacetate glycerol esters, regeneration is no longer possible after a number of cycles. With carbonaceous esters, regeneration is possible and even easier than for silicate-CO_2 sand. If the sand cannot be cooled below 20 ºC before returning to the mixer, esters with a slow reaction need to be used. These cannot be regenerated. This situation may occur during summer in hot climates.

The re-use of the regenerated water glass sand for the preparation of organically bound moulds or cores is problematic. The elevated content of electrolytes (binders) prohibits their use in other core binder systems. The highly basic water glass residues have a negative effect on bonding and core stability, in both neutral as well as alkaline binder systems. Applications in green sand cycles and acidic core binder systems have not yet been successfully implemented. This may be due to a reduced interest in the development of this application.

Because of the low quality of secondary regenerated sand, it is necessary during de-coring and sand collection to identify the amount of regenerated sand and its origin (e.g. number of cycles), and to then discard any unusable sand.

Due to the high costs and relatively low regeneration ratio, depreciation of the installation in a reasonable time can only be guaranteed for plants with a capacity >2500 tonnes/yr.

Economics
The processing cost of this technique for the German example plant is around EUR 60/tonne. This high cost was the reason one operator closed his plant down and went back to the disposal of the water glass sand, which he could do for the lower cost of EUR 30/tonne.
The reported operational cost by the Spanish example plant is EUR 10/tonne.

Driving force for implementation
To enable the regeneration of water glass sand, which has a good environmental performance in certain applications.

Example plants
- KGT Jet Reclaimer centralised regeneration plant for 4 foundries, constructed 1998 at Fa. Bröer, Schwetzingen (D) but stopped operation in 2001
- Metalodlew s.a., Krakow (PL)
- Lur Sue s.l., Lora Del Rio (E)
- Fonderia Arno Metallurgia, S. Vittore Olona (I)
- Faser Spa, Rogeno (I)
- Talleres De Amurrio S.A. Amurrio (E)
- Daros Piston Rings AB, Partilla (S).

Reference literature
[128, IHOBE, 1998], [152, Notzon and Heil, 1998], [154, Baum, 2002], [200, Metalodlew s.a., 2002], [210, Martínez de Morentin Ronda, 2002], [225, TWG, 2003], [228, Galante, et al., 1997]

4.8.11 Internal re-use of uncured core sand

Description
Core production generates sand residues in the form of broken cores, cores with small mistakes and excess sand from the core-making machines. The excess sand can be hardened in a specific unit. Subsequently the various unused core sand flows are fed to a breaking unit. The resulting sand may be mixed with new sand for the production of new cores.

Achieved environmental benefits
Internal re-circulation of 5 - 10 % of the core sand, which otherwise would be disposed of.

Cross-media effects
No cross-media effects occur.

Applicability
This technique applies for polyurethane (cold-box) and furan resin-bonded sands. Other binders do not allow this technique.

The implementation of the technique necessitates changes in the process control. The optimum ratio of re-circulated and new sand will need to be determined. Additionally changes in binder addition or composition may be needed.

Economics
The technique requires an investment cost of EUR 250000 – 500000 for the combined treatment and breaking unit. Operational costs are about EUR 12/t. These costs are balanced by a reduction in disposal costs and purchasing costs for new sand.
The technique is only viable for core intensive production.

Driving force for implementation
Optimisation of the use of primary materials and reduction of the amount of waste for disposal.

Example plants
The technique was reported by several large-scale foundries.

Reference literature
[82, IfG - Institut für Gießereitechnik, 1996], [110, Vito, 2001]

4.8.12 Re-use of dusts from the green sand circuit in mould making

Description
Dust is collected through the exhaust filtration from the shake-out installation and from the dosing and handling stations for dry green sand. The collected dust contains active binder compounds and may be recycled into the green sand circuit.

Achieved environmental benefits
Reduction in the use of binders (bentonite), and additives (carbon), through internal re-circulation.

Cross-media effects
No cross-media effects exist.

Operational data
An iron automotive foundry, using an automated moulding line with a production of 8000 t/yr castings produces 480 t/yr of dust. This sand is collected, cooled and recycled into the sand mixer. The collected dust contains 23 % active bentonite and 10 % carbon. 50 % of the dust can be re-circulated without any risk of loss of quality due to fine dust.

Applicability
The technique may be applied in new and existing green sand installations.

Economics
The technique requires an investment of EUR 25000 for storage and transport equipment. The amortisation period is 8 years, with a discount rate of 8 %, for a 240 tonne/yr installation, resulting in a capital cost of EUR 17/tonne of treated sand. There are no additional operational costs since the operation of the overall installation does not change.

Driving force for implementation
To optimise the use of primary materials and to reduce the amount of waste for disposal.

Example plants
Iron automotive foundry in Germany.

Reference literature
[82, IfG - Institut für Gießereitechnik, 1996]

4.8.13 External re-use of used sand and the undersize from the sand circuit and regeneration processes

Description
Used sand and undersize sand from the sand circuit or sand regeneration may find some external applications, with the main areas of application being:
- the construction industry (road construction, highway construction)
- the building materials industry (cement, bricks, limestone manufacture)
- in the filling of mining cavities
- in landfill construction (roads on landfills, permanent covers).

The limits of these applications are given by either technical criteria for construction materials and/or environmental criteria for the given application. Environmental criteria are generally based on leaching properties and the content of organic compounds. These differ between various European regions. Used sands generally show a low metal leaching potential. An exceedence of the limit values may occur for materials with a high content of organic binder or with specific additives, such as lustrous carbon.

Due to its high quartz content and appropriate granulometry, used sand may be applied as a virgin sand substitute in road construction. Application in the production of building materials (concrete, bricks, tiles, glass wool, …) are technically feasible but require a higher level of composition control and logistics. Industrial scale trials have been successfully applied in:
- road bases
- filling material
- drainage material
- concrete elements
- cement production (depending on the silicon need of the process. In Germany this application is of major importance)
- filling of mining cavities (due to its good supporting capacities. Used sand is used in this application in Germany)
- final cover on landfills (mixed with water glass and other wastes, examples in the Netherlands)
- construction material for the reinforcement of dikes
- vitrification of hazardous waste.

A survey table which gives more detailed information for the different sand types is given in Section 4.9.

Other fields of application are the fabrication of bricks, secondary copper smelting and zinc recuperation.

It should be stressed that discussions on the (type of) external utilisation fall beyond the scope of the current reference document. However, in general, it can be stated that the sand usually needs no pretreatment and is transported from the foundry after collection and intermediate storage. Usually in order to guarantee a continuous quality of the material, a separate collection and storage system will be developed. Furthermore, the quality of the material needs to be controlled through regular analyses.

Achieved environmental benefits
In external applications, the used sand substitutes, and therefore saves, virgin materials. In general, the external application does not require any treatment of the sand and therefore does not generate any energy expense for the foundry.

Cross-media effects
Residues of organic coatings are possible sources of aromatic hydrocarbons.

Applicability
This technique is applicable for new and existing installations, as long as they can find a buyer for the waste sand.

The use of surplus foundry sand does not reduce the wear resistance of asphalt concrete. The use of surplus foundry sand together with the dust from the same foundry process is possible in Portland cement concrete production. The use of surplus foundry sand together with fly ash and steel slag is possible in mineral wool production. The use of surplus foundry sand in the composting process of biowastes does not negatively affect the environmental or technical features of the final product, i.e. the topsoil. The use of surplus green sand in mineral liners is technically and environmentally possible in the top layers of the landfill.

Economics
Costs for external utilisation depend on the local market and the transport and storage costs needed.

Investment costs for separate collection and storage are minimal. Often these can be realised through organisational measures. Operational costs for analyses and administration may be up to EUR 5000/yr. On the benefit side, there is a reduction in the costs for disposal (up to EUR 125/tonne).

Driving force for implementation
Legislation using high disposal fees to reduce the amount of residues for disposal.

Example plants
Multiple examples have been reported throughout Europe, e.g. by Finland, the Netherlands, Belgium, Germany, UK.

Reference literature
[82, IfG - Institut für Gießereitechnik, 1996], [110, Vito, 2001], [128, IHOBE, 1998], [169, Orkas, 2001], [171, The Castings Development Centre, 1999]

4.9 Dust and solid residues: treatment and re-use

4.9.1 Introduction

A good segregation of materials is essential to facilitate opportunities for recovery, recycling and re-use. Waste should always be recycled or recovered unless a satisfactory justification has been accepted by the regulator that recovery is “technically and economically impossible”.

In general, the waste streams comprise:
- raw material dusts collected in bag or cartridge filters
- slag from desulphurisation
- slag/dross from melting
- melting dust and fume collected in a filter plant
- casting dust and fume collected in a filter plant
- fettling dusts collected in an abatement plant
- chips and turnings from fettling
- used abrasives from shot blasting
- scrubber liquors and sludges and output from the effluent treatment plant
- refractory waste from launders and ladles
- sand
- chemical and oil containers
- general inert industrial waste.

Waste should be recovered wherever practicable. Other than sand, the most significant wastes are:
- slag from the melting and metal treatment processes
- dust collected from abatement plants
- collected sludge
- refractory waste.

[160, UK Environment Agency, 2002]

4.9.2 (Pretreatment for) external re-use of solid residues

Description
In order to allow an external re-use of solid residues, the material may need treatment. Table 4.67 gives the required processing for the various (non-sand) solid residues and possible limitations for their re-use.

For cupola furnace slag, the physical form, and therefore to some extent its options for re-use, depend on the type of de-slagging used. Dry slagging, i.e. pouring of the slag in pots for cooling and solidification, produces a crystalline non-porous mineral. Concerning technological aspects, this slag is comparable to blast furnace slag. Wet slagging generates a granular slag by cooling the slag with a water jet.

Residue type	Treatment	Limitations
Air-cooled cupola slag	Crushing	- generation of glassy dust - handling requirements due to glassy nature
Water quenched cupola slag	None	- generation of glassy dust - handling requirements due to glassy nature
Induction melting slag	Crushing	- generation of glassy dust - handling requirements due to glassy nature - little data available on leachates
EAF slag	Crushing	- generation of glassy dust - handling requirements due to glassy nature - little data available on leachates
Desulphurisation slag	Extraction of metal and other coarse particles	- handling requirements, CaC_2 needs careful handling to avoid injury - run-off - may be a special waste
Dusts and sludges	Sludge pressing, drying and granulation needed for most applications	- health and safety requirements for some dusts - problems with transport of dusty materials - high leaching potential due to nature of product and large surface area

Table 4.67: Necessary treatment and possible limitations for external re-use of solid residues [171, The Castings Development Centre, 1999]

Achieved environmental benefits
In external applications, the re-used material will serve as a secondary construction material and can substitute for virgin materials. The recycling results in a reduction in the amount of material for disposal.

Cross-media effects
Pretreatment requires energy and may generate dust emissions.

Applicability

The technique is applicable for new and existing installations, as long as there is a suitable a local market for the residue.

A survey of external re-use applications for various solid wastes is given in Table 4.68.

SUMMARY OF RE-USE APPLICATIONS	SAND						SLAGS					OTHER	
Construction type uses	Greensand	Alkaline phenolic	Phenolic urethane	Furan	Resin shell	Sodium silicate	Air-cooled cupola	Water quenched cupola	Induction	Electric arc furnace	Desulphurisation	Investment casting shell	Dusts and sludges
Asphalt	x	x	+	+	+	O	x						
Ballast							+			+			
Block making	+	x	+	+	x	+		x					
Brick manufacture	x	x	+	+	+		+	+					
Cement	x	x	+		x	x							
Coarse aggregate substitute							x		x	x		x	
Concrete		x	+	+	+								
Fine aggregate substitute	x	x	+	+	+	+							
Foamed concrete, etc.	x	x	+										
Insulating/mineral/glass wools	+	+	+	+	+	+	+	+					+
Lightweight aggregate production													+
Mortar production						+							
Road base construction		x	+		+	x	x		x	x		x	
Roofing felt				x									
Re-use in another foundry													
As new sand addition to greensand				x									
Soil type uses													
Artificial topsoils	x	+	+	x	+								+
Decorative ground cover							+	+					
Ground cover in riding stables								+					
Fertiliser filler													x
Landfill - capping	x	x	+										+
Landfill - daily cover	x	x	+	x	x	x							
Landfill - liner	+												+
Soil modifier/improver	+	+	+	+	+	+		+			+		+
Miscellaneous													
Abrasives/blasting media		x	+					x	+				
Absorbent media												+	
Blast furnace slag cement manufacture						+					+		
Chemical/industrial applications													x
Slaked lime replacement											+		+
Smelting fluxes		+	+		+	+							
Waste vitrification	+	+	+		+	+							

x Proven re-use application, with successful projects running in the UK
+ Re-use application that has been proven in theory but no re-use project is currently running in the UK
O Unsuitable for re-use in untreated from

Table 4.68: Summary of external re-use applications for solid foundry residues (status 1999) [171, The Castings Development Centre, 1999], [202, TWG, 2002]

Economics
The costs associated with re-use are mainly the processing and transport costs, but these can possibly be reduced by taking into account the income generated from selling the material. However, the latter in general may be low or close to zero, whereas typically mechanical treatment costs are in the range of EUR 8/tonne.

The further the materials have to be transported, the greater the increase in costs. In order to assess the economic viability of the re-use option, the applicable disposal costs should be taken into account. These differ between various regions and depend on the residue type.

Driving force for implementation
Legislation stimulating the recycling of mineral wastes, partly by setting high disposal fees to reduce the amount of residues for disposal.

Example plants
Multiple examples of sand and slag re-use have been reported throughout Europe, e.g. in Finland, the Netherlands, Belgium, Germany, UK

Reference literature
[171, The Castings Development Centre, 1999]

4.9.3 Minimisation of slag forming

Description
The production of slag can be minimised using in-process measures, such as:
- using clean scrap
- using a lower metal temperature
- preventing overshoots (temporary high temperatures)
- preventing long standing times of molten metal in the melting furnace
- making adequate use of fluxes
- making adequate use/choice of refractory lining
- applying water cooling of the furnace wall to avoid usage of refractory lining.

Achieved environmental benefits
Minimisation of residue production and reduction of emissions to air.

Cross-media effects
No cross-media effects occur from these minimisation measures. Concerning the melting of clean scrap, the considerations raised in Section 4.1.4 should be taken into account.

Applicability
This technique applies to all new and existing installations. The applicability of the use of clean scrap has been fully discussed in Section 4.1.4.

Economics
This technique does not involve any investement, since it concerns operational measures.

Driving force for implementation
High disposal costs for residues.

Example plants
This technique is part of existing operational procedures in the majority of European foundries.

Reference literature
[103, Vereniging van Nederlandse Gemeenten, 1998]

4.9.4 Cupola furnace

4.9.4.1 Collection and recycling of coke breeze

Description
The handling, transport and charging of coke results in the production of coke breeze. Specific measures may be adopted for the collection and recycling of this material e.g. collection systems below conveyor belts or, at charging points.

The collected material may be recycled into the process by injection into the cupola or in its utilisation for recarburisation.

Achieved environmental benefits
Minimisation of the production of residues.

Cross-media effects
No cross-media effects apply.

Applicability
This technique applies to new and existing installations.

Driving force for implementation
High disposal fees for solid residues.

Example plants
The technique is reported for several foundries in Europe.

4.9.4.2 Recirculation of filter dust into cupola furnace

Description
Cupola filter dust is re-injected into the cupola furnace. The aim of this technique is to achieve an accumulation of zinc in the dust, up to a level that allows reprocessing with Zn recovery (>18 %). Zn recovery is performed using the Waelz process.

Recirculation of the dust can be done through re-injection at the tuyères or by charging dust pellets through the charging door. Both techniques are applied on an industrial scale. A mass balance analysis can be used to show that the zinc is sublimated and reappears in the recuperated dust. After a number of cycles the dust is rich enough in Zn to allow recovery. Recovery is technically possible above an 18 % Zn level.

There are two limits to recycling dust:
- the zinc essentially appears in the form of Zn_2SO_4, a compound containing 64 % Zn. This therefore sets the maximum level of enrichment
- the dust is also enriched in alkali, which causes flame extinction in the combustion chamber. This effect may be solved by injecting water vapour into the combustion air.

Injection at the tuyères can be based on several principles. There are fifteen (status May 2001) European foundries recycling dust by injection at the tuyères. Eleven use the positive pressure technique, and four use the venturi suction technique. The advantage of the venturi technique is that it consumes less injection air and so cools the melting zone less. With both techniques, the dust becomes sticky after successive cycles. In the case of the venturi technique, the dust must therefore be mixed with petcoke to allow its transport in the pipes.

The recirculation of dust through agglomeration and charging is much less common than tuyère injection. This is because the process is much more difficult to automate. Furthermore, good control and knowledge of the pelletisation process is needed to give the pellets the necessary

consistency. Ferrosilicon can be added to produce pellets with good consistency. In practical tests a mix of 2/3 FeSi with 1/3 of dust was needed to allow good operation. On the other hand the pellet technique can be used to treat large quantities. For cupolas with larger diameters, tuyère injection of the dust into the centre of the fire is difficult, this therefore favours the use of pellets.

The properties of both techniques are compared in Table 4.69.

Re-use of the fines collected in the purification of the cupola off-gas	Injection through nozzles	Introduction as pellets	Observations
Influence of the waste			
Limitation in the introduced amount of fines	7 – 8 kg/tonne metal		Problem of extinction of flame
Reduction in the generated amount of fines	40 %	50 %	Approx.(1)
Increase in the content of zinc in the fines	30 %	20 %	Approx.(1)
Increase in slag production	?	?	
Influence on the operation of the cupolas			
Amount of coke necessary to counteract the temperature loss	0.5 – 0.6 %	0.2 – 0.3 %	Approx.(1)
Variation in the analysis of off-gases	No	No	n.a
Influence in melted metal			
Increase in the metal content (Zn, Pb) in the iron	Limited	No	(in the order of thousandths)
Influence in the losses to fire	10 – 30 %	No	Approx. (1)(2)
Effectiveness to add other products (C, FeSi) with the same method	Yes	No	n.a
Costs			
Reduction in the disposal cost of the fines	60 %	50 %	Approx.(1)
Operations			
Possibility of automating the process	Yes	No	n.a
Additional Problem	No	Yes	Crash-resistance of the pellets
Implementation of technology			
Existing Facilities	Yes	Yes	Preferably cupolas of large size
New facilities	Yes	Yes	

(1) Approximation, real value depending on the initial zinc oxide content the fines, of the degree of necessary enrichment for its re-use, and on the characteristics of the cupola
(2) Function of the amount of steel in the load of the cupola
n.a: not applicable

Table 4.69: Properties of injection techniques for recirculation of cupola furnace dust [108, FEAF, 1999]

Achieved environmental benefits

The main benefit of the technique is a decrease in the net amount of dust sent out by the foundry, for disposal or recovery. The foundry typically sends out a smaller amount of dust, but with a higher load of metals. This allows the recovery of Zn from the cupola dusts. The technique results in an enrichment of the Zn in the cupola dust, while for Pb a larger share ends up with the iron. If the Zn is effectively recuperated from the dust, the technique decreases the heavy metal load of the final dust for disposal, as well as its amount. On the other hand, the amount of slag produced increases.

Cross-media effects

Both techniques consume energy, i.e. coke, to melt the product. An increase in coke use of 0.15 to 0.25 kg cokes/kg dust at a thermal efficiency of 40 % of the furnace is reported.

In addition, the injection of cold dust in the hot melting zone will lower the flame temperature, which accordingly will have to be restored by an injection of oxygen. The total amount of slag produced will also increase.

The loading of sticky dust to several of the internal parts of the system will cause medium-term loss of efficiency and possibly operational problems. These have not been quantified.

Operational data

An analysis of the input and output flows of French cupolas resulted in the mass balance shown in Figure 4.33 and Figure 4.34. The contribution of each flow to the Zn-in/output is given together with the zinc-level (as mass and %). The percentages given are average values over the indicated measuring period.

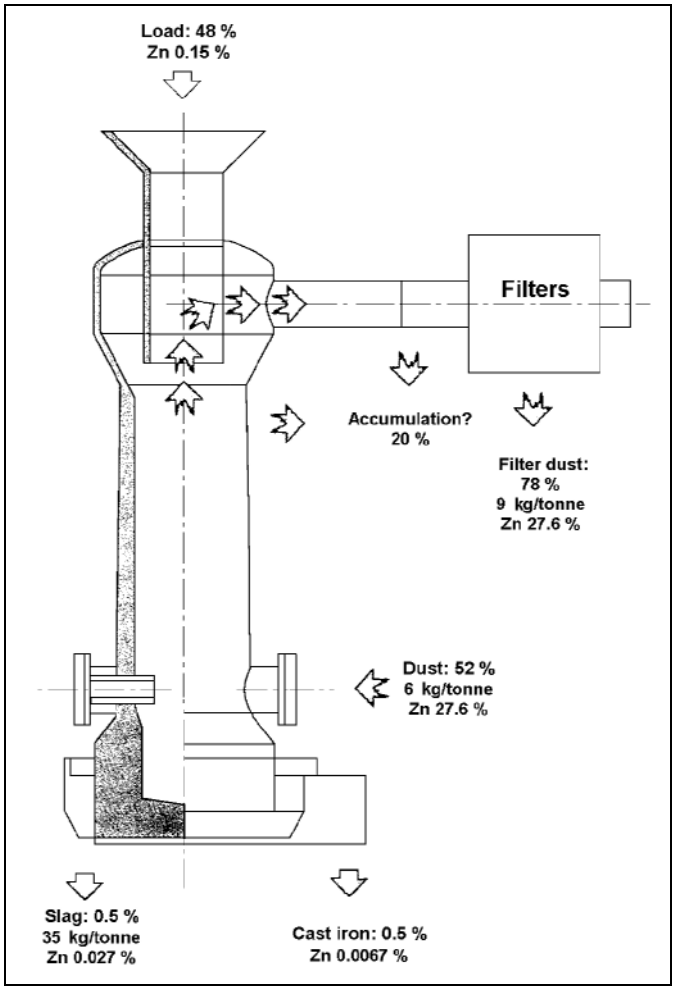

Figure 4.33: Zinc distribution for tuyère injection, upon injection during 20 days [156, Godinot, 2001]

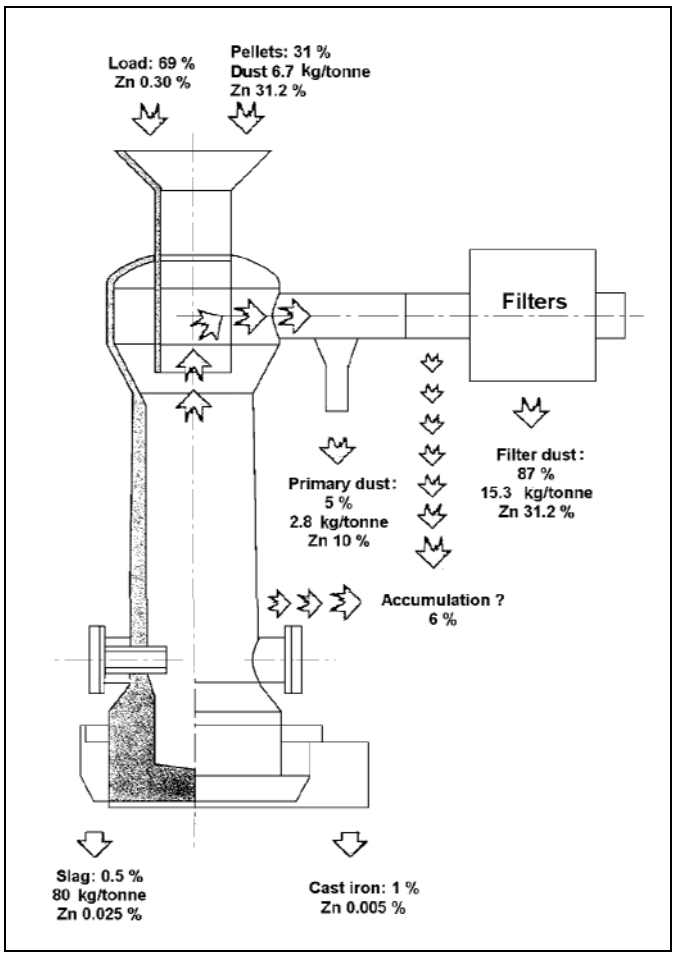

Figure 4.34: Zinc distribution for recirculation through the charge, upon charging during 11 days [156, Godinot, 2001]

The analysis of the input and output flows do not allow a full closure of the zinc balance. This indicates that a considerable part of the zinc (20 % for tuyère injection, 10 % for pellet charging) remains and accumulates in the system. Upon recirculation, the dust gets sticky and deposits in the combustion chamber, heat-exchanger and filters. The recirculation will therefore require increased cleaning efforts and will result in a material for disposal at this cleaning stage.

The recirculation of cupola dust (yearly iron production: 30000 tonnes) in a Dutch iron foundy reduced the net amount of dust by 156 t on a yearly basis, without any significant effect on the environmental and construction qualities of the slag.

Applicability

Recovery is technically possible above an 18 % Zn level. Cupolas with a Zn-rich charge have Zn-levels in the dust >20 %, without recirculation. A minimal content of 40 % Zinc is needed for cost neutral recovery.

It is not possible to re-inject the full dust production of a furnace. Injection of more than 8 kg/tonne metal results in an extinguishing of the flame.

New and existing cupola furnaces with continuous operation can be equipped with these dust recirculation installations.

Economics

Recovery is technically possible above an 18 % Zn level. Operators report profitability of the recirculation and Zn recovery occuring for a Zn-level >40 %.

From the practical data from two foundries in France, additional operational costs were calculated. Tuyère injection showed an additional operational cost of EUR 0.35/tonne cast iron; pellet injection EUR 0.90/tonne cast iron. This calculation does not take into account any extra costs for slag disposal or maintenance works.

In the case of Venturi injection, the following data apply. In a German reference plant over a 5 year period an average of 7.5 kg zinc dust/tonne melted iron could be delivered to the processing industry. Disposal costs were thereby reduced by EUR 1.97/tonne liquid iron. Furthermore, 20 % of the cokes could be replaced by petcokes. This allowed a reduction in the fuel cost of 15 %, which corresponded to a cost reduction of EUR 2.56/tonne liquid iron. This calculation does not take into account any extra costs for slag disposal or maintenance works.

Driving force for implementation
High disposal costs for furnace dusts.

Example plants
Venturi (NPT):
Pont-a-Mousson, Brebach (F)
Positive Pressure (VELCO):
John Deere, Mannheim (D)

Reference literature
[108, FEAF, 1999], [110, Vito, 2001], [140, EU Thematic Network Foundry Wastes, 2001], [156, Godinot, 2001], [181, Ruffin and Godinot, 1998], [198, Georg Fischer,], [202, TWG, 2002]

4.9.5 EAF

4.9.5.1 Recycling of filter dust and sludge (from EAF melting)

Description
Dry collected furnace dust can, under certain circumstances, be recycled in the furnace. The dust will preferably be pretreated, e.g. by pelletising or briquetting, as this will reduce the amount of dust that is just blown through the furnace. The idea is to recover the metallic part of the dust and to melt the inorganic part to slag. In general, the dust is added at the beginning of each melting cycle.

As discussed for cupola furnaces, and for the EAF, in some cases where significant quantities of Zn containing scrap are used, recycling can lead to a Zn enrichment of the furnace dust up to a level where it can be used in the zinc industry for the recovery of Zn if economically viable (up to 30 - 40 %).

Achieved environmental benefits
The main benefit of the technique is a decrease in the net amount of dust sent out by the foundry, for disposal or recovery. The produced dust contains a higher load of metals. This allows the recovery of Zn from the EAF dusts. The technique results in an enrichment of the Zn in the cupola dust, while for Pb a larger share ends up in the iron. If the Zn is effectively recuperated from the dust, the technique decreases the heavy metal load of the final dust for disposal, as well as its amount. On the other hand, the amount of slag produced, increases.

Cross-media effects
Dust recycling possibly reduces furnace efficiency and rises the consumption of electrical energy (approx. 20 - 30 kWh/tonne). The technique results in an increased production of slag.

Operational data
Operational data from EAF steelmaking show a plant which recycles 75 % EAF dust from an original yield of 20 – 22 kg/t, and so only has to take care of about 50 % of the dust, with an average zinc content of 35 %.

Applicability
The technique generally applies for dusts with a high metallic load. The actual applicability though depends on many factors, that may be dissimilar for different plants.

Economics
The technique does not involve any additional investment.

Driving force for implementation
High disposal costs for furnace dusts.

Example plants
This technique is performed in several European foundries.

Reference literature
[32, CAEF, 1997], [211, European IPPC Bureau, 2000]

4.9.5.2 Recycling of Al slags and residues

Description
The possibilities of recycling depend on the product and the generated wastes. Swarfs are mostly recovered for internal remelting while other scrap (containing too much other metal) will usually be sold to secondary aluminium production.

Achieved environmental benefits
Minimisation of the production of residues.

Cross-media effects
No cross-media effects apply.

Applicability
This technique applies to new and existing installations.

Driving force for implementation
High disposal fees for solid residues.

Example plants
The technique is commonly applied in aluminium foundries.

Reference literature
[225, TWG, 2003]

4.10 Noise reduction

Description
The foundry process contains various point sources of noise. These include:
- scrap handling
- furnace charging
- burners
- HPDC automates
- shake-out
- grit-blasting
- core (and mould) shooting
- finishing
- all motors and hydraulic systems
- transport (tipping, loading, etc.).

The overall reduction of noise levels involves developing a noise reduction plan. Here each of the sources needs to be checked and evaluated. Alternative techniques with lower noise levels may be applied and/or point sources may be enclosed. Examples for alternative techniques have been given in Section 4.2.4.2 (oxyburner in RF) and 4.2.2.2 (foamy slag for EAF). Some examples of the enclosure of sources have been given for furnaces (Section 4.5.3.1) and shake-out (4.5.9.3).

General measures include:
- using noise reducing flaps on all outside doors and closing all doors (and keeping them shut as much as possible), especially during the night
- actively blowing air into the foundry hall. This causes a small increase in the indoor pressure and keeps the noise inside
- enclosing fans, insulating of ventilation pipes and using of dampers
- minimising the number of transport activities during the night.

Full enclosure of the foundry building may be considered as well. This will also require setting-up a climate control system, to limit the temperature inside the building.

Achieved environmental benefits
Reduction of noise pollution.

Cross-media effects
Enclosing (parts of) the foundry building may necessitate the installation of a climate control system, the operation of which requires energy.

Operational data
A Belgian aluminium foundry is currently developing a noise reduction plan. The aim is for the general noise level to be reduced from 50 dBA to 40 dBA. This involves the study of 170 sources. Specific measures are taken to reduce the overall noise level between 22.00 h and 6.00 h. Additionally air is blown into the foundry hall, creating a small pressure difference to keep the noise inside. The total inside air volume is refreshed 36 times each hour.

Another Belgian foundry is running a project to reduce noise emissions by fully closing the foundry building. This requires the setting-up of a climate control system, in order to achieve a maximum inside-outside temperature difference of 8 ºC. The system is currently going through subsequent revisions, so tests are still ongoing.

Applicability
This technique applies to all new and existing installations. The level to which measures should be taken depends on the foundry location.

Driving force for implementation
Regulation on noise levels from industrial installations.

Example plants
- MGG, Hoboken (B): noise reduction plan
- Hayes-Lemmertz, Hoboken (B): total building enclosure.

Reference literature
[225, TWG, 2003]

4.11 Decommissioning

Description
Some techniques to consider are:

- considering later de-commissioning at the design stage, thereby minimising risks and excessive costs during later de-commissioning
- for existing installations, where potential problems have been identified, putting in place a programme of improvements. These improvements designs need to ensure that:
  - underground tanks and pipework are avoided where possible (unless protected by secondary containment or a suitable monitoring programme)
  - there is provision for the draining and cleaning-out of vessels and pipework prior to dismantling
  - lagoons and landfills are designed with a view to their eventual clean-up or surrender
  - insulation is used which can be readily dismantled without dust or hazards arising
  - any materials used are recyclable (although bearing in mind they still meet operational or other environmental objectives)

- developing and maintaining a site closure plan, to demonstrate that, in its current state, the installation can be decommissioned to avoid any pollution risk and to return the site of operation to a satisfactory state. The plan should be kept updated as material changes occur. However, even at an early stage, the closure plan can include:
  - either the removal or the flushing out of pipelines and vessels where appropriate and their complete emptying for any potentially harmful contents
  - plans of all underground pipes and vessels
  - the method and resource necessary for the clearing of lagoons
  - the method of ensuring that any on-site landfills can meet the equivalent of surrender conditions
  - the removal of asbestos or other potentially harmful materials unless agreed that it is reasonable to leave such liabilities to future owners
  - methods of dismantling buildings and other structures, for the protection of surface and groundwater at construction and demolition-sites
  - testing of the soil to ascertain the degree of any pollution caused by the activities and the need for any remediation to return the site to a satisfactory state as defined by the initial site report

Achieved environmental benefits
Prevents environmental issues during de-commissioning.

Applicability
Techniques mentioned here are applicable throughout the installation's operational lifetime, during the design and building stage of the site and activities and immediately after the site closure.

Reference literature
[236, UK Environment Agency, 2001]

4.12 Environmental management tools

Description
The best environmental performance is usually achieved by the installation of the best technology and its operation in the most effective and efficient manner. This is recognised by the IPPC Directive definition of 'techniques' as *"both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned"*.

For IPPC installations an Environmental Management System (EMS) is a tool that operators can use to address these design, construction, maintenance, operation and decommissioning issues in a systematic, demonstrable way. An EMS includes the organisational structure, responsibilities, practices, procedures, processes and resources for developing, implementing, maintaining, reviewing and monitoring the environmental policy. Environmental Management Systems are most effective and efficient where they form an inherent part of the overall management and operation of an installation.

Within the European Union, many organisations have decided on a voluntary basis to implement environmental management systems based on EN ISO 14001:1996 or the EU Eco-management and audit scheme EMAS. EMAS includes the management system requirements of EN ISO 14001, but places additional emphasis on legal compliance, environmental performance and employee involvement; it also requires external verification of the management system and validation of a public environmental statement (in EN ISO 14001 self-declaration is an alternative to external verification). There are also many organisations that have decided to put in place non-standardised EMSs.

While both standardised systems (EN ISO 14001:1996 and EMAS) and non-standardised ("customised") systems in principle take the *organisation* as the entity, this document takes a more narrow approach, not including all activities of the organisation e.g. with regard to their products and services, due to the fact that the regulated entity under the IPPC Directive is the *installation* (as defined in Article 2).

An environmental management system (EMS) for an IPPC installation can contain the following components:

(a) definition of an environmental policy
(b) planning and establishing objectives and targets
(c) implementation and operation of procedures
(d) checking and corrective action
(e) management review
(f) preparation of a regular environmental statement
(g) validation by certification body or external EMS verifier
(h) design considerations for end-of-life plant decommissioning
(i) development of cleaner technologies
(j) benchmarking.

These features are explained in somewhat greater detail below. For detailed information on components (a) to (g), which are all included in EMAS, the reader is referred to the reference literature indicated below.

(a) Definition of an environmental policy

Top management are responsible for defining an environmental policy for an installation and ensuring that it:

- is appropriate to the nature, scale and environmental impacts of the activities
- includes a commitment to pollution prevention and control
- includes a commitment to comply with all relevant applicable environmental legislation and regulations, and with other requirements to which the organisation subscribes
- provides the framework for setting and reviewing environmental objectives and targets
- is documented and communicated to all employees
- is available to the public and all interested parties.

(b) Planning, i.e.:

- procedures to identify the environmental aspects of the installation, in order to determine those activities which have or can have significant impacts on the environment, and to keep this information up-to-date
- procedures to identify and have access to legal and other requirements to which the organisation subscribes and that are applicable to the environmental aspects of its activities
- establishing and reviewing documented environmental objectives and targets, taking into consideration the legal and other requirements and the views of interested parties
- establishing and regularly updating an environmental management programme, including designation of responsibility for achieving objectives and targets at each relevant function and level as well as the means and timeframe by which they are to be achieved.

(c) Implementation and operation of procedures

It is important to have systems in place to ensure that procedures are known, understood and complied with, therefore effective environmental management includes:

(i) Structure and responsibility

- defining, documenting and communicating roles, responsibilities and authorities, which includes appointing one specific management representative
- providing resources essential to the implementation and control of the environmental management system, including human resources and specialised skills, technology and financial resources.

(ii) Training, awareness and competence

- identifying training needs to ensure that all personnel whose work may significantly affect the environmental impacts of the activity have received appropriate training.

(iii) Communication

- establishing and maintaining procedures for internal communication between the various levels and functions of the installation, as well as procedures that foster a dialogue with external interested parties and procedures for receiving, documenting and, where reasonable, responding to relevant communication from external interested parties.

(iv) Employee involvement

- involving employees in the process aimed at achieving a high level of environmental performance by applying appropriate forms of participation such as the suggestion-book system or project-based group works or environmental committees.

(v) Documentation

- establishing and maintaining up-to-date information, in paper or electronic form, to describe the core elements of the management system and their interaction and to provide direction to related documentation.

(vi) Efficient process control

- adequate control of processes under all modes of operation, i.e. preparation, start-up, routine operation, shutdown and abnormal conditions
- identifying the key performance indicators and methods for measuring and controlling these parameters (e.g. flow, pressure, temperature, composition and quantity)
- documenting and analysing abnormal operating conditions to identify the root causes and then addressing these to ensure that events do not recur (this can be facilitated by a ‘no-blame’ culture where the identification of causes is more important than apportioning blame to individuals).

(vii) Maintenance programme

- establishing a structured programme for maintenance based on technical descriptions of the equipment, norms etc. as well as any equipment failures and consequences
- supporting the maintenance programme by appropriate record keeping systems and diagnostic testing
- clearly allocating responsibility for the planning and execution of maintenance.

(viii) Emergency preparedness and response

- establishing and maintaining procedures to identify the potential for and response to accidents and emergency situations, and for preventing and mitigating the environmental impacts that may be associated with them.

(d) Checking and corrective action, i.e:

(i) Monitoring and measurement

- establishing and maintaining documented procedures to monitor and measure, on a regular basis, the key characteristics of operations and activities that can have a significant impact on the environment, including the recording of information for tracking performance, relevant operational controls and conformance with the installation's environmental objectives and targets *(see also the Reference document on Monitoring of Emissions)*
- establishing and maintaining a documented procedure for periodically evaluating compliance with relevant environmental legislation and regulations.

(ii) Corrective and preventive action

- establishing and maintaining procedures for defining responsibility and authority for handling and investigating non-conformance with permit conditions, other legal requirements as well as objectives and targets, taking action to mitigate any impacts caused and for initiating and completing corrective and preventive action that are appropriate to the magnitude of the problem and commensurate with the environmental impact encountered.

(iii) Records

- establishing and maintaining procedures for the identification, maintenance and disposition of legible, identifiable and traceable environmental records, including training records and the results of audits and reviews.

(iv) Audit

- establishing and maintaining (a) programme(s) and procedures for periodic environmental management system audits that include discussions with personnel, inspection of operating conditions and equipment and reviewing of records and documentation and that results in a written report, to be carried out impartially and objectively by employees (internal audits) or external parties (external audits), covering the audit scope, frequency and methodologies, as well as the responsibilities and requirements for conducting audits and reporting results, in order to determine whether or not the environmental management system conforms to planned arrangements and has been properly implemented and maintained
- completing the audit or audit cycle, as appropriate, at intervals of no longer than three years, depending on the nature, scale and complexity of the activities, the significance of associated environmental impacts, the importance and urgency of the problems detected by previous audits and the history of environmental problems – more complex activities with a more significant environmental impact are audited more frequently
- having appropriate mechanisms in place to ensure that the audit results are followed up.

(v) Periodic evaluation of legal compliance
- reviewing compliance with the applicable environmental legislation and the conditions of the environmental permit(s) held by the installation
- documentation of the evaluation.

(e) Management review, i.e.:

- reviewing, by top management, at intervals that it determines, the environmental management system, to ensure its continuing suitability, adequacy and effectiveness
- ensuring that the necessary information is collected to allow management to carry out this evaluation
- documentation of the review.

(f) Preparation of a regular environmental statement

- preparing an environmental statement that pays particular attention to the results achieved by the installation against its environmental objectives and targets. It is regularly produced – from once a year to less frequently depending on the significance of emissions, waste generation etc. It considers the information needs of relevant interested parties and it is publicly available (e.g. in electronic publications, libraries etc.).

When producing a statement, the operator may use relevant existing environmental performance indicators, making sure that the indicators chosen:

i. give an accurate appraisal of the installation's performance
ii. are understandable and unambiguous
iii. allow for year on year comparison to assess the development of the environmental performance of the installation
iv. allow for comparison with sector, national or regional benchmarks as appropriate
v. allow for comparison with regulatory requirements as appropriate.

(g) Validation by certification body or external EMS verifier

- having the management system, audit procedure and environmental statement examined and validated by an accredited certification body or an external EMS verifier can, if carried out properly, enhance the credibility of the system.

(h) Design considerations for end-of-life plant decommissioning

- giving consideration to the environmental impact from the eventual decommissioning of the unit at the stage of designing a new plant, as forethought makes decommissioning easier, cleaner and cheaper
- decommissioning poses environmental risks for the contamination of land (and groundwater) and generates large quantities of solid waste. Preventive techniques are process-specific but general considerations may include:
  i. avoiding underground structures
  ii. incorporating features that facilitate dismantling
  iii. choosing surface finishes that are easily decontaminated
  iv. using an equipment configuration that minimises trapped chemicals and facilitates drain-down or washing
  v. designing flexible, self-contained units that enable phased closure
  vi. using biodegradable and recyclable materials where possible.

(i) Development of cleaner technologies

- environmental protection should be an inherent feature of any process design activities carried out by the operator, since techniques incorporated at the earliest possible design stage are both more effective and cheaper. Giving consideration to the development of cleaner technologies can for instance occur through R&D activities or studies. As an alternative to internal activities, arrangements can be made to keep abreast with – and where appropriate – commission work by other operators or research institutes active in the relevant field.

(j) Benchmarking, i.e.:

– carrying out systematic and regular comparisons with sector, national or regional benchmarks, including for energy efficiency and energy conservation activities, choice of input materials, emissions to air and discharges to water (using for example the European Pollutant Emission Register, EPER), consumption of water and generation of waste.

Standardised and non-standardised EMSs
An EMS can take the form of a standardised or non-standardised ("customised") system. Implementation and adherence to an internationally accepted standardised system such as EN ISO 14001:1996 can give higher credibility to the EMS, especially when subject to a properly performed external verification. EMAS provides additional credibility due to the interaction with the public through the environmental statement and the mechanism to ensure compliance with the applicable environmental legislation. However, non-standardised systems can in principle be equally effective provided that they are properly designed and implemented.

Achieved environmental benefits
Implementation of and adherence to an EMS focuses the attention of the operator on the environmental performance of the installation. In particular, the maintenance of and compliance with clear operating procedures for both normal and abnormal situations and the associated lines of responsibility should ensure that the installation's permit conditions and other environmental targets and objectives are met at all times.

Environmental management systems typically ensure the continuous improvement of the environmental performance of the installation. The poorer the starting point is, the more significant short-term improvements can be expected. If the installation already has a good overall environmental performance, the system helps the operator to maintain the high performance level.

Cross-media effects
Environmental management techniques are designed to address the overall environmental impact, which is consistent with the integrated approach of the IPPC Directive.

Operational data
No specific information reported.

Applicability
The components described above can typically be applied to all IPPC installations. The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

Economics
It is difficult to accurately determine the costs and economic benefits of introducing and maintaining a good EMS. A number of studies are presented below. However, these are just examples and their results are not entirely coherent. They might not be representative for all sectors across the EU and should thus be treated with caution.

A Swedish study carried out in 1999 surveyed all 360 ISO-certified and EMAS-registered companies in Sweden. With a response rate of 50%, it concluded among other things that:

- the expenses for introducing and operating EMS are high but not unreasonably so, save in the case of very small companies. Expenses are expected to decrease in the future
- a higher degree of co-ordination and integration of EMS with other management systems is seen as a possible way to decrease costs
- half of all the environmental objectives and targets give payback within one year through cost savings and/or increased revenue
- the largest cost savings were made through decreased expenditure on energy, waste treatment and raw materials
- most of the companies think that their position on the market has been strengthened through the EMS. One-third of the companies report increasing revenue due to EMS.

In some Member States reduced supervision fees are charged if the installation has a certification.

A number of studies[5] show that there is an inverse relationship between company size and the cost of implementing an EMS. A similar inverse relationship exists for the payback period of invested capital. Both elements imply a less favourable cost-benefit relationship for implementing an EMS in SMEs compared to larger companies.

According to a Swiss study, the average cost for building and operating ISO 14001 can vary:

- for a company with between 1 and 49 employees: CHF 64000 (EUR 44000) for building the EMS and CHF 16000 (EUR 11000) per year for operating it
- for an industrial site with more than 250 employees: CHF 367000 (EUR 252000) for building the EMS and CHF 155000 (EUR 106000) per year for operating it.

These average figures do not necessarily represent the actual cost for a given industrial site because this cost is also highly dependent on the number of significant items (pollutants, energy consumption,...) and on the complexity of the problems to be studied.

A recent German study (Schaltegger, Stefan and Wagner, Marcus, *Umweltmanagement in deutschen Unternehmen - der aktuelle Stand der Praxis*, February 2002, p. 106) shows the following costs for EMAS for different branches. It can be noted that these figures are much lower than those of the Swiss study quoted above. This is a confirmation of the difficulty to determine the costs of an EMS.

<u>Costs for building (EUR):</u>
- Minimum: 18750
- Maximum: 75000
- Average: 50000

<u>Costs for validation (EUR):</u>
- Minimum: 5000
- Maximum: 12500
- Average: 6000

[5] E.g. Dyllick and Hamschmidt (2000, 73) quoted in Klemisch H. and R. Holger, *Umweltmanagementsysteme in kleinen und mittleren Unternehmen – Befunde bisheriger Umsetzung,* KNI Papers 01/02, January 2002, p 15; Clausen J., M. Keil and M. Jungwirth, *The State of EMAS in the EU.Eco-Management as a Tool for Sustainable Development – Literature Study,* Institute for Ecological Economy Research (Berlin) and Ecologic – Institute for International and European Environmental Policy (Berlin), 2002, p 15.

A study by the German Institute of Entrepreneurs (Unternehmerinstitut/Arbeitsgemeinschaft Selbständiger Unternehmer UNI/ASU, 1997, *Umweltmanagementbefragung - Öko-Audit in der mittelständischen Praxis - Evaluierung und Ansätze für eine Effizienzsteigerung von Umweltmanagementsystemen in der Praxis*, Bonn.) gives information about the average savings achieved for EMAS per year and the average payback time. For example, for implementation costs of EUR 80000 they found average savings of EUR 50000 per year, corresponding to a payback time of about one and a half years.

External costs relating to verification of the system can be estimated from guidance issued by the International Accreditation Forum (http://www.iaf.nu).

Driving force for implementation
Environmental management systems can provide a number of advantages, for example:

- improved insight into the environmental aspects of the company
- improved basis for decision-making
- improved motivation of personnel
- additional opportunities for operational cost reduction and product quality improvement
- improved environmental performance
- improved company image
- reduced liability, insurance and non-compliance costs
- increased attractiveness for employees, customers and investors
- increased trust of regulators, which could lead to reduced regulatory oversight
- improved relationship with environmental groups.

Example plants
The features described under (a) to (e) above are elements of EN ISO 14001:1996 and the European Community Eco-Management and Audit Scheme (EMAS), whereas the features (f) and (g) are specific to EMAS. These two standardised systems are applied in a number of IPPC installations. As an example, 357 organisations within the EU chemical and chemical products industry (NACE code 24) were EMAS registered in July 2002, most of which operate IPPC installations.

In the UK, the Environment Agency of England and Wales carried out a survey among IPC (the precursor to IPPC) regulated installations in 2001. It showed that 32 % of respondents were certified to ISO 14001 (corresponding to 21 % of all IPC installations) and 7 % were EMAS registered. All cement works in the UK (around 20) are certified to ISO 14001 and the majority are EMAS registered. In Ireland, where the establishment of an EMS (not necessarily of a standardised nature) is required in IPC licenses, an estimated 100 out of approximately 500 licensed installations have established an EMS according to ISO 14001, with the other 400 installations having opted for a non-standardised EMS.

Reference literature
[78, ETSU, 1996]

(Regulation (EC) No 761/2001 of the European parliament and of the council allowing voluntary participation by organisations in a Community eco-management and audit scheme (EMAS), OJ L 114, 24/4/2001, http://europa.eu.int/comm/environment/emas/index_en.htm)

(EN ISO 14001:1996, http://www.iso.ch/iso/en/iso9000-14000/iso14000/iso14000index.html; http://www.tc207.org)

5 BEST AVAILABLE TECHNIQUES FOR FOUNDRIES

In understanding this chapter and its contents, the attention of the reader is drawn back to the preface of this document and in particular the fifth section of the preface: “How to understand and use this document”. The techniques and associated emission and/or consumption levels, or ranges of levels, presented in this chapter have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for the foundries sector
- examination of the techniques most relevant to address these key issues
- identification of the best environmental performance levels, on the basis of the available data in the European Union and worldwide
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of the techniques
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense all according to Article 2(11) and Annex IV of the Directive.

Expert judgement by the European IPPC Bureau and the relevant Technical Working Group (TWG) has played a key role in each of these steps and in the way in which the information is presented here.

On the basis of this assessment, techniques, and as far as possible emission and consumption levels associated with the use of BAT, are presented in this chapter that are considered to be appropriate to the sector as a whole and in many cases reflect current performance of some installations within the sector. Where emission or consumption levels “associated with best available techniques” are presented, this is to be understood as meaning that these levels represent the environmental performance that could be anticipated as a result of the application, in this sector, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross-media considerations, they are not considered to be appropriate as BAT for the sector as a whole. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The emission and consumption levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of “levels associated with BAT” described above is to be distinguished from the term “achievable level” used elsewhere in this document. Where a level is described as “achievable” using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in the previous chapter. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a technique will depend strongly on the specific situation regarding, for example, taxes, fees, and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.

It is intended that the general BAT in this chapter are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way they will assist in the determination of appropriate "BAT-based" conditions for the installation or in the establishment of general binding rules under Article 9(8). It is foreseen that

new installations can be designed to perform at or even better than the general BAT levels presented here. It is also considered that existing installations could move towards the general BAT levels or do better, subject to the technical and economic applicability of the techniques in each case.

While the BAT reference documents do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels when using specified techniques. The appropriate limit values for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

The foundry industry is a differentiated and diverse industry. The elements of BAT applicable to a specific foundry need to be selected according to the type of activity. A foundry basically consists of a melting shop and a casting shop, both with their supply chain. For lost mould casting this supply chain includes all activities related to moulding and core-making. In this chapter, distinction will be made on the following basis: melting of either ferrous or non-ferrous metal and casting in either lost or permanent moulds. Each foundry may be classified as a combination of a melting with a moulding class. BAT is presented for each class as well as generic BAT, common to all foundries.

5.1 Generic BAT (for the foundry industry)

Some BAT elements are generic and apply for all foundries, regardless of the processes they apply and the type of products they produce. These concern material flows, finishing of castings, noise, waste water, environmental management and decommissioning.

Material flows management

The foundry process involves the use, consumption, combination and mixing of various material types. BAT requires the minimisation of raw materials consumption and the furthering of residue recovery and recycling. Therefore, BAT is to optimise the management and control of internal flows.

BAT therefore is to:

- apply storage and handling methods for solids, liquids and gases as discussed in the Storage BREF
- apply the separate storage of various incoming materials and material grades (Section 4.1.2), preventing deterioration and hazards (Section 4.1.3)
- carry out storage in such a way that the scrap in the storage area is of an appropriate quality for feeding into the melting furnace and that soil pollution is prevented as described in Section 4.1.2. BAT is to have an impermeable surface for scrap storage with a drainage collection and treatment system. A roof can reduce or eliminate the need for such a system
- apply internal recycling of scrap metal, under the conditions discussed in Section 4.1.4, 4.1.5 and 4.1.6
- apply the separate storage of various residue and waste types to allow re-use, recycling or disposal
- use bulk or recyclable containers (Section 4.1.7)
- use simulation models, management and operational procedures to improve metal yield (Section 4.4.1) and to optimise material flows
- implement good practice measures for molten metal transfer and ladle handling (Section 4.7.4).

Finishing of castings

For abrasive cutting, shot blasting and fettling, BAT is to collect and treat the finishing off-gas using a wet or dry system. The BAT associated emission level for dust is 5 - 20 mg/Nm³. The techniques for off-gas collection and exhaust air cleaning are discussed in Section 4.5.10.1 and 4.5.10.2.

For heat treatment, BAT is all of the following, to:
- use clean fuels (i.e. natural gas or low-level sulphur content fuel) in heat treatment furnaces (Section 4.5.11.1)
- use automated furnace operation and burner/heater control (Section 4.5.11.1)
- capture and evacuate the exhaust gas from heat treatment furnaces.

Noise reduction
BAT is all of the following, to:
- develop and implement a noise reduction strategy, with general and source-specific measures
- use enclosure systems for high-noise unit operations such as shake-out (see Section 4.5.9.3)
- use additional measures as described in Section 4.10, according to local conditions.

Waste water
BAT is all of the following, to:
- keep waste water types separate according to their composition and pollutant load
- collect surface run-off water and ue oil interceptors on the collection system before discharge to surface water, as discussed in Section 4.6.4
- maximise the internal recycling of process water and the multiple use of treated waste water (Section 4.6.1)
- apply waste water treatment for scrubbing water and other waste water flows, using one or more of the techniques mentioned in Section 4.6.2 and 4.6.3.

Reduction of fugitive emissions
BAT is to minimise fugitive emissions arising from various non-contained sources in the process chain, by using a combination of the following measures. The emissions mainly involve losses from transfer and storage operations and spills, and are discussed in Section 4.5.1.1.
- avoid outdoor or uncovered stockpiles, but where outdoor stockpiles are unavoidable, to use sprays, binders, stockpile management techniques, windbreaks, etc.
- cover skip and vessels
- vacuum clean the moulding and casting shop in sand moulding foundries according to the criteria given in 4.5.1.1
- clean wheels and roads
- keep outside doors shut
- carry out regular housekeeping
- manage and control possible sources of fugitive emissions to water.

These techniques are further specified in Section 4.5.1.1. Additional storage techniques are detailed in the Storage BREF.

Additionally, fugitive emissions may arise from the incomplete evacuation of exhaust gas from contained sources, e.g. emissions from furnaces during opening or tapping. BAT is to minimise these fugitive emissions by optimising capture and cleaning, taking into account the associated emission levels as given in Sections 5.2 and 5.3. For this optimisation one or more of the following measures are used, giving preference to the collection of fume nearest to the source:
- hooding and ducting design to capture fume arising from hot metal, furnace charging, slag transfer and tapping
- applying furnace enclosures to prevent the release of fume losses into the atmosphere
- applying roofline collection, although this is very energy consuming and should only be applied as a last resort.

Environmental management
A number of environmental management techniques are determined as BAT. The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

BAT is to implement and adhere to an Environmental Management System (EMS) that incorporates, as appropriate to individual circumstances, the following features: (see Section 4.12)

- definition of an environmental policy for the installation by top management (commitment of the top management is regarded as a precondition for a successful application of other features of the EMS)
- planning and establishing the necessary procedures
- implementation of the procedures, paying particular attention to
  - structure and responsibility
  - training, awareness and competence
  - communication
  - employee involvement
  - documentation
  - efficient process control
  - maintenance programme
  - emergency preparedness and response
  - safeguarding compliance with environmental legislation.
- checking performance and taking corrective action, paying particular attention to
  - monitoring and measurement (see also the Reference document on Monitoring of Emissions)
  - corrective and preventive action
  - maintenance of records
  - independent (where practicable) internal auditing in order to determine whether or not the environmental management system conforms to planned arrangements and has been properly implemented and maintained.
- review by top management.

Three further features, which can complement the above stepwise, are considered as supporting measures. However, their absence is generally not inconsistent with BAT. These three additional steps are:

- having the management system and audit procedure examined and validated by an accredited certification body or an external EMS verifier
- preparation and publication (and possibly external validation) of a regular environmental statement describing all the significant environmental aspects of the installation, allowing for year-by-year comparison against environmental objectives and targets as well as with sector benchmarks as appropriate
- implementation and adherence to an internationally accepted voluntary system such as EMAS and EN ISO 14001:1996. This voluntary step could give higher credibility to the EMS. In particular EMAS, which embodies all the above-mentioned features, gives higher credibility. However, non-standardised systems can in principle be equally effective provided that they are properly designed and implemented.

Specifically for the foundry sector, it is also important to consider the following potential features of the EMS:

- the environmental impact from the eventual decommissioning of the unit at the stage of designing a new plant
- the development of cleaner technologies
- where practicable, the application of sectoral benchmarking on a regular basis, including energy efficiency and energy conservation activities, choice of input materials, emissions to air, discharges to water, consumption of water and generation of waste.

Decommissioning
BAT is to apply all necessary measures to prevent pollution upon decommissioning. These are described in Section 4.11 and include:
- minimising later risks and costs by careful design at the initial design stage
- developing and implementing an improvement programme for existing installations
- developing and maintaining a site closure plan for new and existing installations.

In these measures, at least the following process parts are considered: tanks, vessels, pipework, insulation, lagoons and landfills.

5.2 Ferrous metal melting

Furnace selection
Steel is melted in both electric arc furnaces (EAF) and induction furnaces (IF). The choice between furnace types is based on technical criteria (e.g. capacity, steel grade). Due to its refining ability, the EAF allows the melting of lower grade scrap. This is an advantage in terms of the recycling of metals, but requires an appropriate flue-gas capture and cleaning system, as will be presented below.

For cast iron melting: cupola, electric arc, induction and rotary furnaces are applicable. The selection will be based on technical and economic criteria.

For the operation of any selected furnaces type, elements of BAT are given below.

Cupola furnace melting of cast iron
For the operation of cupola furnaces, BAT is all of the following, to:
- use divided blast operation (2 rows of tuyères) for cold blast cupolas (Section 4.2.1.5)
- use oxygen enrichment of the blast air, in a continuous or intermittent way, with oxygen levels between 22 and 25 % (i.e. 1 % - 4 % enrichment) (Section 4.2.1.6)
- minimise the blast-off periods for hot blast cupolas by applying continuous blowing or long campaign operation (Section 4.2.1.8). Depending on the requirements of the moulding and casting line, duplex operations must be considered
- apply good melting practice measures for the furnace operation as listed in Section 4.2.1.1
- use coke with known properties and of a controlled quality (Section 4.2.1.2)
- clean furnace off-gas by subsequent collection, cooling and dedusting using a combination of the techniques described in Section 4.5.2.1. BAT for dedusting is to use a bag filter or wet scrubber. BAT associated emission levels are given below (Table 5.1, Table 5.2)
- apply post combustion in the cupola shaft of CBC, if the off-gases can burn autothermally and then to recover the heat for internal use (Section 4.5.2.3). For HBC, use a separate combustion chamber (Section 4.5.2.2), and recover the heat for blast air preheating and other internal uses (Section 4.7.3)
- evaluate the possibility of waste heat utilisation from holding furnaces in duplex configuration and to implement heat recovery if applicable (Section 4.7.2)
- prevent and minimise dioxins and furan emissions to a level below 0.1ngTEQ/Nm³, using a combination of measures as given in Section 4.5.1.4. In some cases this may result in a preference for wet scrubbing. Industry has expressed doubts on the implementation of secondary measures that have only been proven in other sectors and in particular questions the applicability for smaller foundries
- use a wet scrubber system when melting with basic slag (basicity up to 2) (Section 4.2.1.3).

Residues produced by cupola melting include dust, slags and coke breeze.
BAT for residue management is all of the following, to:
- minimise slag forming using one or more of the in-process measures listed in Section 4.9.3
- pretreat the slags in order to allow external re-use (Section 4.9.2)
- collect and recycle coke breeze (Section 4.9.4.1).

Electric arc furnace melting of steel and cast iron

For the operation of electric arc furnaces, BAT is all of the following, to:

- apply reliable and efficient process controls to shorten the melting and treatment time (Section 4.2.2.1)
- use the foamy slag practice (Section 4.2.2.2)
- capture furnace off-gas using one of the techniques discussed in Section 4.5.3.1
- cool the furnace off-gas and dedust using a bag filter (Section 4.5.3.2).

Residues produced by EAF melting include dust and slags.

BAT for residue management is to:

- recycle filter dust into the EAF furnace (Section 4.9.5.1).

BAT associated emission levels are given below (Table 5.1, Table 5.3)

Induction furnace melting of cast iron and steel

For the operation of induction furnaces, BAT is all of the following, to:

- melt clean scrap, avoiding rusty and dirty inputs and adhering sand
- use good practice measures for the charging and operation as discussed in Section 4.2.3.1
- use medium frequency power, and when installing a new furnace, to change any mains frequency furnace to medium frequency (Section 4.2.3.2)
- evaluate the possibility of waste heat recuperation and to implement a heat recovery system if applicable (Section 4.7.2)
- use a hood, lip extraction or cover extraction on each induction furnace to capture the furnace off-gas (Section 4.5.4.1) and to maximise off-gas collection during the full working cycle
- use dry flue-gas cleaning (Section 4.5.4.2), taking into account the BAT associated emission levels as given in Table 5.1
- keep dust emissions below 0.2 kg/tonne molten iron.

Rotary furnace melting of cast iron

For the operation of rotary furnaces, BAT is all of the following, to:

- implement measures to optimise furnace yield as discussed in Section 4.2.4.1
- use an oxyburner (Section 4.2.4.2)
- collect the off-gas close to the furnace exit, apply post combustion, cool it using a heat-exchanger and then to apply dry dedusting (Section 4.5.5.1), taking into account the BAT associated emission levels as given in Table 5.1 and Table 5.4
- prevent and minimise dioxins and furan emissions to a level below 0.1ngTEQ/Nm³, using a combination of measures as given in Section 4.5.1.4. In some cases this may result in a preference for wet scrubbing. Industry has expressed doubts on the implementation of secondary measures that have only been proven in other sectors and in particular questions the applicability for smaller foundries.

Ferrous metal treatment

If an AOD converter is used for steel refining, BAT is to

- extract and collect the exhaust gas using a roof canopy.

For the production of nodular iron, nodularisation is performed. BAT for nodularisation is to:

- select a nodularisation technique with no off-gas production or to capture the produced MgO smoke, using a lid or cover equipped with extraction equipment or by using a fixed or movable hood, and to
- dedust the exhaust gas using a bag filter and to make the dust available for recycling.

BAT associated emission levels are given below (Table 5.1)

BAT associated emission levels

The following emission levels are associated to the BAT measures stated above. All associated emission levels are quoted as an average over the practicable measuring period. Whenever continuous monitoring is practicable, a daily average value is used. Emissions to air are based on standard conditions**,** i.e. 273 K, 101.3 kPa and dry gas.

Parameter	Emission level
Dust (1)	5 – 20 mg/Nm³
PCDD/PCDF	≤0.1 ng TEQ/Nm³
(1) The emission level of dust depends on the dust components, such as heavy metals, dioxins, and its mass flow.	

Table 5.1: Emission to air associated with the use of BAT for ferrous metal melting and treatment

Type	Parameter	Emission level (mg/Nm³)
Hot blast	Carbon monoxide	20 – 1000
	SO_2	20 – 100
	NO_x	10 – 200
Cold Blast	SO_2	100 – 400
	NO_x	20 – 70
	NM - VOC	10 – 20
Cokeless	NO_x	160 – 400

Table 5.2: Emissions to air associated with the use of BAT for the cupola melting of ferrous metals

Parameter	Emission level (mg/Nm³)
NO_x	10 – 50
CO	200

Table 5.3: Emissions to air associated with the use of BAT for the EAF melting of ferrous metals

Parameter	Emission level (mg/Nm³)
SO_2	70 – 130
NO_x	50 – 250
CO	20 – 30

Table 5.4: Emissions to air associated with the use of BAT for the rotary melting of ferrous metals

5.3 Non-ferrous metal melting

For non-ferrous metals, this document (only) considers the melting of ingots and internal scrap, since this is standard practice in non-ferrous foundries.

For aluminium melting, multiple furnace types apply. The selection of the furnace type is based on technical criteria (e.g. regime, capacity, type of casting line). These are given in Section 3.3 and Table 3.21. One foundry can use several furnace types. Operational practice and logical reasoning shows that centralised melting in higher capacity furnaces has a more favourable energy efficiency than small crucible melting for large-scale plants. No data are available however to select it as BAT.

For the melting of copper, lead and zinc and their alloys, induction or crucible furnaces are used. For copper alloys, hearth type furnaces are used as well. The selection depends on technical criteria.

For magnesium melting, only crucible furnaces are used. A cover gas is used to prevent oxidation.

Induction furnace melting of aluminium, copper, lead and zinc

For the operation of induction furnaces, BAT is all of the following, to:

- use good practice measures for the charging and operation as discussed in Section 4.2.3.1
- use medium frequency power, and when installing a new furnace, to change any mains frequency furnace to medium frequency (Section 4.2.3.2)
- evaluate the possibility of waste heat recuperation and to implement a heat recovery system if applicable (Section 4.7.2)
- minimise emissions in accordance to the associated emission levels stated below, and if needed to collect the furnace off-gas (Section 4.5.4.1) maximising off-gas collection during the full working cycle, and to apply dry dedusting.

Rotary furnace melting of aluminium

For the operation of rotary furnaces, BAT is to:

- implement measures to optimise the furnace yield as discussed in Section 4.2.4.1
- collect the off-gas close to the furnace exit and to evacuate it through a stack, taking into account the BAT associated emission levels given below.

Hearth type furnace melting of aluminium and copper

For the operation of hearth type furnaces, BAT is all of the following, to:

- collect the furnace off-gas and to evacuate it through a stack, taking into account the BAT associated emission levels given below
- capture fugitive and visible emissions according to the BAT elements for fugitive emissions as mentioned above (Section 5.1) and to apply hooding as discussed in Section 4.5.6.1.

Shaft furnace melting of aluminium

For the operation of shaft furnaces, BAT is all of the following, to:

- allow efficient exhaust collection upon tilting of the furnace, and to evacuate the exhaust gas through a stack, taking into account the BAT associated emission levels given below.

Radiant roof furnace holding of aluminium

For the operation of radiant roof furnaces, BAT is all of the following, to:

- follow the BAT elements for fugitive emissions as mentioned above (Section 5.1) and to apply hooding under the conditions discussed in Section 4.5.6.1.

Crucible melting and holding of aluminium, copper, lead and zinc

For the operation of crucible furnaces, BAT is to:

- follow the BAT elements for fugitive emissions as mentioned above (Section 5.1) and to apply hooding under the conditions discussed in Section 4.5.6.1.

Degassing and cleaning of aluminium

BAT for the degassing and cleaning of aluminium is to:

- use a mobile or fixed impeller unit with Ar/Cl_2 or N_2/Cl_2 gas (Section 4.2.8.1).

Melting of magnesium

For the melting of magnesium, BAT is to:

- use SO_2 as a cover gas or to replace SF_6 by SO_2 as a cover gas. This applies for installations with an annual output of 500 tonnes and more (Section 4.2.7.1)
- for smaller plants, use SO_2 as a cover gas or take measures to minimise SF_6 consumption and emissions, as discussed in Section 4.2.7.1. In the case where SF_6 is used, the BAT associated consumption level is <0.9 kg/tonne casting for sand casting and <1.5 kg/tonne casting for pressure die-casting.

Note: At the time of reaching this conclusion, other alternatives to SF_6 were just being brought into use (see 4.2.7.1). SO_2 can be of concern on health and safety grounds and can be corrosive to equipment.

BAT associated emission levels

The following emission levels are associated to the BAT measures stated above. All associated emission levels are quoted as an average over the practicable measuring period. Whenever continuous monitoring is practicable, a daily average value is used. Emissions to air are based on standard conditions**,** i.e. 273 K, 101.3 kPa and dry gas.

The BAT AEL for dust for non-ferrous metal melting and treatment is 1 – 20 mg/Nm³. Additional values for the melting of aluminium are given in Table 5.5.

The emission factor associated with BAT for dust emissions from aluminium melting is 0.1 – 1 kg/t of molten aluminium.

In order to comply with these BAT associated emission levels it may be necessary to install a flue-gas cleaning installation; in this case BAT is to use dry dedusting.

Furnace Type	**Parameter**	**Emission level (mg/Nm³)**
General	Chlorine	3
Shaft	SO_2 NO_x CO VOC	30 – 50 120 150 100 – 150
Hearth	SO_2 NO_x CO TOC	15 50 5 5

Table 5.5: Emissions to air associated with the use of BAT in the melting of aluminium

5.4 Lost mould casting

Lost mould casting involves moulding, core-making, pouring, cooling and shake-out. This includes the production of green sand or chemically-bonded sand moulds and chemically-bonded sand cores. Mould and cores are assembled and the molten metal is poured into the assembled mould. The casting is allowed to solidify and cool before shake-out. The available techniques and their environmental effects for moulding and casting are closely interlinked. BAT elements will be presented in three categories: green sand moulding, chemically-bonded sand moulding and pouring/cooling/shake-out.

Green sand moulding

Green sand preparation starts with the mixing of the sand, clay binder and necessary additives. This may be done in atmospheric- (the most common situation) or vacuum mixers (see Section 4.3.2.1). Both methods are considered to be BAT. For vacuum mixing, an additional condition is that the sand capacity needs to be higher than 60 t/h.

Furthermore, BAT for green sand preparation is to:

- enclose all the unit operations of the sand plant (vibrating screen, sand dedusting, cooling, mixing operations) and to dedust the exhaust gas (Section 4.5.8.1), taking into account the BAT associated emission levels as given in Table 5.6. If the local market allows, the captured dust is made available for external re-use (Section 4.8.13). Dust collected from shake-out, dosing and handling is recycled into the green sand circuit, at up to 50 % of the collected mass (Section 4.8.12)
- apply primary regeneration as discussed in Section 4.8.2. The new sand addition depends on the amount of cores used and their compatibility. For green sand monosystems, regeneration ratios (mass of regenerated sand/total sand mass) of 98 % is associated with the use of BAT. For systems with a high degree of incompatible cores the BAT-associated regeneration ratio is 90 – 94 %.

Chemically-bonded sand mould and core-making

Various binder types are in use, all with their own specific properties and applicability. All binders are determined as BAT if they are applied according to the discussed good practice measures, which mainly involve process control and exhaust capture measures to minimise emissions (Section 4.3.3.3, 4.3.3.4). BAT associated emission levels are given below (Table 5.6).

For chemically-bonded sand preparation, BAT is all of the following, to:

- minimise the binder and resin consumption and sand losses, using process control measures, i.e. (manual or automated) mixer control, as discussed in Section 4.3.3.1. For series production involving frequent changes of production parameters and with high production throughputs, BAT is to apply the electronic storage of production parameters (see Section 4.3.3.2)
- capture exhaust gas from the area where cores are prepared, handled and held prior to dispatching
- use water-based coatings and to replace alcohol-based coatings for the refractory coating of moulds and cores, in foundries producing medium and large series. The use of alcohol-based coatings is BAT
  - for big or complex moulds and cores
  - for water glass bonded sands
  - in magnesium casting
  - in the production of manganese steel with MgO-coating.

  Both water-based and alcohol-based coating techniques are BAT in small-scale foundries and large-scale jobbing foundries (see Section 4.3.3.5). Implementation of the water-based technique in these two foundry types is supported by the availability of microwave drying (Section 4.3.3.6) and other novel drying techniques for which no information was submitted. When alcohol-based coatings are used, BAT is to provide evacuation at the coating stand, using movable or fixed hoods, noting that in jobbing foundries that apply floor moulding this is not feasible.

Additionallly, for amine-hardened urethane-bonded (cold-box) core preparation, BAT is all of the following, to:

- treat the evacuated exhaust gas for cold-box core preparation, using one of the methods mentioned in Section 4.5.8.4. The amine emission can be maintained below 5 mg/Nm³
- recover amine from cold-box exhaust scrubbing liquor, provided the total volume allows economic operation (Section 4.6.5)
- use either aromatic-based or vegetable-based (i.e. non-aromatic) solvents. Both methods are BAT (Section 4.3.3.7).

BAT is to minimise the amount of sand going to disposal, by adopting a strategy of regeneration and/or re-use (see section 4.8.13) of chemically-bonded sand (as mixed or monosand). In the case of regeneration, the following conditions apply:

- cold setting monosands (e.g. furan sand) are regenerated using simple mechanical techniques, as presented in Section 4.8.3. This applies to all cold setting monosands, except silicate sand. A regeneration ratio of 75 – 80 % may be achieved
- uncured cold-box and cold setting core sand are hardened and broken in a specific unit, allowing a minimum internal re-circulation of 5 – 10 % of the core sand (Section 4.8.11)
- silicate monosand is regenerated using heating and pneumatic treatment. A regeneration ratio of 45 – 85 % (as yearly average) may be achieved (Section 4.8.10). The use of slow-reacting esters should be minimised
- cold-box, SO_2, hot-box and Croning monosands and mixed organic sands are regenerated using one of the following techniques: cold mechanical regeneration (e.g. grinding, impact drum, pneumatic chafing) or thermal regeneration (Sections 4.8.4, 4.8.5, 4.8.6, 4.8.7). The overall regeneration ratio depends on the amount of cores used. For core-making 40 – 100 % of regenerated sand can be used; in mould making 90 – 100 % of regenerated sand can be used
- mixed green and organic sand are regenerated using mechanical-thermal-mechanical regeneration (Section 4.8.8), grinding (Section 4.8.4) or pneumatic chafing (Section 4.8.6).

For core-making 40 – 100 % of regenerated sand can be used; in mould making 90 – 100 % of regenerated sand can be used
- the quality and composition of the regenerated sand is monitored
- regenerated sand is re-used only in compatible sand systems. Non-compatible sand types are kept apart (see Section 4.8.1).

Alternative moulding methods (Section 4.3.4) and inorganic binders (Section 6.5) are considered to have a promising potential for the minimisation of the environmental impact of moulding and casting processes.

Pouring, cooling and shake-out

Pouring, cooling and shake-out generate emissions of dust, VOCs and other organic products. BAT is to:
- enclose pouring and cooling lines and to provide exhaust extraction, for serial pouring lines (Section 4.5.9.2), and
- enclose the shake-out equipment, and to treat the exhaust gas using wet or dry dedusting as discussed in Section 4.5.9.3. The BAT associated emission level for dust is specified in Table 5.6.

BAT associated emission levels

The following emission levels are associated to the BAT measures stated above. All associated emission levels are quoted as an average over the practicable measuring period. Whenever continuous monitoring is practicable, a daily average value is used. Emissions to air are based on standard conditions**,** i.e. 273 K, 101.3 kPa and dry gas.

Emission Source	**Parameter**	**Emission level (mg/Nm³)**
General	Dust	5 – 20
Core shop	Amine	5
Regeneration units	SO_2 NO_x	120 150

Table 5.6: Emissions to air associated with the use of BAT for moulding and casting using lost moulds

5.5 Permanent mould casting

Permanent mould casting involves the injection of molten metal into a metal mould. The mould is opened after solidification and the casting is taken out for finishing. Chemically-bonded sand cores are used to a limited extent in gravity and low-pressure die-casting.

HPDC dies need coating and cooling in order to provide good solidification and release properties. For these purposes, a release agent and cooling water are sprayed onto the die.
BAT for permanent mould preparation is all of the following, to:
- minimise the consumption of the release agent and water for HPDC dies, using one or more of the process measures discussed in Section 4.3.5.1. This prevents the formation of a mist. If prevention measures do not allow the BAT associated emission level for organic substances as defined in Table 5.7 to be reached, use hooding and EP, as discussed in Section 4.5.8.7
- collect run-off water into a waste water circuit for further treatment
- collect water leakage liquid from hydraulic systems into a waste water circuit for further treatment, using oil interceptors (Section 4.6.4) and distillation, vacuum evaporation or biological degradation as discussed in 4.6.6.

BAT for chemically-bonded sand preparation is analogous to the elements mentioned in Section 5.4. Since lower amounts of waste sand are generated, BAT for shake-out and used sand management are different. BAT for used sand management in permanent mould foundries is to:

- enclose the de-coring unit, and to treat the exhaust gas using wet or dry dedusting as discussed in Section 4.5.9.3, taking into account the BAT associated emission level given in Table 5.7, and
- if a local market exists, make sand from de-coring available for recycling (Section 4.8.13).

BAT associated emission levels

The following emission levels are associated to the BAT measures stated above. All associated emission levels are quoted as an average over the practicable measuring period. Whenever continuous monitoring is practicable, a daily average value is used. Emissions to air are based on standard conditions**,** i.e. 273 K, 101.3 kPa and dry gas.

Parameter	**Emission level (mg/Nm^3)**
Dust	5 - 20
Oil mist, measured as total C	5 - 10

Table 5.7: Emissions to air associated with the use of BAT for permanent mould casting (incl. HPDC)

6 EMERGING TECHNIQUES FOR FOUNDRIES

6.1 Use of low cost combustible materials in cupola melting

Description
In order to reduce the consumption of (high quality) coke, techniques have been developed to allow the use of high calorific value solid waste and lower grade coke as a fuel.

A particular type of cupola, named the FAR furnace, has been developed in Brazil, that allows the melting of a conventional charge using tyres and plastic pieces (automotive shredder residue - ASR, fluff, etc.), mixed with second rate coke. The cupola structure is totally different from the conventional one. Only the metallic charge enters from the top. The solid fuel is fed in from the side, so that it reaches the hot zone very quickly. Here hydrocarbons are cracked and combusted.

Alternative injection systems allow the addition of fluff or dust directly through the tuyères or by using specific injectors.

Achieved environmental benefits
A reduction in the consumption of cokes, as they are replaced by solid waste (ASR, fluff), which is difficult to treat in conventional combustion systems.

Operational data
For the FAR furnace, the best results have been obtained using 35 % fluff and 65 % coke. This technique has been developed up to pilot scale.

Cross-media effects
The application of alternative fuels will cause a change in the flue-gas composition; leading to higher amounts of dust for disposal, possibly with a higher content of pollutants and an increased risk of dioxins, PAHs and heavy metals. The thermal efficiency will be reduced.

Applicability
The application of this specific cupola type is only possible for new installations, since it has a specific furnace layout. Injection systems for solid or fluffy fuels may be applied on existing cupola furnaces.

Economics
Since the process has only been developed up to pilot scale, there are no economic data available for industrial scale application.

Driving force for implementation
To reduce the costs for fuels and to integrate the foundry into a waste management policy.

Reference literature
[140, EU Thematic Network Foundry Wastes, 2001]

6.2 Recycling of metal-bearing filter dust (ferrous metals)

Description
Metal-bearing dust can be agglomerated either using a binder (most preferably cement) or by mixing it with chips from machining, when the foundry has a machining shop. In the latter case the agglomerates may also include metal-bearing sludge. These agglomerates will be mixed in the induction furnace charge and melted. The metal yield can be over 90 %. The rest of the dust goes into the slag. Suitable agglomeration machines exist on the market.

Achieved environmental benefits
The amount of waste to be disposed of in landfills will be reduced, as will the need to buy metallic material outside the foundry. The mineral part of the metallic dust will not melt and is taken up by the slag. Thus it is converted into a less hazardous form of waste.

Operational data
Operational data are currently not available.

Cross-media effects
It may be possible that the slag formed will increase lining wear. Also the energy used in melting may increase slightly. In steel foundries, there is a risk of carbon pick-up.

Applicability
The technique applies to new and existing iron and steel foundries using induction melting furnaces.

Economics
In its current stage of development, no ecomic data are yet available. However, in initial estimates for one iron foundry with a machining shop, the payback time was calculated to be between two and four years.

Driving force for implementation
The main driving force for implementation may be that melting dust could, at least in some cases, be classified as hazardous waste. This would incur very high disposal costs for foundries.

Example plants
No example plants are available.

Reference literature
The technique is under development in the EU in an FP5 Growth project BRICETS "Metal By-Product Recovery in Induction Furnaces - Commercial, Environmental and Technical Solutions", contract number G1RD-CT-2001-00482. The project is due to finish in spring 2004.
[140, EU Thematic Network Foundry Wastes, 2001], [202, TWG, 2002]

6.3 Amine recovery from the core-making waste gas by gas permeation

In a pilot plant, amine (DMIA) was recycled from the exhaust air of a core shop by means of gas permeation. Its composition was as follows:
- 80 – 90 % amine (DMIA)
- 10 – 20 % solvent
- 0 % water.

After several test series, the recycled amine was used to gas brake-disk cores. It was found that there was no difference between these cores and the cores which were gased with standard commercial DMIA. The test cores were poured under normal production conditions and the finished brake disks underwent the usual technical tests.

All the results turned out to be within permissible tolerance. This showed that recycled DMIA can be used under normal production conditions. Economic efficiency may be achieved after further optimisation of the plant.
[217, Paul, et al., 1994]

6.4 Separate spraying of release agent and water in aluminium die-casting

Description

In aluminium high-pressure die-casting, the permanent moulds are cooled and sprayed with release agent prior to casting to prevent the casting adhering to the mould. The conventional technique for release agent use is that a mixture of release agent and water is applied to the hot mould in one go, by means of several linearly arranged nozzles. Some of the water evaporates, cooling the mould and leaving the release agent in place, whilst another part of the mixture runs off the mould, leading to a loss of release agent and water. The evaporation may also cause the formation of a mist. (see Section 4.5.8.7)

In an alternative process, water and release agent are applied separately. For this purpose, a row of nozzles was added to the spray head for the separate application of release agent. These nozzles can be actuated individually via a computer (see Figure 6.1).

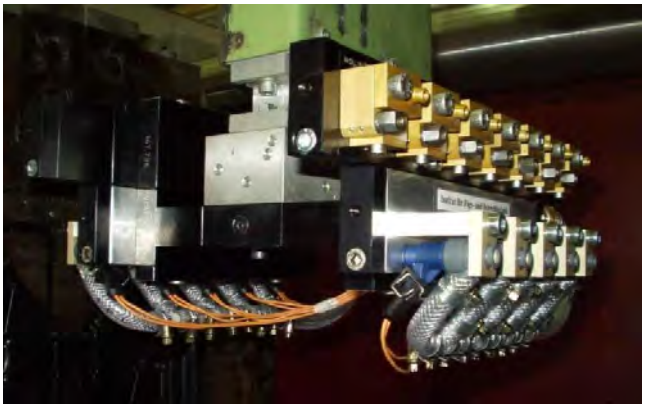

Figure 6.1: Spray head with separate nozzles for water and release agent

Water is sprayed on first, cooling the mould by approximately 20 ºC, followed by spray application of the release agent. The preliminary cooling causes less release agent to evaporate and improves its adhesion to the mould. This reduces the consumption of release agent by some 25 %. Thermographic measurements showed that the technique cools moulds more strongly and more evenly. Tests proved that it involves no leakage of release agent which otherwise would have had to be collected and disposed of.

Release agent is applied only to those parts of the mould which come into contact with the molten aluminium. This can reduce the consumption of release agent by another 30 %.

The use of computer-assisted actuation of the nozzles for the release agent has made the previously used existing array of nozzles for compressed air redundant. This function is now taken over by the nozzles for the release agent.

An advantage with small series and frequent mould changes is that the spraying programme can be saved on the computer and can thus be reproduced quickly after a mould change.

Achieved environmental benefits

The consumption of release agent can be reduced by 25 % by the separate application of water and release agent. Separate actuation of the nozzles makes it possible to achieve a further saving of up to 30 %, depending on the geometry of the casting, as the release agent is applied only to those parts of the mould which come into contact with the casting.

Water consumption can be reduced by about 15 %. There are no losses of water or release agent to be disposed of. No gaseous emissions due to evaporation of release agent are generated.

Cross-media effects

No cross-media effects apply. No increase in energy costs is expected.

Applicability
Previous tests were carried out in aluminium die-casting. The technique can also be applied in zinc die-casting and in the injection moulding of plastics. Modifications are necessary when the spray head is used at higher temperatures. These have not yet been tested.

Economics
Economic advantages result from the considerable savings in release agent and water, and from the elimination of disposal costs.

Further advantages result from the major time savings achieved in the mould change, due to the fact that spraying programmes can be saved and re-run.

The investment costs for this technique are higher than those of the conventional process. On the plus side, different moulds can be sprayed individually with the same spray head.

Driving force for implementation
Considerable saving of material and water.
The loss of release agent-water mixture, which needs to be collected, is avoided.
Short time-scales required for machine set up and adaptation.
High reproducibility of the results (consistent quality).

Example plants
The spray heads are produced and sold by a German producer from the end of 2003. Enquiries from the industry have already been received. Industrial use is expected to start by the end of 2003.

Reference literature
[234, Anders, 2003]

6.5 Inorganic binder material for core-making

Description
In order to reduce the consumption of organic binding material, which is responsible for emissions and odour in foundries (which can lead to complaints from neighbours), different compositions of inorganic binding materials have been developed for use in core-making in aluminium die-casting and have already been used in the series production of intake pipes for car engines.

The cores are produced using a binder that contains magnesium sulphate and/or polyphosphate. The inorganic binders consist essentially of salt-water mixtures, as well as small amounts of additives (e.g. ceramic) to prevent sand adhering or sticking to the casting. The proportion of binder relative to the quantity of sand by weight is 3 to 8%. About half of this amount is solvent and crystal water.

In order to achieve short drying times of 10 to 20 seconds, preheated sand (60 – 80 ºC) is blown into heated core-shooting tools (120 – 140 ºC), in which the solvent water and the crystal water evaporate and are flushed out by air. The inorganic ceramic core will then have a temperature stability of more than 1000 ºC, and will maintain high strength. When coming directly into contact with water, the core disintegrates within a few seconds. The mixing and shooting of warm sand is a patented core-shooting method.

After casting, core removal can be performed either wet or dry. In dry core removal, the lumps of sand are ground to grain size, which leaves the binder layer on the quartz sand largely intact. Therefore, once core sand is in the core sand cycle, binder must be added to it at only 5 % of the binder quantity originally used. In wet core removal, the castings are cooled rapidly by quenching. This can cause a desired improvement of the microstructure and causes the binder to dissolve completely.

The different sand flowing properties will require revision of the core models and venting upon implementation of this technique in an existing plant. In the drying step, all the moisture needs to leave the core, a requirement which may limit the core dimensions.

Achieved environmental benefits
Unlike the cold-box process, which gives rise to emissions of organic compounds such as amines, pyrolysis products and smoke, this technique involves no emissions from the binder, neither during core-shooting nor during casting. No waste is generated through the disposal of sand residues, and there is no need for costly sand regeneration. The quantity of sand to be replaced is very small.

The ceramic additives contained in the binder eliminate the need to coat the cores.

When a dry technique is used for core removal, all the binder remaining in the sand can be re-used.

Operational data
The fluidity of the binder-sand mixture is sufficient to produce complex shapes such as water jacket cores (cylinder head). The stability of test cores is 250 - 300 N/cm^3. The stability can be adapted to core requirements by adding more binder.

As no gases form during casting, no problems with gas permeability arise. The binder therefore allows the use of very fine sands, which significantly improve surface quality (e.g. depth of roughness). As the regeneration rate is high, it is economically viable to use even expensive alternative synthetic ceramic sands or e.g. zircon sand.

Cross-media effects
As there are no emissions from the binder, there is no need for waste gas collection and treatment. The heating of the binder-sand mixture and the preheating of the core-shooting tools give rise to higher energy costs compared to other core-making techniques.

Applicability
This technique is applicable for core-making in aluminium die-casting in new plants and in existing plants after adaptation of the core-shooting automates. Further developments are aimed at adapting the binder for use in iron casting and as a moulding material.

Economics
Despite the need to heat core-shooting tools, this technique leads to overall cost savings for core-making, due among other things to the lower consumption of new sand and the fact that costly thermal regeneration or the disposal of sand is no longer necessary. Costs savings can also be generated by recirculating the binder. Considerable cost reductions are achieved by the fact that there is no need for waste gas treatment systems to remove organic compounds, such as amines and pyrolysis products, which can arise during core-shooting and casting when organic binders are used.

According to rough estimates, the use of this technique reduces the costs for core-making by 30 to 50 % compared to the cold-box process.

Driving force for implementation
Considerable cost reduction.
Reduction of odour problems and organic emissions.

Example plants
Foundry of VW AG, Hanover, Germany

Reference literature
[235, Bischoff, 2003]

7 CONCLUDING REMARKS

7.1 Timing of the work

The first plenary meeting of the TWG was in April 1999. However, shortly after this, the project was put on hold from January 2000 due to a change of lead expert in the EIPPCB. The work recommenced in November 2001. A second plenary meeting of the TWG was organised in January 2002 to review the status of the work and the conclusions of the first meeting, taking into account possible new developments in the sector. The first draft of the BREF was then sent out to the TWG for consultation in November 2002. The comments were assessed and integrated into the document and a second draft, including proposals for BAT conclusions was sent out in May 2003. The final plenary meeting of the TWG was organised in October 2003. After the final meeting there was a short consultation on the concluding remarks and executive summary chapters before the final version of the document was produced.

7.2 Sources of information

Many documents were sent in by research centres, authorities and by industry as a basis of information for this document. The BAT documents from Belgium [110, Vito, 2001] and from the industry [32, CAEF, 1997] may be considered as the cornerstone documents. These were used as a starting point in the writing of the chapter on techniques to be considered in the determination of BAT (Chapter 4). These were supplemented by BAT documents and good environmental practice guides from the UK, Spain, Denmark and the Netherlands. Valuable information on specific techniques and their implementation in example plants was provided by Germany. Throughout the project there was a good and open communication with foundry experts from research centres and associations in France, Germany, Spain, UK, Finland, Belgium, Italy, Sweden and Portugal. Site visits were carried out in Germany, France, Spain, Belgium and Poland. The consultation rounds provided specific feedback from foundry operators, remarks on applicability and implementation of some techniques and additional operational data. Throughout the project, special attention was given to the involvement of the new Accession Countries that have important foundry industries. This resulted in the active participation of Poland, the Czech Republic and Hungary in particular in the information exchange.

In order to get a better view on what information was available on dioxin emission and abatement, the industry delegation organised a special workshop, in September 2003. This workshop was attended by over 30 participants, both TWG members and industry experts. It provided additional operational data and useful technical information.

The majority of the documents arising from the information exchange related to ferrous foundries. Non-ferrous foundry processes have been underrepresented throughout the exchange process. Nevertheless, there was a good communication with a few industry experts, although they did not attend the plenary meetings of the TWG. Valuable information was gathered during site visits at non-ferrous foundries in Germany, France and Belgium. The International Magnesium Association provided useful input on cover gases for magnesium melting.

The data quality of this document shows an imbalance, in that, for instance, consumption and emission levels mentioned in Chapter 3 and Chapter 4 vary from survey data for the sector in a whole country, to data covering several example plants, to specific data on single plants.

Emission data for non-ferrous metals are mainly based on single installations. For the melting of copper and zinc, only emission factors (given in kg/tonne of metal or kg/tonne of casting) were supplied. For the melting of magnesium and lead, no consumption and emission levels were provided. For the melting of aluminium, no emission data were provided for induction, rotary or

crucible furnaces. Where available, the emission factors are mentioned in Chapter 3. However, there was no clear correlation between the mentioned emission factors and applied techniques. Therefore BAT conclusions with an associated emission level were not possible for the melting of non-ferrous metals other than aluminium.

The document contains information on waste water prevention and treatment techniques. However, no data were supplied on the emission levels associated with these techniques. No operational data on waste water quality in relation to the applied treatment were provided. It was therefore not possible to determine a BAT associated emission level for waste water.

No information was provided concerning techniques for the abatement of VOC-emissions. The lack of information on abatement techniques and associated emission levels made it impossible to formulate a BAT conclusion. Techniques for the reduction of VOC-emissions related to coating processes (as applied to cores and moulds) may be found in the BREF on Surface Treatment Using Solvents.

In the discussion on the re-use of dust and residues, no information was provided on treatment or re-use techniques for dust from induction furnace melting, for dross from aluminium melting, fettling dusts, abrasives or for blasting grit, although a re-use of most of these materials into secondary metal production is possible.

Legislation surveys were sent in by two member states, but these are not necessarily representative for the whole of the European Union. Information on the applicable legislation in these two member states can be found at the following internet addresses:
- Austria: http://www.ris.bka.gv.at/
- Germany: http://www.bmu.de/de/txt/download/b_taluft/

7.3 Degree of consensus reached

The conclusions of the work were agreed at the final plenary meeting in October 2003 and a high level of consensus was reached. The industry expressed one concern on the dioxin issue, as expressed in detail in Section 5.2. Besides this concern, there was full agreement on all the BAT conclusions as presented in this document.

The main issues of discussion at the final meeting concerned the techniques for the collection and treatment of off-gas, the minimisation of fugitive emissions, noise reduction, the role of environmental considerations in technical choices and the BAT associated emission levels. For some processes, mainly in the field of non-ferrous metal melting, the information was incomplete and therefore no BAT AEL could be agreed. During the meeting, there was little discussion on the techniques that are specific for non-ferrous foundries, partially due to the absence of industry experts in this field.

The issue about whether environmental considerations play a detrmining role in the basic choice of melting furnaces and moulding methods, as formulated in Chapter 4 of the document, was carefully considered. There was a general agreement that these choices are complex and should be based on technical reasons and market considerations, on a case-by-case basis. Therefore the issue was not selected as BAT.

The discussions on the treatment of off-gases concluded with an agreement that for most operations in ferrous foundries both dry systems and well-performing wet systems are BAT. The associated emission levels were based on the information available in the document.

Concerning the reduction of fugitive emissions and noise, there was some discussion on the presentation of the topics and the level of detail to be given in Chapter 4 and Chapter 5. There was a general agreement not to conclude on a specific level of noise which could be associated with BAT.

7.4 Recommendations for future work

The information exchange and the result of this exchange, i.e. this document, present an important step forward in achieving the integrated prevention and control of pollution from the foundry industry. On a few topics, however, the information is incomplete and did not allow BAT conclusions to be reached. The main issues have been presented in Section 7.2. Future work could usefully focus on collecting the following information:

- *Techniques for VOC-abatement*: VOC-emissions are generated by the thermal decomposition of the binders upon pouring, in coating the cores and moulds and in the melting of dirty scrap, and are one of the key environmental issues for the sector. VOC-emissions in foundries typically involve large-volume, low-level flows, which represent a significant load to the environment and may result in an odour emission. Information is needed on techniques for the efficient capture and treatment of these flows, together with associated emission and economic data. The prevention of VOC emissions through the use of alternative binder and coating materials, also deserves further study. Data should be gathered and reported from the implementation of these techniques in operational practice
- *Waste water treatment*: Waste water treatment is presented in a general descriptive way in this document, and indeed operational data are given for only one example plant. The basis for discussion should be broadened, through an exchange of information on the performance of a broader range of treatment plants and providing further operational data. In view of the selection of wet scrubbing as part of BAT, information should be gained on the associated treatments of waste water and on emission levels to surface and sewage water flows
- *Melting of non-ferrous metals*: The discussion on non-ferrous metal melting is based on the melting of clean ingots and clean internal return material. On this basis, low emission levels are presumed. There is a need for more complete information on both guided and fugitive emissions (e.g. of metals, organics) from non-ferrous metal melting in foundries, based on operational practice and expressed both as an emission level (mass/exhaust volume) and as a mass flow (mass/output of metal or castings)
- *Economic data*: There is a lack of economic information for many of the techniques presented in Chapter 4. This information needs to be collected by industry and Member States from ongoing projects dealing with the implementation of the presented techniques
- *Energy Efficiency:* Examples of techniques for heat recovery for induction and cupola furnaces are given in this document. There is a need for additional examples of heat recovery systems, with performance data. Information should be gathered concerning enrgy consumption and energy losses for all types of furnaces, related to specific techniques to increase the energy efficiency. This may then allow the determination of BAT-associated energy consumption levels for metal melting.

7.5 Suggested topics for future R&D projects

The information exchange has also exposed some areas where additional useful knowledge could be gained from research and development projects. These relate to the following subjects:

- *Dioxin monitoring and abatement:* In order to allow the full implementation of primary measures for dioxin prevention, there is a need for a better understanding of the contribution of the process parameters to the formation of dioxins. This requires the monitoring of dioxin emissions for various installations and under varying conditions. Additionally, there is a need for research on the use and effectiveness of secondary measures in the foundry industry. Secondary measures (e.g. additive injection, catalytic filter bags) have been implemented in other sectors (e.g. steel, waste incineration, non-ferrous metals production), but there is very little experience of their performance and of possible operational problems which may occur in applying then in foundries

- *Mercury emissions:* Stack emissions of metals are largely related to dust. The minimisation of dust emissions, as presented in the BREF will therefore also minimise possible metal emissions. This holds true for all metals of concern for the sector, besides mercury. Uniquely for metals the high volatility of mercury may cause gaseous emissions which are not related to dust. In view of the implementation of a European policy on mercury emissions, there is a need for research on the emissions of mercury from melting processes in general and more specifically from (non-ferrous) foundries in particular
- *Oxygas burners and their use in cupola furnaces*: The application of oxygas burners in the cupola furnace is described in Section 4.2.1.10. The technique shows some environmental benefits. The difficulties encountered in the implementation of this technique, however limit its widespread take-up. The TWG reported that new applications have been set up as a result of ongoing research. There is a scope for further research and development here, to bring this technique up to a development level that allows its further implementation.
- *Alternative replacement gases for SF_6 in magnesium melting:* Alternative covers gases to replace SF_6 such as HFC-134a and Novec 612 have been developed and successfully tested with some recent industrial implementation. These gases present an alternative for the substitution by SO_2. Further research and demonstration projects would provide more detailed knowledge on the protective properties decomposition behaviour and emission pattern of these compounds. This should allow a clearer indication of the applicability and may support industrial implementation.

The EC is launching and supporting, through its RTD programmes, a series of projects dealing with clean technologies, emerging effluent treatment and recycling technologies and management strategies. Potentially these projects could provide a useful contribution to future BREF reviews. Readers are therefore invited to inform the EIPPCB of any research results which are relevant to the scope of this document (see also the preface of this document).

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Note: The numbers do not follow sequentially. They refer to the document numbers in the EIPPCB database (Technical material on Smitheries and Foundries). Only the references utilised in this document are quoted here.

9 GLOSSARY

9.1 Abbreviations

AEL	associated emission level
ADI	austempered ductile iron
AFS	American Foundrymen Society
AFS-number	measure of particle size distribution of foundry sand
AOD converter	argon oxygen decarburisation converter
AOX	absorbable organic halides
BAT	best available techniques
BREF	BAT reference document
BTEX	benzene, toluene, ethylbenzene,xylene
BTX	benzene, toluene,xylene
CAD	(before number): Canadian Dollar - ISO currency unit
CAD	(general): Computer aided design
CAEF	Committee of Associations of European Foundries
CAM	computer-aided manufacturing
CBC	cold blast cupola
CNC	computer numerical controlled
DEM	Deutsche Mark (German Mark - ISO currency unit)
DMEA	dimethyl ethyl amine
DMIA	dimethyl isopropyl amine
DMPA	dimethylpropylamine
DS	dry solid
EAF	electric arc furnace
EEA	European Environment Agency
EFR	Emission Factor Rating
EIPPCB	European IPPC Bureau
EMS	environmental management system
EP	electrostatic precipitator
EPER	European Pollutant Emission Register
EPS	expanded polystyrene
EUR	euro
FA	furfuryl alcohol
GWP	global warming potential
GBP	Great Britain Pound – ISO currency unit
HBC	hot blast cupola
HCE	hexachloroethane
HFC	hydrofluoro carbon
HIP	hot isostatic pressing
HP	high purity (for Magnesium alloys)
HPDC	high pressure die-casting
ID-fan	induced draught fan
IEF	Information Exchange Forum (informal consultation body in the framework of the IPPC Directive)
IF	induction furnace
IMA	International Magnesium Association
IPA	isopropyl alcohol
IPPC	integrated pollution prevention and control
IPTS	Institute for Prospective Technological Studies
JRC	Joint Research Centre
l.	left
LCA	life cycle assessment
LOI	loss on ignition

m.	middle
MDI	methyl di-isocyanate
n.a	not applicable
n.d	no data
NM-VOC	non-methane volatile organic carbons
OU	odour units
PAH	polycyclic aromatic hydrocarbon
PCDD/F	polychlorinated dibenzodioxins and -furans
PCB	polychlorinated biphenyl
PE	polyethylene
PEVA	polyethylene vinyl acetate
PF	phenol - formaldehyde
PFC	perfluorinated carbon
PM	particulate matter
PMMA	polymethylmethacrylate
ppm	parts per million
r.	right
RF	rotary furnace
RP	rapid prototyping
RPM	respirable particulate matter
SG	spheroidal graphite
SME	small and medium enterprise(s)
TEA	triethyl amine
TEQ	toxicity equivalent factor
TWA	time-weighted average
TWG	technical working group
VOC	volatile organic compound
VODC	vacuum oxygen decarburisation converter
UF	urea-formaldehyde
USD	United States Dollar – ISO currency unit

9.2 Terms

Annealing	a heat treating process that softens the alloy by slow cooling the metal through its critical temperature range
Austenitising	a heat treating process that holds the alloy above the critical temperature for a sufficient period of time to ensure that the matrix is fully transformed to austenite
Air factor	λ, the ratio of the air added to a combustion process over the stoechiometric quantitiy of air needed for complete oxidation
Cast iron	a ferrous alloy which solidifies with an eutectic solidification reaction, whatever the chemical composition, but normally with a carbon content above 2 %
Casting *(noun)*	general term used for products at or near their finished shape, formed by solidification of a metal or alloy in a mould (ISO 3134-4: 1985)
Diffuse emission	emissions arising from direct contact of volatile or light dusty substances with the environment (atmosphere, under normal operating circumstances). These can result from: - inherent design of the equipment (e.g. filters, dryers…) - operating conditions (e.g. during transfer of material between containers) - type of operation (e.g. maintenance activities) - or from a gradual release to other media (e.g. to cooling water or waste water). Fugitive emissions are a subset of diffuse emissions
Emission	the direct or indirect release of substances, vibrations, heat or noise from individual or diffuse sources in the installation into the air, water or land
“End-of-pipe” technique	a technique that reduces final emissions or consumptions by some additional process but does not change the fundamental operation of the core process. Synonyms: "secondary technique", "abatement technique". Antonyms: "process-integrated technique", "primary technique" (a technique that in some way changes the way in which the core process operates thereby reducing raw emissions or consumptions)
Existing installation	an installation in operation or, in accordance with legislation existing before the date on which this Directive is brought into effect, an installation authorised or in the view of the competent authority the subject of a full request for authorisation, provided that that installation is put into operation no later than one year after the date on which this Directive is brought into effect
Ferrous materials	those materials of which iron is the major constituent, i.e. the content of Fe (%w/w) is higher than that of any other element (following EN10020:2000; §2.1)
Full mould process	moulding technique using a foam model in chemically bonded sand, in which the model is lost upon pouring, generally used only for large castings
Grain refinement	a liquid metal treatment made late in the melting operation to produce a finer and equiaxed grain during solidification.
Green sand	mix of sand, clay and additives as used for mould making
Grey iron	cast iron with grey-coloured fracture; may be found with lamellar, nodular and compact graphite but the term is most often used for lamellar iron
Hearth type furnace	static furnace with direct heating, also called reverberatory furnace and bale-out furnace

Inclusion	(specific term for this sector) impurity in the metal structure, producing structural defects; mostly used for non-ferrous metals (e.g. oxides in magnesium, hydrogen in aluminium)
Jungbüth or net diagram	diagram representing the influence of the blast rate and the coke charge on the tapping temperature of the metal and the melting rate; used for cupola furnaces
Lamellar iron	cast iron with carbon in the form of flakes
Lost Foam process	moulding technique using foam models in unbonded sand, in which the model is lost upon pouring of the metal, used for series production
Lost mould	or single use moulds, a mould that is specially made for each casting and is destroyed after pouring. The moulds are generally made of sand, chemically-bonded or clay-bonded, or even unbonded. Investment casting can also be included in this family
Lost mould casting	all processes of the moulding and casting shop in a foundry using lost moulds, such as sand preparation, moulding, core-making, pouring, cooling and shake-out
Malleable iron	iron that is capable of extension or of being shaped under the hammer; produced by decarburising (whiteheart malleable iron) or not decarburising (blackheart malleable iron) heat treatment of graphite-free iron with white fracture surface (white cast iron)
Melting capacity	the aggregate 'plated' capacity of the furnaces at an installation; where the hourly rate multiplied by 24 should be used if appropriate
Modulus	silica-to-soda ratio SiO_2/Na_2O, used to characterise (sodium) silicates
Nodular iron	cast iron with carbon in nodular/spheroidal shape, commonly refered to as ductile iron
Nodularisation	magnesium treatment of cast iron to change the carbon particles into nodular/spheroidal shape
Non-ferrous materials	all materials that are not ferrous
Normalising	a heat treating process that cools the alloy in air from a temperature above its critical range
Off-site sand re-use	utilisation of sands in various ways
Permanent mould	or multi use a mould, mould that is used for gravity and low-pressure casting, pressure die-casting, or centrifugal casting; typically the moulds are metallic
Permanent mould casting	all processes of the coreshop and casting shop in a foundry using permanent moulds, such as sand preparation, core-making, die-casting, take-out and decoring
Pollutant	individual substance or group of substances which can harm or affect the environment
Post combustion	ignition and burning of exhaust gas through the injection of air or the use of a burner; used in order to reduce the amount of CO and (volatile) organic compounds
Primary regeneration	the processing of used green sand for internal re-use in the sand circuit, using screening, sieving, cooling and mixing with new sand, fresh bentonite and other additives
Production capacity	production of 'good castings' and capacity based on the theoretical capacity of the foundry if it was operated for 24 hours, provided that it is technically able to operate that way
Regeneration ratio	the ratio between the mass of regenerated sand and the total mass of sand used in mould and core-making, expressed as a percentage

Sand circuit	the various parts of the installation for storage, transport, preparation and treatment of sand
Sand recycling	on-site used-sand preparation, for external re-use
Secondary (sand) regeneration	measures (mechanical, pneumatic, thermal and wet) aimed at removing spent binder layers from the sand corn (= reclamation); returning the sand to a quality similar to, or better than, new sand
Steel	a ferrous alloy which solidifies according a preritetic reaction. The (mass) content of iron is bigger than that of any other element, and the carbon content is generally lower than 2%; the alloy also usually contains other elements
Tempering	a heat treatment that after the hardening of the alloy consists of heating to a temperature below Ac_1 and cooling in air; after austenitising and liquid quenching, this provides to the alloy the highest possible hardness and strength

9.3 Lexicon

English	Deutsch	Français	Nederlands	Español	Italiano	Magyar
bentonite	Bentonit	bentonite	bentoniet	bentonita	bentonite	bentonit
bridging	Brückenbildung	accrochage	brugvorming	colgadura	formazione di corona	adagfennakadás
burr	Grat	barbe	braam	rebarba	bava	fánc
cast iron	Gusseisen	fonte	gietijzer	hierro	ghisa	öntöttvas
cast steel	Stahlguss	acier moulé	gietstaal	acero moldeado	getti d'acciaio	öntött acél
casting	Giessen	couler	het gieten	fundición	colata	öntés
chamfer	Abschrägung	chanfrein	gietsysteem	chaflán	cianfrinatura	formázási ferdeség
channel induction furnace	Rinnenofen	four à induction à canal	kanaal inductieoven	horno de inducción de canal	forno a canale	csatornás indukciós kemence
coating	Schlichte	enduit, poteyage	coating/deklaag	pintura	vernice, verniciatura	formabevonó anyag
cold-box	kalter Kernkaste, Cold-box	boîte froide	cold-box	caja fria	cassa fredda	cold-box
core	Kern	noyau	kern	macho	anima	mag
corebox	Kernkasten	boîte à noyaux	kerndoos	caja de macho	cassa d'anima	magszekrény
core-making	Kernfertigung	noyautage	kernmakerij	macheria	formatura di anime	magkészítés
crucible furnace	Tiegelofen	four à creuset	kroesoven	horno de crisol	forno a crogiolo	tégelykemence
decoring	Entkernen	debourrage	ontkernen	extracción de macho	sterratura delle anime	kimagozás
die	Druckgiessform	moule	vorm	mole metálico	stampo	kokilla, nyomásos öntőforma
die lubricant	Druckgiessschlichte	poteyage	koelsmeermiddel	lubricante	distaccante	kokilla-, nyomásos öntőforma kenőanyag
drying oven	Backofen	étuve	droogstoof	estufa	essiccatore	szárító kemence
fettling	putzen	ébarbage	ontbramen	desmazarotado	sbavatura	tisztítás
grinding	schleifen	meulage	slijpen	esmerilada	molatura	csiszolás, köszörülés
induction furnace	Induktionsofen	four à induction	inductieoven	horno de inducción	forno ad induzione	indukciós kemence
lamellar iron *or* grey cast iron	Grauguss, GGL	fonte lamellaire, fonte grise	lamellair gietijzer	hierro gris	ghisa a grafite lamellare, ghisa grigia	lemezgrafitos *vagy* szürke öntöttvas
lustrous carbon	Glanzkohlenstoff	carbone brillant	glanskoolvormer	carbono brillante	carbonio brillante	fényes karbon
malleable iron	temperguss (GT)	fonte malléable	smeedbaar gietijzer	fundición maleable	ghisa malleabile	tempervas
mixer	Menger	malaxeur	menger	mezclador	mescolatore	keverő
mould	Form	mote	vorm	molde	forme	forma
nodular iron, ductile iron, SG iron	GGG, Gusseisen mit Kugelgraphit	fonte à graphite sphéroidal, fonte ductile	nodulair gietijzer	hierro nodular	ghisa sferoidale	gömbgrafitos öntöttvas
pouring	Giessen	couler	gieten	colada	colata	öntés
sand	Sand	sable	zand	arena	sabbia	homok

English	Deutsch	Français	Nederlands	Español	Italiano	Magyar
shaft furnace	Schachtofen	four à cuve	schachtoven	horno de cuba	forno a tino	aknás kemence
shake-out	Ausleeren	décochage	uitschudden	desmoldeo	distaffatura	ürítés, kirázás
shot blasting	Schleuderstrahlen	grenaillage	gritstralen	granallado	granigliatura	szemcseszórás
sprue	Einguss	canal de coulée	voedingskanaal	canal de colada	canale di colata	álló beömlő
turnings	Späne	copeaux	spanen	viruta	trucioli	forgács
veins	rissen	gerces	vinnen	venas	crestine	repedések

10 ANNEXES

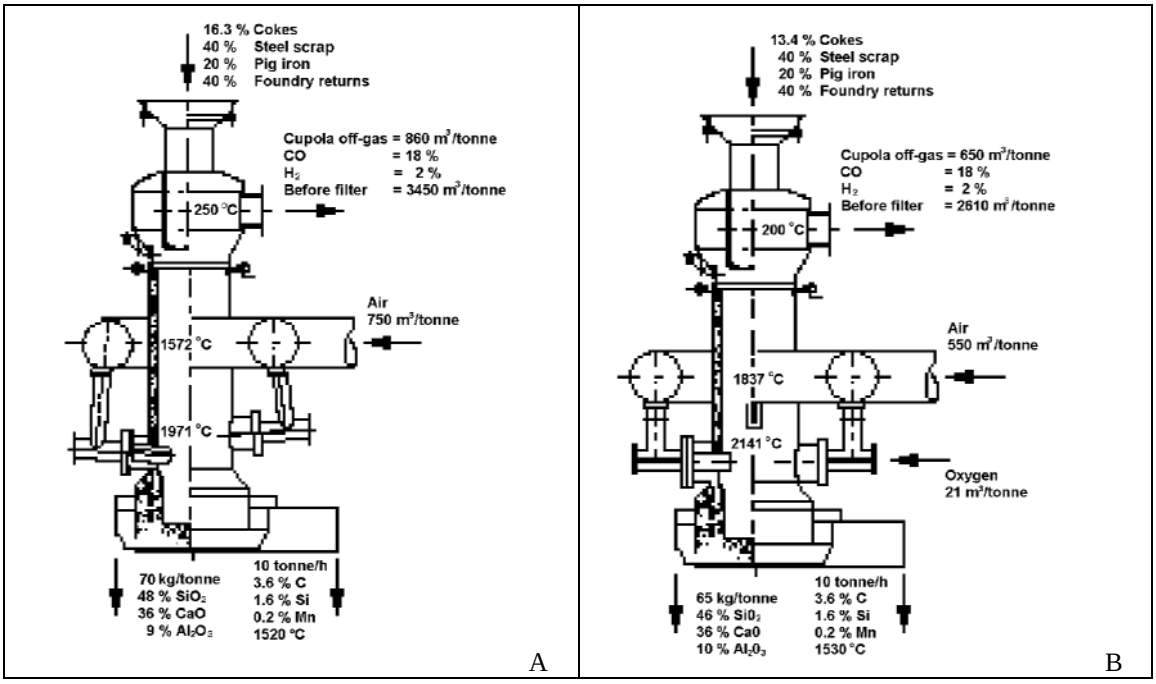
10.1 Annex 1 Overview of data for cast iron melting in various cupola types and in the induction furnace

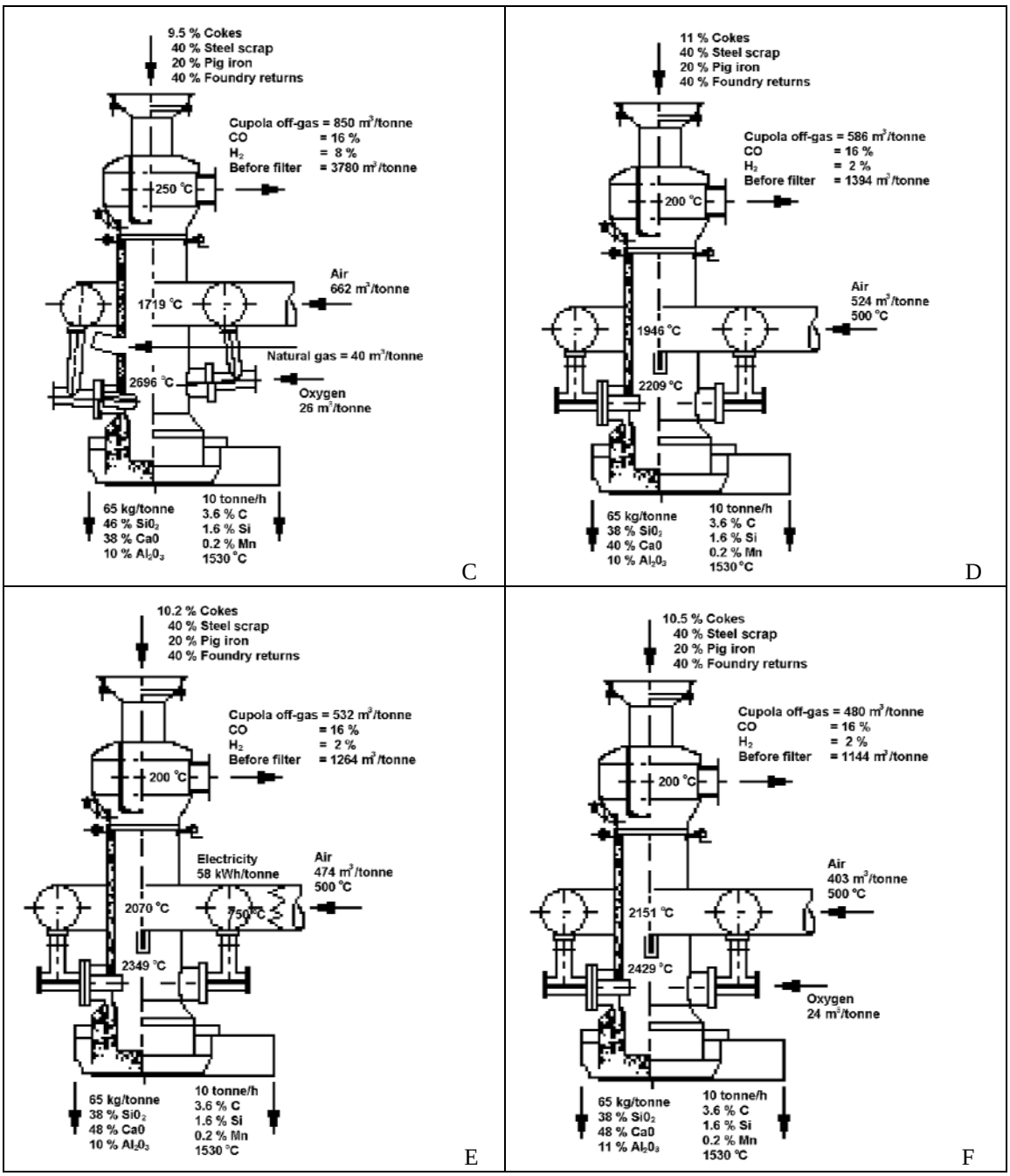
A survey of the consumption and emission levels of the various technical modifications of cupola melting was set up by Neumann in 1994, as given below. All data refer to a system for the production of 10 tonne/h nodular iron with 3.6 % C and 1.6 % Si and at a pouring temperature of 1530 ºC. The balances in Figure 10.1 show inputs, outputs and process temperatures. The latter will be higher compared to operational practice. Comparison of the various balances allows an assessment of the effect of all the modifications.

Additional operational data for cold and hot blast cupolas, with various flue-gas cleaning equipment types, are given and discussed in Section 4.5.2. Those data are taken from operating plants.

The pictures show the following techniques:

(A): cold blast, secondary row of tuyères
(B): cold blast, oxygen injection
(C): cold blast with gas burner, oxygen injection
(D): hot blast (500 ºC), long campaign
(E): hot blast with electrical support heating (750 ºC)
(F): hot blast, oxygen injection (6 %)
(G): hot blast, with plasma support heating (1450 ºC)
(H): cokeless cupola in duplex operation (electrical superheating).




9.5 % Cokes
40 % Steel scrap
20 % Pig iron
40 % Foundry returns
Cupola off-gas = 850 m³/tonne
CO = 16 %
H₂ = 8 %
Before filter = 3780 m³/tonne
250 °C
Air
662 m³/tonne
1719 °C
Natural gas = 40 m³/tonne
2696 °C
Oxygen
26 m³/tonne
65 kg/tonne
46 % SiO₂
38 % CaO
10 % Al₂O₃
10 tonne/h
3.6 % C
1.6 % Si
0.2 % Mn
1530 °C
C
11 % Cokes
40 % Steel scrap
20 % Pig iron
40 % Foundry returns
Cupola off-gas = 586 m³/tonne
CO = 16 %
H₂ = 2 %
Before filter = 1394 m³/tonne
200 °C
Air
524 m³/tonne
500 °C
1946 °C
2209 °C
65 kg/tonne
38 % SiO₂
40 % CaO
10 % Al₂O₃
10 tonne/h
3.6 % C
1.6 % Si
0.2 % Mn
1530 °C
D
10.2 % Cokes
40 % Steel scrap
20 % Pig iron
40 % Foundry returns
Cupola off-gas = 532 m³/tonne
CO = 16 %
H₂ = 2 %
Before filter = 1264 m³/tonne
200 °C
Electricity
58 kWh/tonne
Air
474 m³/tonne
500 °C
2070 °C
750 °C
2349 °C
65 kg/tonne
38 % SiO₂
48 % CaO
10 % Al₂O₃
10 tonne/h
3.6 % C
1.6 % Si
0.2 % Mn
1530 °C
E
10.5 % Cokes
40 % Steel scrap
20 % Pig iron
40 % Foundry returns
Cupola off-gas = 480 m³/tonne
CO = 16 %
H₂ = 2 %
Before filter = 1144 m³/tonne
200 °C
Air
403 m³/tonne
500 °C
2151 °C
2429 °C
Oxygen
24 m³/tonne
65 kg/tonne
38 % SiO₂
48 % CaO
11 % Al₂O₃
10 tonne/h
3.6 % C
1.6 % Si
0.2 % Mn
1530 °C
F

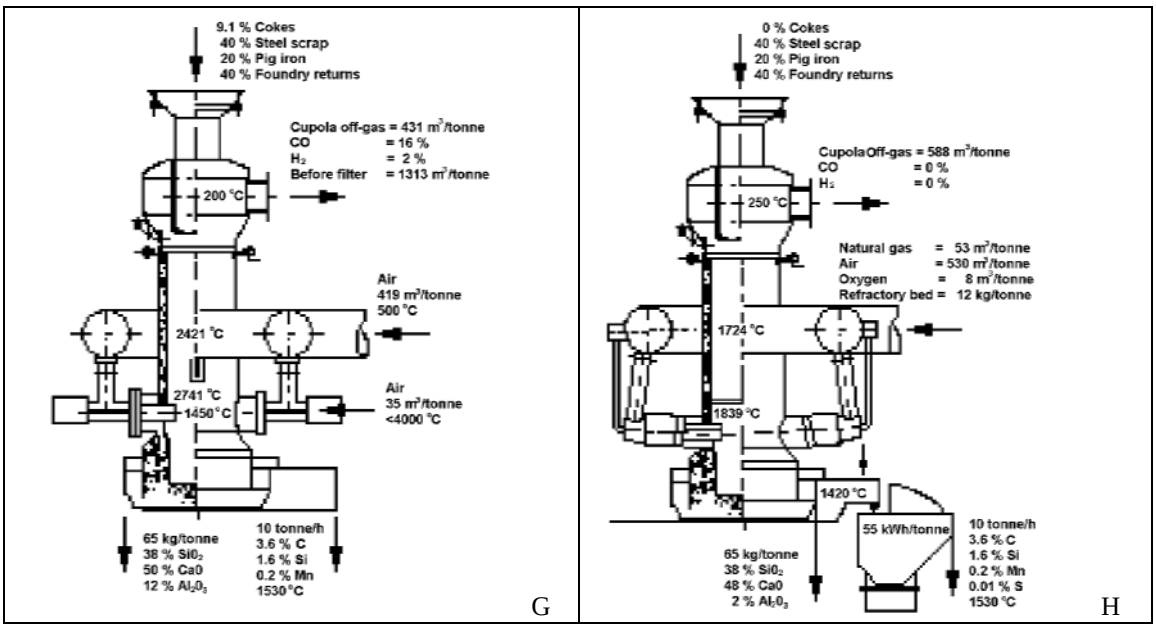


Figure 10.1: Input-output balance for various technical modifications of cupola melting [172, Neumann, 1994]

Operational data are given in Table 10.1, Table 10.2 and Table 10.3. These include economic data based on the stated unit costs. Operational data are based on the production of a cast iron with 3.3 % C and 2 % Si. In the cold blast operation 35 % steel scrap is used, while the hot blast operation allows 60 %. This is taken into account when considering the necessary carburisation. For this, C is also supplied through the addition of the SiC briquettes.

Calculation of the heat balance results in the stated heat transfer efficiencies. The cold blast cupola shows an efficiency of <30 %. The application of oxygen or secondary air increases the efficiency to 37 – 40 %. The hot blast cupola shows a further increased efficiency, providing the furnace wall is refractory lined. In liningless operation, the efficiency drops below 40 %, which may be somewhat compensated for by adding oxygen. The cokeless cupola with inductive superheating results in a very high efficiency, close to 60 %.

The calculated operational costs include depreciation of the investment cost, but exclude personnel costs. The cost difference between the various techniques is rather small. The calculation takes account of higher cokes consumption and more expensive scrap/raw material costs for the cold blast cupola. In the case of air preheating using a plasma torch, the increased electricity use leads to increased costs. In practice, this increase may be balanced by an increased usage of swarf as raw material. The cokeless cupola shows the lowest cost. In this evaluation, however, local cost effects and uncertainties, such as the effect of hourly rate, have not been taken into account, but need to be considered. The quoted data are all for installations with a significant hourly rate. This disfavours the performance of cold blast cupolas.

	Units or Cost per unit	Normal	O_2	Second-ary row	Second-ary + O_2
Specific quantity					
Melting cokes	kg/tonne	150	125	120	105
Cokes for carburisation	kg/tonne	10	10	10	10
Natural gas	m^3/tonne				
Electricity	kWh/tonne	20	20	20	20
Oxygen	%	-	3	-	2
Blast air	m^3/tonne	711	562	604	517
Cupola off-gas	m^3/tonne	902	724	731	628
Filtered off-gas	m^3/tonne	3022	2150	1765	1646
Slags	kg/tonne	36	35	46	45
Refractory	kg/tonne	5.2	5.2	4.8	4.8
SiC- briquettes(45 % SiC)	kg/tonne	28.5	28.5	31.3	30.3
Total heat input	MJ/tonne	5003	3643	3588	3416
Heat transfer to iron	%	26.9	37.2	37.8	39.8
Costs					
Investment	EUR million	2.81	2.91	3.06	3.16
Alloy	EUR 332/tonne	9.44	9.44	10.36	10.36
Additives	EUR 10/tonne	0.20	0.20	0.20	0.20
Cokes	EUR 204/tonne	32.65	27.55	26.53	23.47
Steel scrap	EUR 128/tonne	44.64	44.64	44.64	44.64
Scrap iron	EUR 128/tonne	12.76	12.76	12.76	12.76
Pig iron	EUR 194/tonne	38.78	38.78	38.78	38.78
Natural gas	EUR 153/1000 m^3	0.31	0.31	0.31	0.31
Electricity	EUR 89/MWh	1.79	1.79	1.79	1.79
Oxygen	EUR 179/1000 m^3	-	3.01	-	1.84
Graphite	EUR 561/tonne	-	-	-	-
Refractory	EUR 765/tonne	3.98	3.98	3.67	3.67
Capital	10 years/8 %	11.22	11.63	12.24	12.65
Total melting cost	**EUR/tonne**	**155.77**	**154.08**	**151.28**	**150.46**
Iron composition: 3.3 % C; 2.0 % Si; 0.3 % Mn; 0.1 S; 1500 ºC Load composition: 35 % steel scrap; 35 % returns; 20 % pig iron; 10 % scrap iron					

Table 10.1: Operational data of a cold blast cupola (10 tonne/h)
[172, Neumann, 1994]

	Units or Cost per unit	Type A*	Type B	Type C	Type D	Type E
Characteristics						
Daily furnace change		Yes	No	No	No	No
Oxygen enrichment		No	No	Yes	No	Yes
Lining		Yes	Yes	Yes	No	No
Specific quantity						
Melting cokes	kg/tonne	95	100	85	115	100
Cokes for carburisation	kg/tonne	8	7	7	8	8
Oxygen	%	-	-	3	-	3
Air	m^3/tonne	571	566	425	626	473
Cupola off-gas	m^3/tonne	680	667	519	746	586
Filtered gas	m^3/tonne	1798	1471	1134	1819	1473
Slag	kg/tonne	60	60	60	60	60
Refractory	kg/tonne	15	6	6	1.5	1.5
SiC- briquettes(45 % SiC)	kg/tonne	50	53	53	50	50
Total heat input	MJ/tonne	3756	3630	3076	4098	3534
Heat transfer to iron	%	39.8	40.2	44.9	36.5	38.7
Costs						
Investment	EUR million	3.42	3.57	3.65	3.49	3.55
Alloy	EUR 332/tonne	16.58	17.60	17.60	16.58	16.58
Additives	EUR 10/tonne	0.20	0.20	0.20	0.20	0.20
Cokes	EUR 204/tonne	21.02	21.84	18.78	25.10	22.04
Scrap steel	EUR 128/tonne	76.53	76.53	76.53	76.53	76.53
Scrap iron	EUR 128/tonne	12.76	12.76	12.76	12.76	12.76
Oxygen	EUR 179/1000 m^3	-	-	3.06	-	3.42
Refractory	EUR 765/tonne	11.48	4.59	4.59	1.12	1.12
Capital	10 years/8 %	13.67	14.29	14.59	13.98	14.18
Total melting cost	**EUR/tonne**	**152.24**	**147.81**	**148.11**	**146.28**	**146.84**

* Is no longer built as new plant
Iron Composition: 3.3 % C; 2.0 % Si; 0.3 % Mn; 0.1 S; 1530 ºC
Load composition: 60 % steel scrap; 30 % returns; 10 % scrap iron

Table 10.2: Operational data of a hot blast long campaign cupola (10 tonne/h) [172, Neumann, 1994]

	Units or Cost per unit	Cokeless Cupola with O_2 + induct. superh.	Hot blast cupola	
			air preh. using plasma	air preh. using electric resistance
Specific quantity				
Melting coke	kg/tonne	-	81	90
Coke for carburisation	kg/tonne	-	10	12
Natural gas	m^3/tonne	55	2	2
Electricity	kWh/t	80	175	82
Oxygen	%	1.5	-	-
Air	m^3/tonne	5.30	419	474
Cupola off-gas	m^3/tonne	692	451	531
Cleaned off-gas	m^3/tonne	815	1313	1264
Slags	kg/tonne	58	59	60
Refractory	kg/tonne	16	9.3	4.3
SiC- briquettes (45 % SiC)	kg/tonne	-	13.7	15.4
FeSi- briquettes (1 kg Si per briquette)	kg/tonne	8	-	-
Total heat input	MJ/tonne	2562	3952	3320
Heat transfer to iron	%	58.4	41.4	41.5
Cost				
Investment	EUR million	2.81	5.10	3.83
Alloy	EUR 332/tonne		4.54	5.10
Fe-Si-briquettes	EUR 454/tonne Si	3.62		
Additives	EUR 10/tonne	0.56	0.56	0.56
Cokes	EUR 204/tonne		18.57	23.06
Electricity	EUR 89/MWh	7.14	15.61	7.30
Gas	EUR 128/1000 m^3	6.99	0.31	0.31
Scrap steel	EUR 128/tonne	44.64	44.64	44.64
Scrap iron	EUR 128/tonne	44.64	44.64	44.64
Graphite	EUR 561/tonne	6.73		
Oxygen	EUR 179/1000 m^3	1.43		
Refractory	EUR 102/tonne	0.61	0.31	0.20
Refractory	EUR 765/tonne	7.65	4.80	1.79
Capital	10 years/8 %	11.22	20.41	15.31
Total melting cost	**EUR/tonne**	**135.26**	**154.39**	**142.91**
Iron composition: 3.3 % C; 2.0 % Si; 0.3 % Mn; 0.1 S; 1530 ºC Load composition: 35 % steel scrap; 30 % returns; 35 % scrap iron				

Table 10.3: Operational data of a cokeless cupola and hot blast cupola with air preheating [172, Neumann, 1994]

CTIF also calculated the costs of liquid cast iron in a comparative study about the different melting ways [226, CTIF, 1997]. This study, made in 1997, was updated in 2003 [227, Godinot, 2004].

Units	GRADE	Lamellar cost iron (ENGJL 250)				Nodular cost iron (ENGJS 400 – 15)		
	Melting device	Cold blast cupola	Hot blast cupola	Cokeless cupola	Induction furnace	Hot blast cupola	Cokeless cupola	Induction furnace
EUR/t	Metallic charge	95.80	59.52	96.68	72.97	49.75	73.52	59.80
	Ferro alloys + additives	7.62	13.09	27.22	25.72	5.27	24.17	24.85
	Energy and fluids	33.14	35.26	20.29	27.28	40.12	21.07	27.28
	Linings	3.73	4.29	8.79	1.47	4.55	8.79	1.47
	Personnel costs	10.05	10	11	9.10	10.42	11	9.10
	Maintenance	1.55	3.15	0.16	0.93	3.15	0.16	0.93
	Environment	4.50	4.30	3.15	0.55	4.30	3.15	0.55
	Desulphurisation					10.33		
	Depreciation of investment	5.92	14.81	8.89	8.89	14.81	8.89	8.89
	Total per tonne charged	162.31	144.42	176.78	146.91	142.70	150.75	132.97
%	Fire loss	5	5	5	3	5	5	3
EUR/t	Total per tonne liquid	170.85	152.02	185.45	151.45	150.21	158.68	136.98
%	Returns percentage	35	40	35	40	50	50	50
EUR/t	Total per tonne of casting	262.85	253.36	285.31	252.42	300.42	317.37	273.96

Table 10.4: Comparison of liquid cast iron costs -June 2003. Mass production – 10 t/h

		Cold blast cupola			Induction			Coreless furnace			Hot blast cupola			Cokeless cupola		
Characteristic	**Unit**	Price EUR/unit	Ratio	Price EUR/t	Price EUR/unit	Ratio	Price EUR/t	Price EUR/unit	Ratio	Price EUR/t	Price EUR/unit	Ratio	Price EUR/t	Price EUR/unit	Ratio	Price EUR/t
Coke	tonne	210	0.145	30.45							210	0.125	26.25			
Electricity	kWh	0.0513	20	1.027	0.0448	609	27.28	0.0448	609	27.28	0.0513	128	6.57	0.0513	165	8.46
Oxygen	Nm^3	0.535	2	1.07							0.535	2	1.07	0.23	11	2.53
Gas	kWh (NCV)	0.0296	20	0.59							0.228	60	1.37	0.0186	500	9.30
Sub total				33.14			27.28			27.28			35.26			20.29
Returns	tonne	0	0.35	0	0	0.40	0	0	0.50	0	0	0.40	0	0	0.35	0
Pig iron	tonne	185	0.20	37	185	0.15	27.75	200	0.10	20				185	0.25	46.25
Scrap iron	tonne	167	0.20	33.4										167	0.15	25.05
Scrap steel (E3)	tonne	101.5	0.25	25.4	101.5	0.225	22.83				101.5	0.30	30.45	101.5	0.25	25.38
Scrap steel (E8)	tonne				99.5	0.225	22.39	99.5	0.40	39.80						
Scrap steel (E1 C)											96.9	0.30	29.07			
Sub total				95.8			72.97			59.80			59.52			96,68
Graphite	kg				0.70	16.7	11.69	0.80	17.92	14.34				0.7	8.12	5.68
FeSi	kg Si	0.68	8	5.44	1.13	10.6	11.98	1.13	9.39	10.61	0.68	15.8	10.74	0.68	11. 71	7.96
FeMn	kg Mn	0.595	2.7	1.60	0.79	2.6	2.05				0.59	3.2	1.89	0.595	1.45	0.86
$CaCO_3$ + div	tonne	12.2	0.048	0.58							12.2	0.0375	0.46			12.72
Balls	tonne															
Sub total				7.62			25.72			24.95			13.09			27.22

Table 10.5: Price of lamellar cast iron: Metallic charge + energy

	Units	Hot blast cupola			Cokeless cupola		
		Price EUR/unit	Ratio	Price EUR/t	Price EUR/unit	Ratio	Price EUR/t
Coke	tonne	210	0.14	29.40			
Electricity	kWh	0.0513	140.5	7.21	0.0513	180	9.23
Oxygen	Nm^3	0.535	4	2.14	0.23	11	2.53
Gas	kWh (NCV)	0.0228	60	1.37	0.0186	500	9.30
Sub total				40.12			21.07
Returns	tonne	0	0.40	0	0	0.40	0
Pig iron	tonne				199	0.20	39.8
Scrap iron	tonne				167	0.05	8.35
Scrap steel (E8)	tonne	99.55	0.50	49.75			
Scrap steel (E3)	tonne				101.5	0.25	25.38
Sub total				49.75			73.52
Graphite	kg				0.7	12.37	8.66
FeSi	kg Si	0.68	7	4.76	0.68	4.11	2.79
FeMn	kg Mn						
$CaCO_3$ + div	tonne	12.2	0.042	0.51			12.72
Balls	tonne						
Sub total				5.27			24.17

Table 10.6: Price of nodular cast iron: Metallic charge + energy

Table 10.4 summarises the costs of cast iron calculated for the 3 main cupola types compared with coreless induction furnace. Some items greatly depend on the melting device and the grade: energies and fluids, metallic charge and ferro alloys. They are detailed in Table 10.5 and Table 10.6.

The compared melting devices melt at 10 - 12 t/h, in 2 shifts for a mass production typically, e.g. the automotive industry. The investments are paid in 10 years and correspond to the industrial practice in each case, i.e.:

Cold blast cupola
- 2 daily drop cupolas (one per day)
- treatment of fumes: combustion, cooling, dry filtration.

Hot blast cupola
- long campaign cupola
- treatment of fumes: combustion, blast heating, cooling, dry filtration
- holding in a channel induction furnace.

Cokeless cupola
- long campaign cupola
- treatment of fumes: cooling, dry filtration
- heating and recarburisation in a superheater
- holding in a channel induction furnace.

Introduction furnace
- 2 furnaces 12 tonne
- 1 power supply 10MW – 250 Hz.

The cost of cast iron must take into account its downstream recarburisation (cokeless cupola), its holding and also the importance of the fume treatment system.

The price of cast iron was compared for 2 different alloys in the case of mass automotive industry:

- lamellar cast iron (ENGJL 250)
- nodular graphite base cast iron (base for ENGJS 400-15).

The cold blast cupola is increasingly less used for nodular cast iron and was not considered in this case.

Comparing the calculations of CTIF and Neumann:

The position of the melting devices, from the least to the most expensive, is not the same depending on the type of alloy and the authors:

- Lamellar graphite cast iron (LG cast iron)
  CTIF: induction furnace, hot blast, cold blast, cokeless cupola
  Neumann: cokeless, hot blast, cold blast cupola
- Nodular base cast iron
  CTIF: induction furnace, hot blast, cokeless (little different).

The comparison of the different items for Neumann and Godinot leads to the following conclusions:

1. Energies and fluids
- the cokeless cupola is the least expensive in all cases
- it is noticeable that the energy costs strongly depend on the country, particularly with regard to the price and availability of electricity and gas. In the CTIF study, energy costs correspond to the French case (prices published in the review "Energy Plus").

2. Metallic charges and ferro alloys

The classification technique applied of disadvantages the cokeless cupola for CTIF and not for Neumann. The principal differences are the following ones:

- Neumann indicates 0 % pig iron for cokeless cupola, when Godinot indicates a minimum of 25 % according to the industrial practice. Pig iron is the most expensive metallic charge.
- Neumann gives the same cost for steel scrap and cast iron scrap. In the French case, the ratio between these 2 costs has been between 2 and 1.3 for 10 years. This ratio was 1.6 in June 2003, the date considered for the calculation, as indicated in the attached Figure 10.2.

It is noticeable that the cost of raw materials, including scrap, are fixed today at an international level.

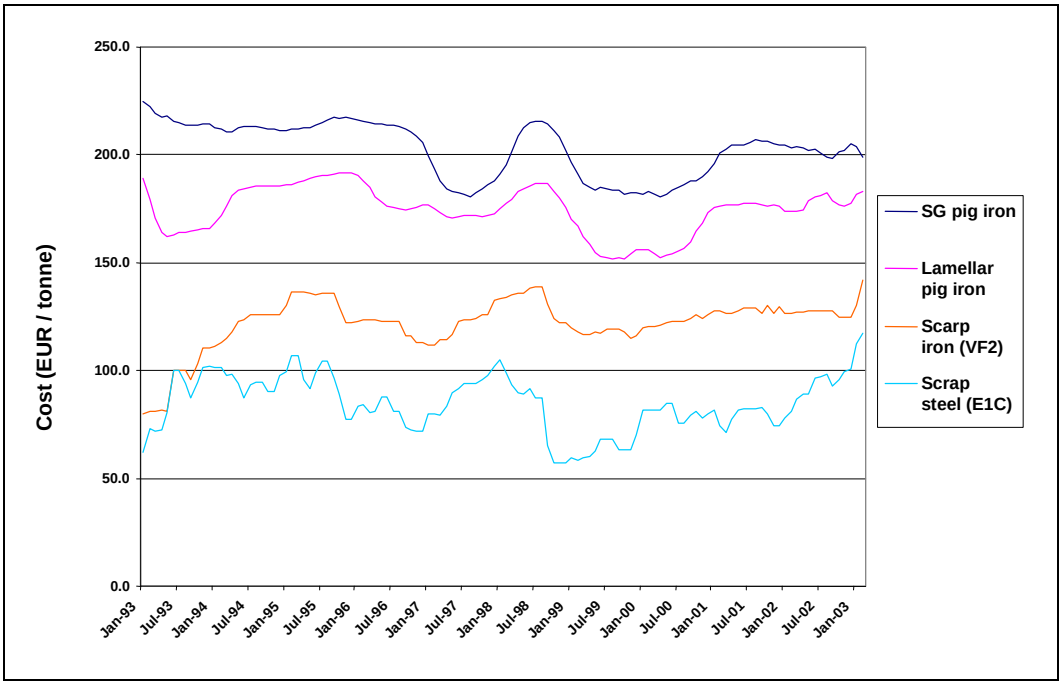


Figure 10.2: Cost of raw materials (France: 1993 to 2003)

3. Other items

The investment is less important than for cold blast, cokeless cupola and coreless induction furnace.

- in the case of the cold blast cupola liquid, cast iron is produced at a good temperature and analysis is possible at the spout of the cupola; moreover the metallurgical results depend little on the hourly production. It is not necessary to hold the cast iron in a channel induction furnace
- in the case of the hot blast cupola, or of the cokeless cupola, it is difficult to modify the hourly production. A reservoir of liquid metal is necessary between the cupola and the moulding shop, i.e. generally a channel induction furnace
- in the case of the cokeless cupola, the specific volume of fumes to be treated is low and it is not necessary to burn CO
- finally, in the case of the coke cupola (hot or cold blast), a desulphurisation is generally practised before holding the base nodular liquid cast iron. The cost of this operation is high, which is favours the cokeless cupola, whose cast iron does not contain any sulphur.

4. Conclusion

Taking industrial practice into account, according to Godinot, the cokeless cupola has the advantage of a low energy consumption but it incurs extra cost for the raw charging materials.

In the case of base nodular cast iron, the cokeless cupola produces a metal without sulphur and with a cost level similar to the hot blast. In the case of lamellar cast iron, in France, this melting device produces a more expensive metal than coke cupolas.

Today, for this type of production in France the limit between cupola and induction is 10 t/h (lamellar cast iron) and probably more in the case of nodular cast iron (the cupola is less expensive for 20 t/h).

These calculations have been made for an automotive type mass production. For other applications, they need to be slightly modified. At least it is possible to say the relative order depends on the local conditions, especially energy costs which depend strongly on the country of application.

10.2 Annex 2 Dust control equipment at a large-scale automotive foundry

Dust emission monitoring data were provided by a Swedish large-scale automotive foundry. The foundry uses a continuous particulate emission monitoring system on 17 bag filter exhausts. Data were plotted on a graph for various time ranges and for 4 measurement points as shown in Figure 10.3, Figure 10.4 and Figure 10.5. The figures show a continuous dust level well below 1 mg/Nm³ for sand preparation and shot blasting. A 24h-average of 1.3 – 1.6 mg/Nm³ was obtained for the sand transport.

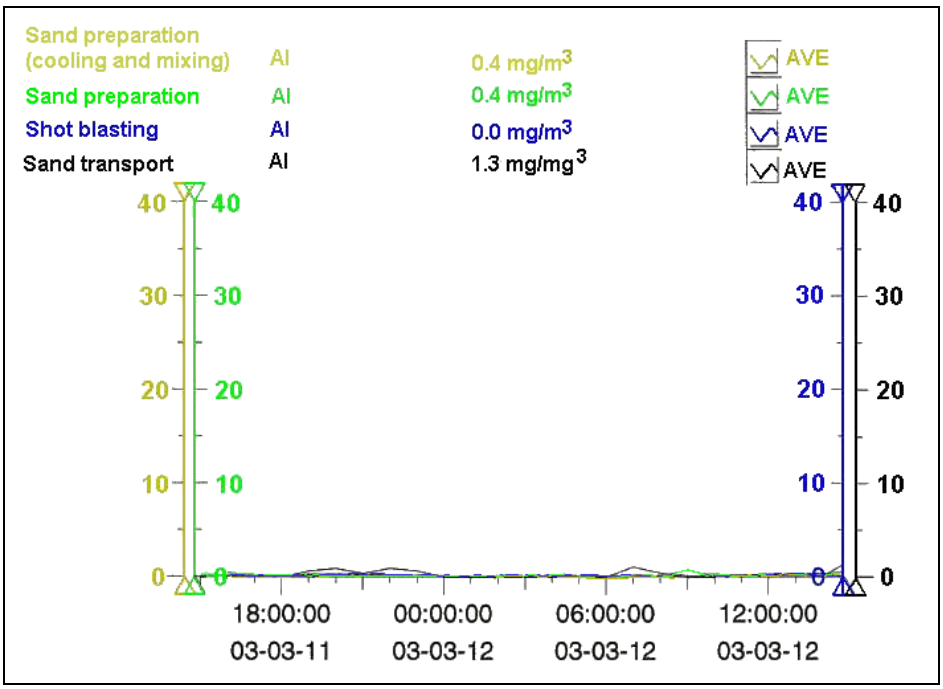


Figure 10.3: Monitoring data for dust emissions from 4 locations in the sand plant (24 hours continuous monitoring)

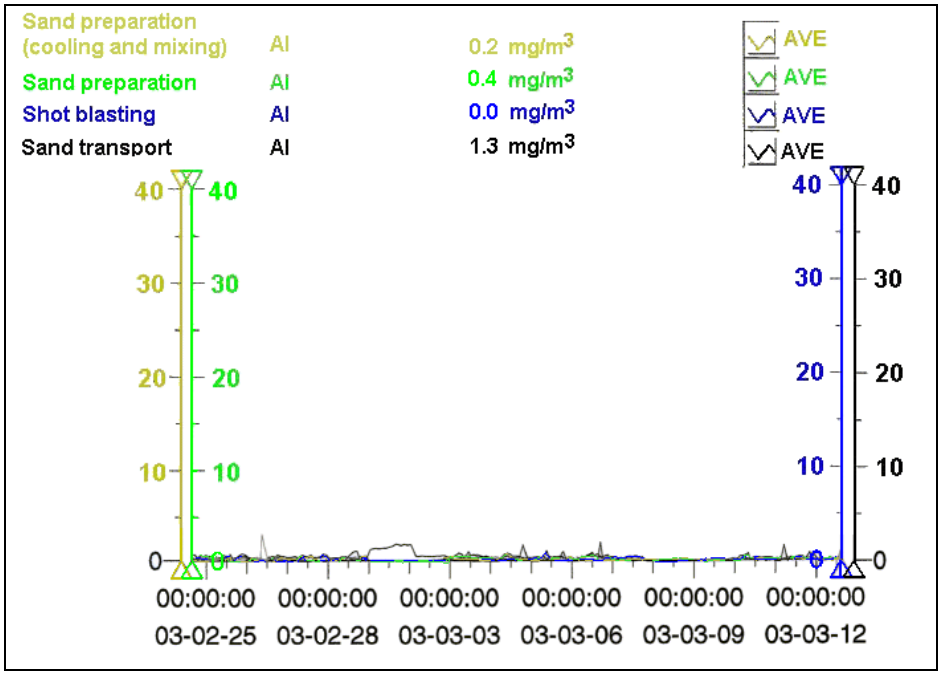


Figure 10.4: Monitoring data for dust emissions from 4 locations in the sand plant (2 weeks continuous monitoring)

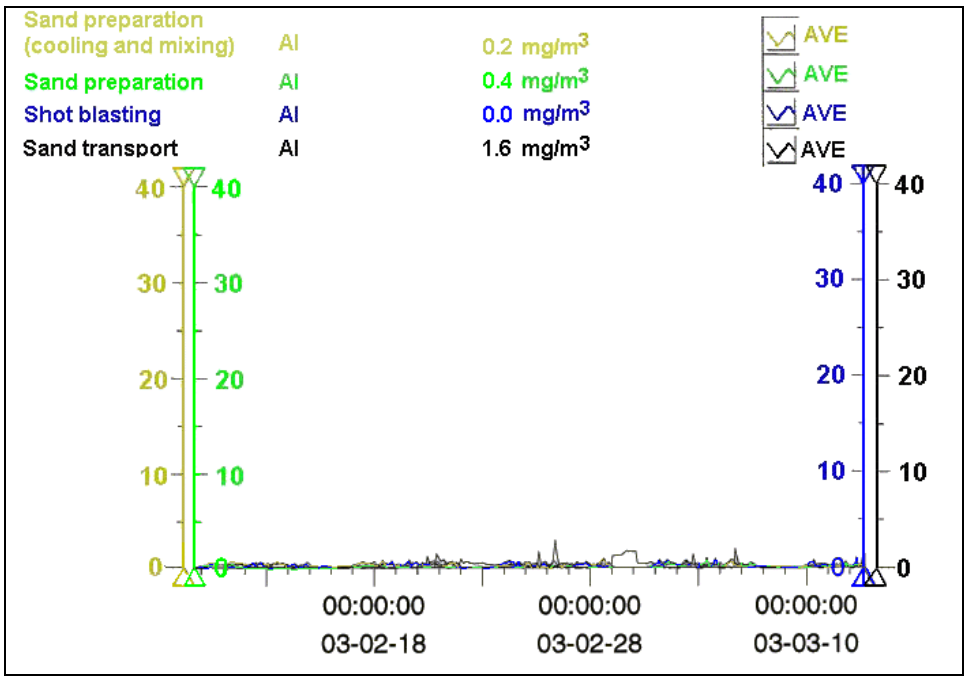


Figure 10.5: Monitoring data for dust emissions from 4 locations in the sand plant (30 days continuous monitoring)

This example plant has a permitted emission limit value for dust of 10 mg/Nm³. The monitoring system has an alarm limit of 5 mg/Nm³. If this limit is passed, the filter is checked and tested with fluorescence material. If the measured value passes 10 mg/Nm³, the production and filter are stopped. Calibration of the monitoring equipment is performed twice a year by an external contractor.

The service and maintenance instructions are as follows:

- daily
  - pressure drop check
  - visual check
  - magnetic valve check
  - condensation water drain
- monthly
  - check tightness
- quarterly (every 3 months)
  - control with fluorescence material.

Best Available Techniques (BAT) Reference Document for the Smitheries and Foundries Industry

Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)

Colour code:

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Black italics and highlighted in yellow are messages to the TWG, not part of the BREF

JOINT RESEARCH CENTRE
Directorate B – Growth and Innovation
Circular Economy and Industrial Leadership Unit

European IPPC Bureau

Draft 1 (February 2022)

This document is one from the series of foreseen documents listed below (at the time of writing, not all documents have been drafted):

Reference Document on Best Available Techniques (BREF)	**Code**
Ceramic Manufacturing Industry	CER
Common Waste Gas Management and Treatment systems in the Chemical Sector	WGC
Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector	CWW
Emissions from Storage	EFS
Energy Efficiency	ENE
Ferrous Metals Processing Industry	FMP
Food, Drink and Milk Industries	FDM
Industrial Cooling Systems	ICS
Intensive Rearing of Poultry or Pigs	IRPP
Iron and Steel Production	IS
Large Combustion Plants	LCP
Large Volume Inorganic Chemicals	LVIC
Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers	LVIC-AAF
Large Volume Inorganic Chemicals – Solids and Others Industry	LVIC-S
Large Volume Organic Chemical Industry	LVOC
Management of Tailings and Waste-rock in Mining Activities	MTWR
Manufacture of Glass	GLS
Manufacture of Organic Fine Chemicals	OFC
Non-ferrous Metals Industries	NFM
Production of Cement, Lime and Magnesium Oxide	CLM
Production of Chlor-alkali	CAK
Production of Polymers	POL
Production of Pulp, Paper and Board	PP
Production of Speciality Inorganic Chemicals	SIC
Production of Wood-based Panels	WBP
Refining of Mineral Oil and Gas	REF
Slaughterhouses, Animals By-products and Edible Co-products Industries	SA
Smitheries and Foundries Industry	*SF*
Surface Treatment of Metals and Plastics	STM
Surface Treatment Using Organic Solvents including Preservation of Wood and Wood Products with Chemicals	STS
Tanning of Hides and Skins	TAN
Textiles Industry	TXT
Waste Incineration	WI
Waste Treatment	WT
Reference Document (REF)	
Economics and Cross-media Effects	ECM
Monitoring of emissions to Air and Water from IED Installations	ROM

Electronic versions of draft and finalised documents are publically available and can be downloaded from http://eippcb.jrc.ec.europa.eu/.

~~EXECUTIVE SUMMARY~~

The executive summary of the previous BREF has been deleted.

PREFACE

1. Status of this document

Unless otherwise stated, references to 'the Directive' in this document refer to Directive 2010/75/EU of the European Parliament and the Council on industrial emissions (integrated pollution prevention and control) (Recast).

This document is a working draft of the European IPPC Bureau (of the Commission's Joint Research Centre). It is not an official publication of the European Union and does not necessarily reflect the position of the European Commission.

2. Participants in the information exchange

As required in Article 13(3) of the Directive, the Commission has established a forum to promote the exchange of information, which is composed of representatives from Member States, the industries concerned and non-governmental organisations promoting environmental protection (Commission Decision of 16 May 2011 establishing a forum for the exchange of information pursuant to Article 13 of the Directive 2010/75/EU on industrial emissions (2011/C 146/03), OJ C 146, 17.05.2011, p. 3).

Forum members have nominated technical experts constituting the technical working group (TWG) that was the main source of information for drafting this document. The work of the TWG was led by the European IPPC Bureau (of the Commission's Joint Research Centre).

3. Structure and contents of this document

This document contains six main chapters:

Sections 1.1 and 2.1 provide general information on the industrial sectors concerned.

Sections 1.2 and 2.2 provide information on the industrial processes and techniques used within these sectors.

Sections 1.3 and 2.3 provide data and information concerning the environmental performance of installations within the smitheries and foundries sectors, and in operation at the time of writing, in terms of current emissions to air and to water, consumption of raw materials, water and energy and the generation of waste.

Chapter 3 describes in more detail the techniques to prevent or, where this is not practicable, to reduce the environmental impact of installations in these sectors that were considered in determining the BAT. This information includes, where relevant, the environmental performance levels (e.g. emission and consumption levels) which can be achieved by using the techniques, the associated monitoring and the costs and the cross-media issues associated with the techniques. Chapter 3 is structured as follows:

- Section 3.1: Common techniques to consider in the determination of BAT for smitheries and foundries;
- Section 3.2: Techniques to consider in the determination of BAT for foundries;
- Section 3.3: Techniques to consider in the determination of BAT for smitheries.

Chapter 4 presents the BAT conclusions as defined in Article 3(12) of the Directive.

Chapter 5 presents the identified emerging techniques for both smitheries and foundries.

Concluding remarks and recommendations for future work regarding smitheries and foundries are presented in Chapter 6 ***[It will be drafted at a later stage]*** .

4. Information sources and the derivation of BAT

This document is based on information collected from a number of sources, in particular through the TWG that was established specifically for the exchange of information under Article 13 of the Directive. The information has been collated and assessed by the European IPPC Bureau (of the Commission's Joint Research Centre) who led the work on determining BAT, guided by the principles of technical expertise, transparency and neutrality. The work of the TWG and all other contributors is gratefully acknowledged.

The BAT conclusions have been established through an iterative process involving the following steps:

- identification of the key environmental issues for the sectors on smitheries and foundries,
- examination of the techniques most relevant to address these key issues;
- identification of the best environmental performance levels, on the basis of the data available in the European Union and worldwide;
- examination of the conditions under which these environmental performance levels were achieved, such as costs, cross-media effects, and the main driving forces involved in the implementation of the techniques;
- selection of the best available techniques (BAT), their associated emission levels (and other environmental performance levels) and the associated monitoring for this sector according to Article 3(10) of, and Annex III to, the Directive.

Expert judgement by the European IPPC Bureau and the TWG has played a key role in each of these steps and the way in which the information is presented here.

Where available, economic data have been given together with the descriptions of the techniques presented in Chapter 3. These data give some indication of the magnitude of the costs and benefits. However, the actual costs and benefits of applying a technique may depend greatly on the specific situation of the installation concerned, which cannot be evaluated fully in this document. In the absence of data concerning costs, conclusions on the economic viability of techniques are drawn from observations on existing installations.

5. Review of BAT reference documents (BREFs)

BAT is a dynamic concept and so the review of BREFs is a continuing process. For example, new measures and techniques may emerge, science and technologies are continuously developing and new or emerging processes are being successfully introduced into the industries. In order to reflect such changes and their consequences for BAT, this document will be periodically reviewed and, if necessary, updated accordingly.

6. Contact information

All comments and suggestions should be made to the European IPPC Bureau at the Joint Research Centre (JRC) at the following address:

European Commission
JRC Directorate B – Growth and Innovation
European IPPC Bureau
Edificio Expo
c/Inca Garcilaso, 3
E-41092 Seville, Spain
Telephone: +34 95 4488 284
E-mail: JRC-B5-EIPPCB@ec.europa.eu
Internet: http://eippcb.jrc.ec.europa.eu

Best Available Techniques Reference Document for the Smitheries and Foundries industry

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SCOPE

The BREF for the smitheries and foundries industry concerns the following activities specified in Annex I to Directive 2010/75/EU:

2.3. Processing of ferrous metals:
(b) operation of smitheries with hammers the energy of which exceeds 50 kilojoules per hammer, where the calorific power used exceeds 20 MW.

2.4. Operation of ferrous metal foundries with a production capacity exceeding 20 tonnes per day.

2.5. Processing of non-ferrous metals:
(b) melting, including the alloyage, of non-ferrous metals, including recovered products, and operation of non-ferrous metal foundries, with a melting capacity exceeding 4 tonnes per day for lead and cadmium or 20 tonnes per day for all other metals.

6.11 Independently operated treatment of waste water not covered by Directive 91/271/EEC, provided that the main pollutant load originates from the activities covered by these BAT conclusions.

This document also covers the following:

- Ferrous metal foundries employing continuous casting processes for the production of grey or nodular iron castings at or near their final shape.
- Non-ferrous metal foundries using alloyed ingots, scrap, recovered products or liquid metal for the production of castings at or near their final shape.
- The combined treatment of waste water from different origins, provided that the waste water treatment is not covered by Directive 91/271/EEC and that the main pollutant load originates from the activities covered by these BAT conclusions.
- The coating of moulds and cores in ferrous and non-ferrous metal foundries.
- The storage, transfer and handling of materials, including the storage and handling of scrap and sand in foundries.
- Combustion processes directly associated with the activities covered by these BAT conclusions provided that the gaseous products of combustion are put into direct contact with material (such as direct feedstock heating or direct feedstock drying).

This document does not cover the following:

- The continuous casting of iron and/or steel (i.e. to produce thin slabs, thin strips, and sheets). This is covered by the BAT conclusions for Iron and Steel production (IS).
- The production of semi-finished non-ferrous metal products requiring further forming. This is covered by the BAT conclusions for the Non-Ferrous Metals industries (NFM).
- Cadmium, titanium and precious metal foundries, as well as bell and art casting.
- The coating of castings. This may be covered by the BAT conclusions for Surface Treatment Using Organic Solvents including Wood and Wood Products Preservation with Chemicals.
- Forging presses.
- Rolling mills. This is covered by the BAT conclusions for the Ferrous Metals Processing Industry (FMP).

Other reference documents which could be relevant for the activities covered by this BREF are the following:

- Large Combustion Plants (LCP);
- Surface Treatment of Metals and Plastics (STM);
- Waste Treatment (WT);
- Monitoring of Emissions to Air and Water from IED Installations (ROM);
- Economics and Cross-Media Effects (ECM);
- Emissions from Storage (EFS);
- Energy Efficiency (ENE);

1 SMITHERIES

This chapter summarises the results of an exchange of information on the activities covered under activity 2.3 (b) of Annex I to the IED (i.e. '2.3 Installations for the processing of ferrous metals: (b) smitheries with hammers the energy of which exceeds 50 kilojoule per hammer, where the calorific power used exceeds 20 MW').

This chapter on smitheries does not focus on the use of presses or rolling mills. Information on rolling mills can be found in the FMP BREF. [168, COM 2021]

1.1 General information

[137, Herbertz et al., 2013][156, FIA 2021]

Forging is a process where prepared metal workpieces are heated and then transformed into a component part by using hammers or presses. The metal is pressed, pounded or squeezed under great pressure into high-strength parts.

It should be noted that, in the forging process, the metal used to make forged parts is never melted and poured (as in the casting process). The forging process is entirely different from the casting (or foundry) process (see Section 2.2). Furthermore, the forging process can create parts that are stronger than those manufactured by any other metalworking process. [156, FIA 2021]

Ferrous forgings are produced using principally three main production processes which are as follows:

- Closed-die forging process: Closed-die forging utilises pressure to compress a workpiece in an enclosed die. Closed-die forging is the main manufacturing process to produce small steel forgings.
- Open-die forging process: It involves deforming a piece of metal between multiple dies that do not completely enclose the workpiece. Usually, metal billets are deformed using hammers or presses delivering successive blows or press operations with very high compressive forces. This process is mostly used for the production of large steel forgings.
- Cold forging process: Cold forging takes place at room temperature. A workpiece is inserted between two dies and is pressed with high pressure until it has adopted the die shapes.

The choice of the production technique used depends on different criteria: shape, size, weight, batch size, material, cost-effectiveness, lead time, etc.

In this document, only forging installations using hammers, either for closed or open-die forging applications, are considered because these installations are covered under Annex I to the IED (activity 2.3). Such installations are designated as smitheries in this document.

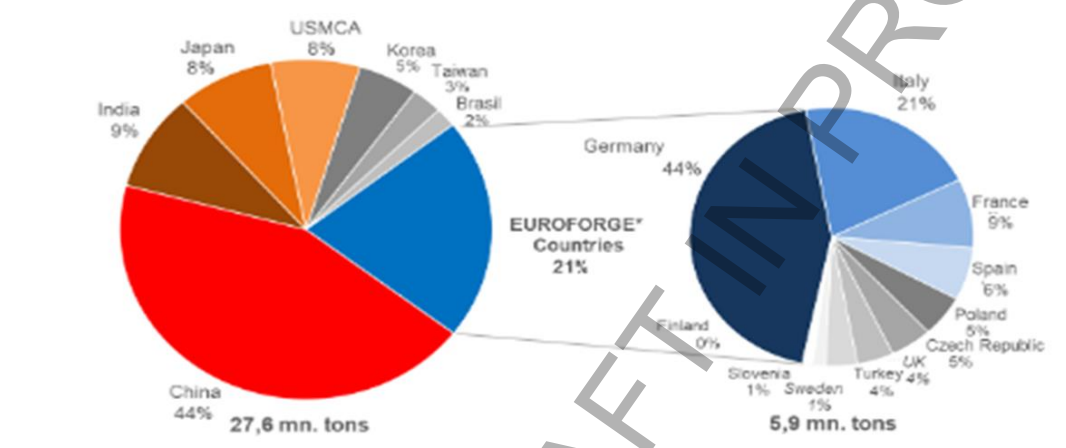
There is a higher number of forging installations in Europe that use press forging rather than forging hammers. Such plants are usually designated as forging presses; however, they are not currently covered under the IED and therefore are not described in great detail in this document. Also, hot rolling mills (e.g. ring rolling mills in particular), which are covered in the Ferrous Metals Processing Industry BREF, are not covered in this document.

1.1.1 Sector overview

1.1.1.1 Size of the industrial sector

In 2019, the European forging industry is the second largest in the world with a production volume of 21 %, as shown in Figure 1.1. In the EU-27, 44 % of the forging production volume is produced in Germany, and Italy has a production volume of 21 %. The total production of die-forging products varies in the various European countries. The EU forging industry is present in several EU Member States and involves the use of forging hammers and presses.

However, there are a small amount of smitheries installations using forging hammers that meet the threshold of IED Annex I.



Source: [138, Euroforge 2020]

Figure 1.1: Figures on global and European forging industries in 2019

The following table (Table 1.1) shows a survey regarding the production volume of forgings for different countries of the world and the countries affiliated to Euroforge in 2018. It shows from which industry sector the production of forgings comes from. Globally, China produced the highest volume, around six times more than Japan or India. Countries affiliated to Euroforge produce about half the volume of China. [154, Euroforge 2020]

The European forging production figures for 2018 are shown in Table 1.2. The countries affiliated to Euroforge consists of the following: Spain, Germany, Finland Norway, Great Britain, France, Belgium, Czech Republic, Poland, Slovenia and Italy. Germany is the biggest producer of forgings, followed by Italy, France, Spain, Poland and the Czech Republic. [154, Euroforge 2020]

Table 1.1: 2018 production volumes of forgings – World and Europe (countries affiliated to EUROFORGE)

PRODUCTION VOLUME OF FORGINGS (metric net tonnes x 1 000)	Countries affiliated to Euroforge*	Japan	USA, Canada, Mexico[1]	China	India[2]	Brazil	Korea	Taiwan	World
	2018	**2018**	**2018**	**2018**	**2018**	**2018**	**2018**	**2018**	**2018**
CLOSED-DIE FORGING TOTAL	4 361	1 926	1 492	7 953	1 525	498	1 137	852	19 744
• of which production of forging industry (subcontracting)	3 515	1 625	1 492	7 953	1 525	460	1 137	852	18 559
• of which in-house production of the automotive industry	313	301	0	0	0	0	0	0	614
• of which in-house production of the finished assembly subcontracting	202	116	0	0	0	36	0	0	238
• of which catalogue items (flanges and fittings, pipes, connectors, armatures, tools, etc.)	331	116	0	0	0	2	0	0	333
COLD FORGING TOTAL	743		0	0	187	3	112	96	1 257
• of which production of cold forging industry (subcontracting)	662	402	0	0	187	2	112	96	1 175
• of which in-house production of final customer industries	71	289	0	0	0	1	0	0	72
OPEN-DIE FORGING TOTAL	974	113	536	4 128	401	0	130	15	6 587
• of which ring rolling	326	47	161	765	120	0	88	6	1 755
• of which other open-die forging (excluding steel bars, blanks and railway stacks)	494	2 491	375	3 363	281	0	42	9	4 677
CLOSED-DIE FORGING NON-FERROUS	133		98	0	152	0	30	18	478
TOTAL FORGING PRODUCTION VOLUME	**6 211**		**2 126**	**12 081**	**2 265**	**501**	**1 409**	**981**	**28 065**

* Countries affiliated to Euroforge: Belgium, Czech Republic, Finland, France, Germany, Great Britain, Norway, Italy, Poland, Slovenia and Spain.
[1] No update available for 2017/2018 – data base is 2016.
[2] No data available for 2018 – data base is 2017.

Source: [154, Euroforge 2020]

Table 1.2: European survey of production volume of forgings

PRODUCTION VOLUME OF FORGINGS (metric net tonnes x 1 000)	Germany	Italy	France	Spain	Sweden	Czech Republic	Poland	Slovenia	Finland	Countries affiliated to Euroforge *
	2018	**2018**	**2018**	**2018**	**2018**	**2018**	**2018**	**2018**	**2016**	**2018**
CLOSED-DIE FORGING TOTAL	1 802	950	408	345	78	151	189	51	8	4 361
• of which production of forging industry (subcontracting)	1 311	795	408	304	74	60	189	18	5	3 515
• of which in-house production of the automotive industry	210					70		33		313
• of which in-house production of the finished assembly subcontracting	110	68				5				202
• of which catalogue items (flanges and fittings, pipes, connectors, armatures, tools, etc.)	171	87		41	4	16			3	331
COLD FORGING TOTAL	602	0	50	25	0	27	0	10	1	743
• of which production of cold forging industry (subcontracting)	532		50	25		27				662
• of which in-house production of final customer industries	70								1	71
OPEN-DIE FORGING TOTAL	287	315	39	66	0	97	115	0	1	974
• of which ring rolling	141	90		35		38				326
• of which other open-die forging (excluding steel bars, blanks and railway stacks)	146	225		31		59			1	494
CLOSED-DIE FORGING NON-FERROUS	86		15			28				133
TOTAL FORGING PRODUCTION VOLUME	**2 777**	**1 265**	**512**	**436**	**78**	**303**	**304**	**61**	**10**	**6 211**
* Countries affiliated to Euroforge: Spain, Germany, Finland Norway, Great Britain, France, Belgium, Czech Republic, Poland, Slovenia, Italy.										
Source: [154, Euroforge 2020]										

In 2021, at the time of writing this document, there were 3 smitheries installations reported to be using hammers and meeting the capacity threshold of activity 2.3 (b) of Annex I to the IED. These installations are located in Germany, Poland and Spain. However, in the EU-27, there are more smitheries using hammers which did not meet the capacity threshold and the requirements of Annex I to the IED. Furthermore, besides hammers, most of the forging installations also use presses for forging. However, presses are not currently included in the scope of the SF BREF. [169, TWG 2021]

Many workpieces can only be produced using a hammer. These include workpieces that require a large forming force or that have to be forged quickly because of the risk of cooling. For example, the warm forging of aluminium parts requires a fast deforming process. Especially flat workpiece shapes can often only be achieved by using hammers. Also, effects on the microstructure of the material and tribological aspects due to the shorter contact time between tool and workpiece are considered when choosing a hammer. Other workpieces can be forged both by hammer and by press. Although a comparison is only possible to a limited extent, reference values are given for the allocation of press size and hammer size. The operating characteristics of the various closed-die forging machines and their influence on the tool and workpiece are shown. [152, DE VDI/ADB 1973], [148, Euroforge 2021], [155, Euroforge 2020]

Hammers are usually used for flattish parts, like con-rods, knives or tools. For these parts, due to the short contact time and high forming speed, they allow the material flow to fill the flat die sufficiently with comparable low force.

In order to achieve the same effect with a press (if possible at all), it would be necessary to use a much bigger press with a much higher pressing power, which would result in much higher investment/costs (per machine and therefore per part) and energy input.

Furthermore, as hammers are mostly fed manually, this allows the last blow to be in the central part of the die which avoids a bending of the flat workpiece. With a press, the different pressing steps are arranged in a linear flow which leads to a non-centric pressure at the last step and could lead to a bending of the part. [155, Euroforge 2020]

1.1.1.2 Type of products and applications

The forging industry supplies a number of industrial sectors with simple or complex forgings. Typical products include blocks, bars, blanks, disc or shafts. More complex forgings, e.g. rings, cylinders, punched bosses and stepped shafts, require the use of additional, auxiliary tools such as fullers, swages, punches and drifts.

Source: [148 Euroforge 2021]

Figure 1.2: Forging products

Forging products have always been of great significance in many sectors as they are used in a wide variety of applications. Further product design opportunities have been created by the development of processes and process combinations, basic/raw materials, tool engineering and equipment used. [137, Herbertz et al., 2013]

The production of forgings ranges from a few units to series of millions.

Forgings are used:

- to transfer forces, moments and movements;
- for highly static and dynamic loads;
- in the event of major wear and tear loads;
- for space- and weight-saving designs,
- for high safety, reliability and availability standards,
- for sustainable resource conservation, recycling potential and environmental conservation.

Forging products are mostly employed in the following applications:

- Automotive and trucks: A number of forged components are commonly found at points of shock and stress and include crankshafts, transmission shafts and gears, differential gears, drive shafts and clutch hubs.
- Aerospace: Both ferrous and non-ferrous forgings are used in aerospace applications (e.g. helicopters, aircrafts). In this sector, a very high number of forged parts are employed such as bulkheads, wing roots and spars, hinges, engine mounts, brackets, beams, shafts, bell cranks, landing-gear cylinders and struts, wheels, brake carriers and discs.
- Off-road and agricultural vehicles: these off-road vehicles require a number of engine and transmission parts and forgings are used for example for gears, sprockets, levers, shafts, wheel hubs and axle beams.
- Military equipment: Forgings are used in many types of military equipment (e.g. rifles, tanks and fighting vehicles, submarine drive shafts).
- Valves and fittings: A high number of corrosion- and heat-resistant forgings are used for example for flanges, valve bodies and stems, elbows and saddles.

- Hardware and tools: Forgings are used to produce hand tools such as pliers, hammers, sledges, wrenches and garden tools.
- Energy.
- Wind energy.
- Ship-building.
- Heavy machinery. [156, FIA 2021]

The solid forging industry is an important supplier to the high-tech industries in Europe and internationally. [146, DE 2017], [156, FIA 2021]

The specifications of the features of the parts include material quality, micro-structure and size/shape of the workpiece. Furthermore, forged products are used due to specific material properties and characteristics, e.g.:

- durability;
- strength;
- ductility;
- material efficiency due to near net shape;
- materials in use cannot be processed in any other way;
- grain flow supports part structure.

The resilience potential of solid forged components is very high due to the availability of a large number of formable materials, which can be used to provide a wide range of strength and toughness in conjunction with the various heat treatment processes. This high resilience potential provides a further basis for lightweight material construction. [148, Euroforge 2021]

1.1.2 Key environmental issues

Depending on the production processes, smitheries cause emissions to air. Additionally, the environment can be affected by noise and vibrations. The type and quantity of air pollution, residues and waste water depend on different parameters such as the heating technology, furnace type, batch size and product features due to energy-intensive forging processes.

Furthermore, processes might have an effect on water and land (residues). In some cases, waste water may occur as well as residues.

1.1.2.1 Emissions to air, water, soil, noise emissions and vibrations

Emissions to air as well as noise emissions and vibrations have been defined as key environmental issues (KEIs) for smitheries.

Emissions to air: gaseous emissions arise during heating, reheating, heat treatment and processing of products. Carbon monoxide and nitrogen oxides are of particular importance among the gaseous emissions. Noise emissions and vibrations occur during several smitheries processes, especially during the hammering process.
Dust may arise from the handling or processing of raw materials or product processing and finishing; however, these emissions were not identified as key environmental issues (KEIs) at the Kick-off Meeting (KoM).

Emissions to water: these emissions occur in rare cases in the forging process, but mainly during the cooling processes where closed circuits are applied and during cleaning processes. Apart from this, rainwater and sanitary waste water may contribute to the emissions to water from the plant. However, emissions to water were not identified as a KEI at the KoM.

Residues/process losses/waste: process losses originating from smitheries manufacturing mainly arise from raw material preparation, such as metals for example from cutting and sawing, and other losses arise from closed-die forging, i.e. deburring, and forging scale may arise. Furthermore, residues/process losses may consist of packaging waste (plastic, wood, metal, paper, etc.)

According to the KoM conclusions, residues/process losses/waste were not identified as a KEI.

1.1.2.2 Energy efficiency

For the smitheries sector, energy is a crucial production factor. [146, DE 2017]

Both the hot and warm forging processes are energy-intensive processes.

Process heat from preheating can partly be reused and be applied for heat treatment if this process is not outsourced. Also, the distance between different process steps/installations and the non-continuous pattern of production processes can limit the possibilities of reusing process heat.

Excess heat from the preheating process is reused in the process by preheating the air before the burner process. [137, Herbertz et al., 2013]

1.1.2.3 Material/resource efficiency – residues, reuse, recycling

[137, Herbertz et al., 2013]

Raw materials are particularly important in the smitheries sector. The recycling potential of solid forged products is very high. All solid forged products (steel, aluminium, other non-ferrous materials) and the excess production material can be recycled almost up to 100 % and can be reused endlessly, e.g.:

- metallic waste and by-products;
- swarf from raw material preparation, such as sawing and cutting (causes a loss of material);
- the pieces of both beginning and end of the bars from raw material preparation and cutting/shearing, slitting/cleaving;
- flash from closed-die forging;
- forging scale.

1.2 Applied processes and techniques in smitheries

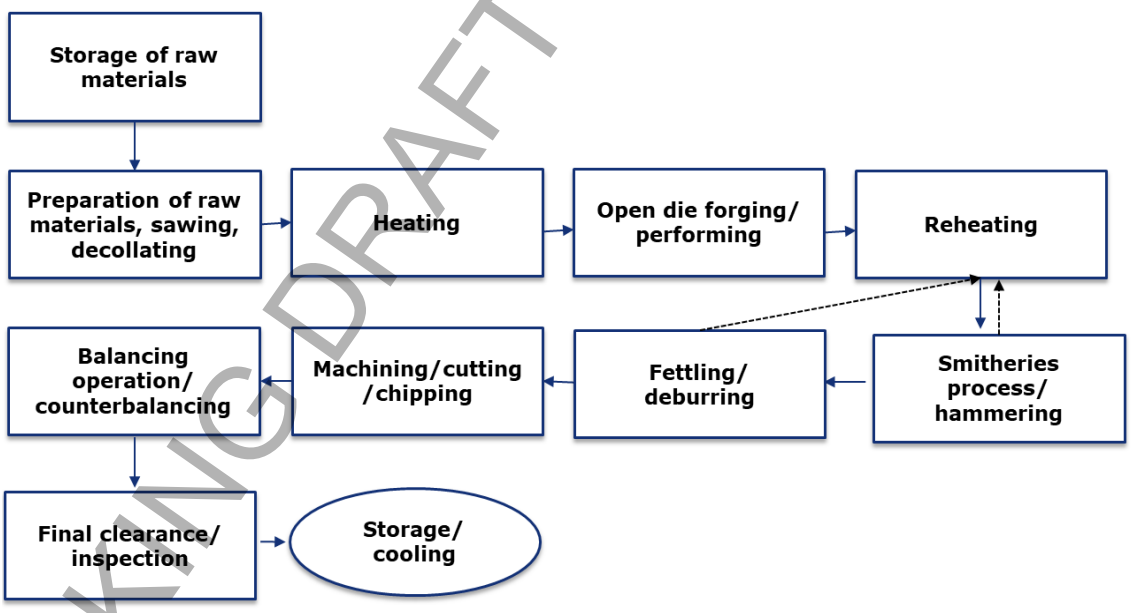
1.2.1 Overview

Forging in general, is a metal-shaping process in which a malleable metal part, known as a blank, billet or workpiece, is worked to a certain shape by one or more processes such as hammering, upsetting, pressing, rolling etc.. [147, Total Materia 2010]
However, for the purposes of this document, forging is defined as a deformation and metal-shaping process using heating (at temperatures below the recrystallisation temperatures of metals) and hammers (e.g. pneumatic, steam-driven, mechanical, electrical, hydraulic).

The following process steps are applied in smitheries:

- raw material storage and handling;
- raw material preparation;
- heating, reheating;
- forging (i.e. hammering);
- cooling, heat treatment (e.g. reheating, carburisation, hardening, cooling, quenching, tempering);
- machining;
- finishing.

A simplified flow diagram of the smitheries process is given in the following figure.



Source: [148, Euroforge 2021]

Figure 1.3: Simplified flow diagram of a smitheries process

The manufacture of a solid forging part from a semi-finished product to a finished forging product is, in principle, similar in various transformation processes and requires the processes of pre-preparation, heating, transformation and finishing. The individual processes consist of several process steps. The individual process steps can be linked in terms of both time and space to each other within a production unit. Some process steps can also take place by being separated in time and space; however, heating and forging cannot be separated in time. [137, Herbertz et al., 2013]

The process steps are logically separated if the production performance of each process step is very different. For example, the semi-finished product is usually separated from the rest of the process chain. It is also possible to merge individual process steps, e.g. the heat treatment processes called 'hardened and tempered/quenched and tempered/heat-treated from forged heat' and 'controlled cooling from hot forging' are directly linked to the transformation process.

The process chain starts with preparation (Figure 1.4). In this case, the basic input material is separated into individual sections, which are weighed due to very high weight accuracy requirements. [137, Herbertz et al., 2013]

Source: [137, Herbertz et al., 2013]

Figure 1.4: Basic process chain of forging processes

In addition to the production-specific equipment, handling, transport (belt-type conveyers, vehicles, forklift trucks, etc.) and sorting/separation systems (vibration spiral conveyors) are applied. [139, Probst 2006]

1.2.2 Smitheries – Drop forging process

Forging is a deformation process using heating temperatures below the recrystallisation temperatures of metals and by using pneumatic, steam-driven, mechanical, electrical and hydraulic hammers. However, material- and application-specific heat treatment is necessary. The temperature of the material has to be low enough not to reach melting temperature, because the metal will start to burn and will then not be usable for applications.

Cross-sectional changes can be achieved by crowding out and accumulation of substances, where the techniques of crowding out substances predominate in application. In addition to the cross-sectional changes, methods to change direction, such as bending, are also used.

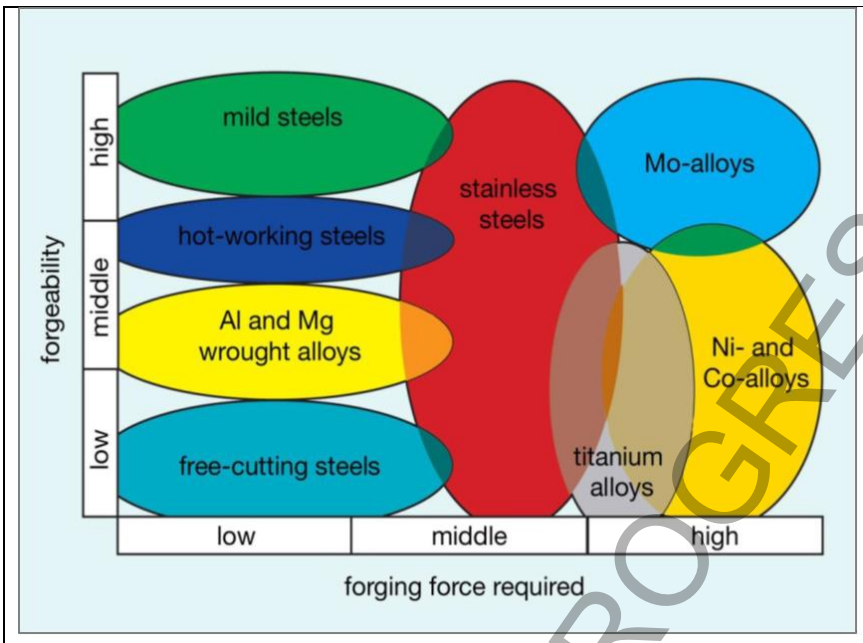
The transformation processes are classified according to the main load. Forging processes are related to pressure forging processes using drop forging. [137, Herbertz et al., 2013]

Hammer mills can be used for the production of specially shaped parts in order to form the rods, rings, shafts or stubs. The weight of hammered products can range from 100 g up to several tons. [148, Euroforge 2021]

Hammering is used in both open-die and closed-die forging methods.
[137, Herbertz et al., 2013]

1.2.3 Raw materials suitable for solid forging

The forging sector can use just about any metal that can be forged. Some of the most common metals include: carbon, alloy and stainless steels, very hard tool steels, aluminium, titanium, brass and copper, and high-temperature alloys which contain cobalt, nickel or molybdenum. Each metal has distinct strength or weight characteristics that best apply to specific parts as determined by the customer. [156, FIA 2021]



Source: [153 Witt DE 2011], [137, Herbertz et al., 2013]

Figure 1.5: Suitable types of raw materials

Furthermore, all metals and metal alloys are suitable for solid forging, with a few exceptions, but they are of varying quality. In addition to the material group, the forging temperature has a very significant influence on the forging (shape-changing) behaviour.

A large group of materials used are structural steels. These steels have a very high capacity for forging with low energy/power and operational requirements while nickel and cobalt alloys act in exactly the opposite way.

In terms of areas of use and production volume, the main material group for solid forging is the group of steel materials. In combination with the various heat treatment processes (Chapter 6.7 DE textbook), a very wide range of tensile strength and toughness properties can be set.

For the cold forging process, only steel grades with a carbon content limited to approximately 0.5 wt-% and alloying constituents limited to approximately 5 wt-% are suitable. Even within these limits, the transforming capacity is significantly lower than in the case of the hot forging process.

For the warm forging process, all steel alloys are suitable, except the precipitation-hardening ferritic-pearlitic (AFP) steels and stainless steels. However, the transforming capacity is lower than in the case of the hot forging process.

It has to be noted that hot forging cannot generally be replaced by warm forging as the range of shapes is limited and the microstructure features of the products are also limited when the higher temperature range is not reached. Therefore, a limited capacity is available. [148, Euroforge 2021]

The large group of structural steels has a very high forging capacity for warm forging, with little effort and labour required for the forging process. [137, Herbertz et al., 2013]

A large variety of materials can be used for forging.

As an example, the following materials are used in smitheries installations in Germany. The product range is generally known for its variety. It is based upon supplies from steel manufacturers with ISO certification:

1. high-grade structural steels;
2. case-hardening steels;
3. steels for quench and tempering (QT steels);
4. nitriding steels;
5. creep-resistant steels;
6. low-temperature steels;
7. roller-bearing steels;
8. steels for surface hardening;
9. ferritic, stainless steels;
10. stainless, acid- and heat-resistant steels;
11. tool steels;
12. modified special steels on demand;
13. nickel and cobalt super alloys;
14. aluminium;
15. high-alloy steel;
16. low-alloyed steel;
17. unalloyed steel;
18. heat-resistant steels;
19. high-grade carbon and alloy steel components.

[149, HWE DE 2020], [150, Stooss AG DE 2020]

Lubricants

Lubricants are used in hot and warm forging. In 2020, lubricants often include water-based dispersions of graphite. Graphite can support the metal-forming process and can resist high pressures applied perpendicularly to the planes, avoiding metal-to-metal contact between the workpiece and dies, thus minimising die wear. However, there are also disadvantages. An issue with water-based graphite lubricants is the effect of galvanic corrosion, which is supported by the conductivity of graphite. However, there is a clear trend to replace graphite-based die lubricants with synthetic lubricants. This is driven by the need for cleaner work environments, easier handling and to avoid graphite-induced galvanic corrosion of equipment. [165, Odink, G. J. 2021]

Lubricants have to be selected in a proper way in order to ensure a successful forging process and to increase productivity. For hot forging, four main types of die lubricants are used: oil-based graphite, water-based graphite emulsions, water-based graphite and water-based synthetics, or non-graphite. The majority of the lubricants used are water-based graphite forging lubricants (approximately 60 %) while approximately 25 % are oil-based graphite lubricants and approximately 15 % of the lubricants are synthetic or non-graphite lubricants. [166, Goodchild, S. 2015]

The use of graphite-free lubricants may reduce costs since they help to improve the die life which also leads to improved productivity. [167, Shenoy, S. P. 2013]

1.2.4 Raw material preparation – process steps before forging – cutting and slicing

[137, Herbertz et al., 2013]

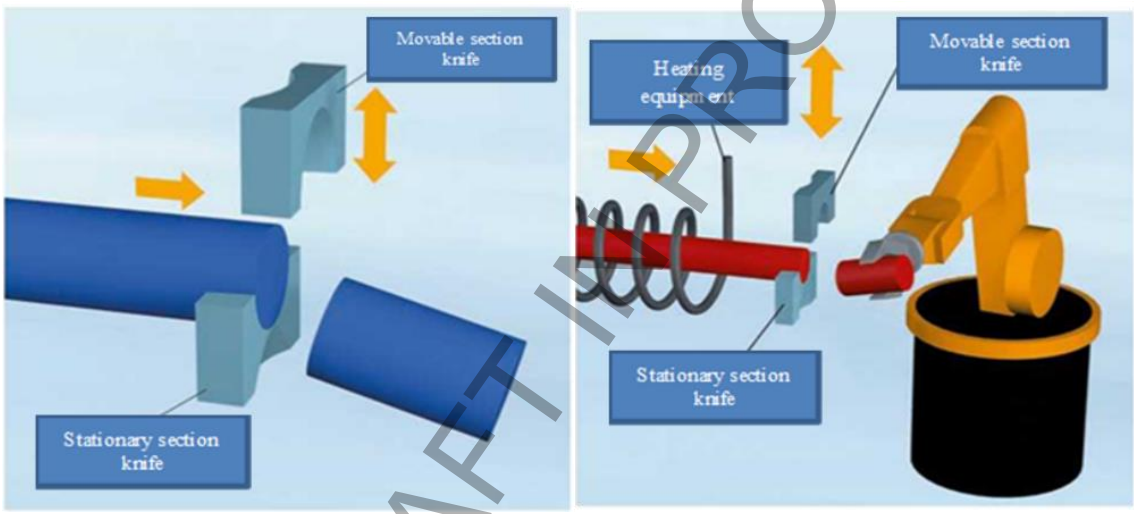
The semi-finished raw material/product is delivered by the steelworks.

The raw material is prepared, i.e. the basic input material is cut and sliced, e.g. by cold-shearing, into individual sections, which are weighed due to very high weight accuracy requirements.

It is very important to produce feed-products that are precise in length or in weight. If the cutting surface is located inside the component during the subsequent forging step, a perfect cutting surface quality is of great importance. Otherwise, it may lead to a defective product. Depending on the hardness of the raw material, the cross-section and the separation speed, different separation methods are used, such as cutting using scissors/shearing, blasting, sawing and splitting tools.

Cutting

In the case of cutting a semi-finished product, a movable section knife is passed over to a stationary section knife around the section width. The material is cut and separated. Cutting consists of an initial cutting process before the final separation is performed by breaking the residual cross-section. The procedure may be used as cold cutting or hot cutting (see Figure 1.6). Hot cutting takes place in the range of the cure temperature of the material, immediately before the forging process.



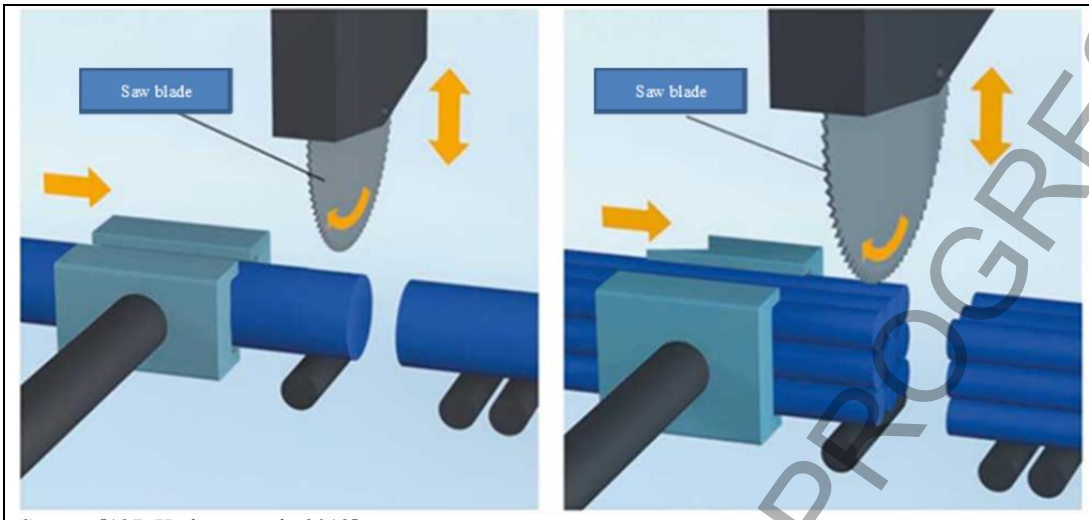
Source: [137, Herbertz et al., 2013]

Figure 1.6: Cold cutting and hot cutting

Advantages	Carried out without a loss of material, except the pieces of both beginning and end of the bars. Low clock cycles/cycle times ensure a high productivity.
Disadvantages	Used to separate semi-finished steel products for diameters or edge lengths up to approximately 120 mm. It is independent of the hardness of the material. It is applicable for integration in fast-moving automated forging processes or in the case of using materials with large cross-sections.
Applications	Used to separate semi-finished steel products for diameters or edge lengths up to approximately 120 mm. It is independent of the hardness of the material. It is applicable for integration in fast-moving automated forging processes or in case of using materials with large cross-sections.
Source: [137, Herbertz et al., 2013]	

Sawing

Sawing is a chip-removing cutting process. Each separation cut is associated with loss of material. Sawing can also be used for materials with smaller cross-sections in order to separate whole bundles of bars (see Figure 1.7).



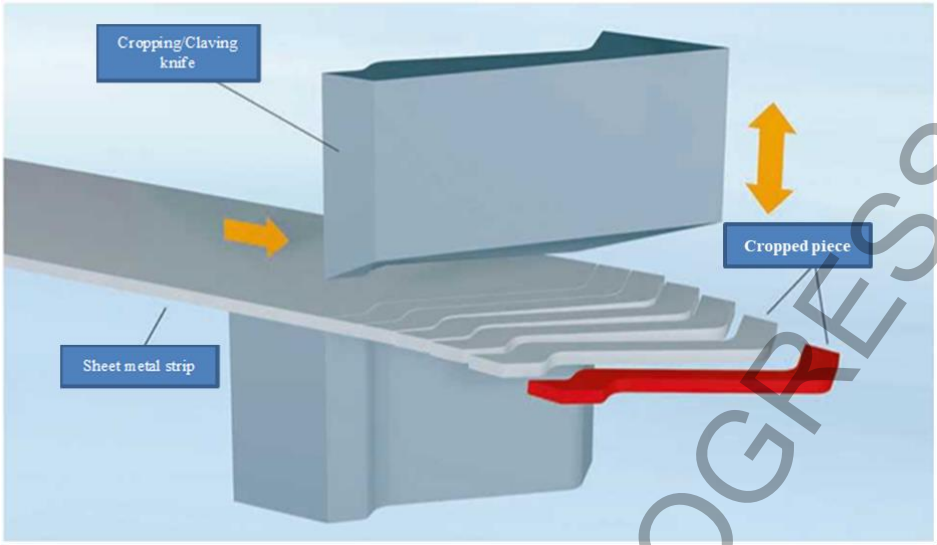
Source: [137, Herbertz et al., 2013]

Figure 1.7: Sawing a bar and a bundle of bars

Advantages	Allows the achievement of precise and repeatable section lengths with a high-quality cut surface. Applicable for processing semi-finished products with very large cross-sections. Furthermore, it is applicable to all material qualities and material grades/varieties. Usually, there is no need for changing a cutting tool when sawing semi-finished products with different cross-sections.
Disadvantages	Chip-removing cutting process/cutting method which requires more time than scissoring and therefore leads to a lower productivity/efficiency. Causes a loss of material which increases in percentage with decreasing product length.
Applications	Manufacture of products from soft materials, such as aluminium or in the case of high requirements on length accuracy of the product, such as flashless forging, and/or high requirements on the surface quality of the cut surfaces. Separating semi-finished products for diameters or edge lengths greater than 120 mm. Manufacture of precursors with a small length/diameter ratio.
Source: [137, Herbertz et al., 2013]	

Cleaving

Usually, cleaving corresponds to shear cutting and it is a combination of a splitting process along with mass pre-distribution. The working component is split without losses from a sheet metal strip, with the exception of the beginning and the end of the pieces (see Figure 1.8).



Source: [137, Herbertz et al., 2013]

Figure 1.8: Slitting

Advantages	No generation of material losses, except of beginning and end of the workpieces. Allows a simultaneous mass distribution of the pre-product.
Disadvantages	The fibre pattern of the slit/cleaved piece cannot be adapted optimally to the shape of the forging piece.
Applications	Manufacture of pre-product for long and flat pieces such as screw keys, pliers, knife blades, scissors.
Source: [137, Herbertz et al., 2013]	

1.2.5 Metal forging processes

[137, Herbertz et al., 2013]

Metal forging (plastic deformation, shaping) is carried out by plastically changing the shape of a solid body, plastic moulding. In this chapter, only solid forging processes are covered.

Transforming is the finishing process that changes the shape of a solid body in a visual (plastic) way; both mass and cohesion will be maintained. Unlike deformation, forging changes the shape by controlling the geometry.

There are no general recommendations available for each of the three forging processes, i.e. the hot, warm or cold forging process. Each of these processes has their own specific advantages and disadvantages. A technically and economically rational selection of a given method can only be made on a component-specific basis, taking into account the geometry of the component, the desired shape and dimensional accuracy, the material used and the mechanical properties of the component as well as the production quantity.

These three different types of transforming processes are used for the following forming procedures:

- forgings (hot forging);
- extruding (cold forging),
- combination methods (hot and cold forging);
- free moulds (hot forging) and ring rollers (hot forging).

Fundamental methods for solid forging are the following:

- rolling:
  - rectangle rollers, transverse wedges, ring rollers;
- open-die forging:
  - rectangles, round kneads, crushing/heading method;
- closed-die forging:
  - closed-die forging with burr,
  - closed-die forging without burr;
- extruding presses;
- specific methods for specific products.

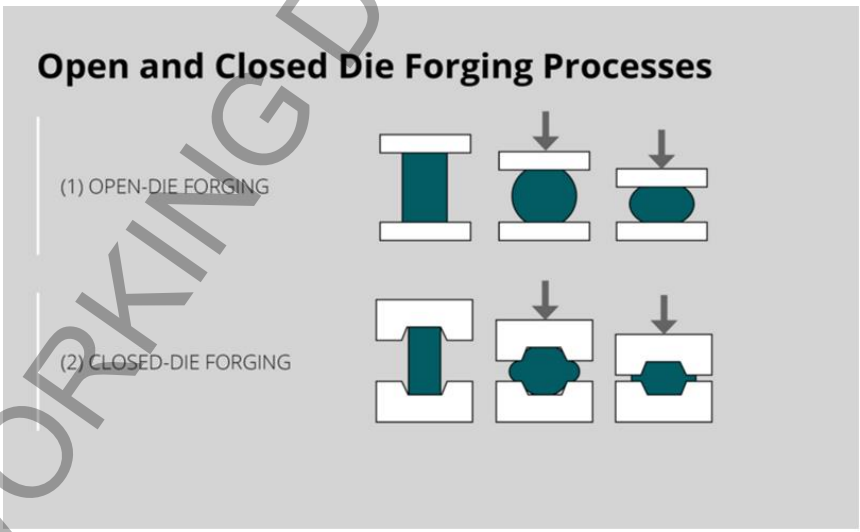
The processes of ring rolling and rolling are described and covered by the FMP BREF. Further information can be found under the section on hot rolling in the FMP BREF. [168, COM 2021]

1.2.5.1 Open-die forging and closed-die forging

The open-die forging process is also known as free forging. The piece of metal is deformed between multiple dies that do not enclose the metal entirely. The dies hammer or stamp the metal through a series of movements to alter its dimensions until the desired shape is achieved.

The closed-die forging process is also referred to as impression forging. During the metal forming process, a piece of metal is compressed under high pressure to fill an enclosed-die impression. For some special shapes, a second forging operation is required to achieve final shapes and dimensions. For bigger parts, gas heating can also be used in closed-die forging. [157, Grillo 2017]

The techniques of open-die forging and closed-die forging are different, as shown in Figure 1.9. In general, for closed-die forging, first the moulding dies are made. The metal bars are then placed on the dies and forged to any shapes that are desired. The closed-die forging technique utilises very little or no machining throughout the process. Also, net shape end products can be achieved.



Source: [157, Grillo 2017]

Figure 1.9: Open-die and closed-die forging

For open-die forging, very high compressive forces are imposed by the continuous strike of a forging hammer or repeated press operations to deform the metal billets or ingots.

The forged components obtained by open-die forging and closed-die forging, if compared, are not identical in their application scope.

A rough precision machining is further required after the open-die forging process and open-die hammering as imprecise dimensions are achieved by hammering. The open-die metal forge parts are more suitable for large parts in a number of tonnes, but the weight of the components can start at 10-15 kg. At the same time, closed-die forging can go up to a components weight of 1-1.5 t. Generally, the products in this category of forging include forged long shafts, forged rollers, forged cylinders, forged bars, discs, punched discs, hubs, blocks, plates (forged three-dimensionally), forged tubes, cylinders and other hollow forgings, forge rings, seamless rolled rings and flame-cut forgings. They are utilised in several sectors, e.g. rail, aircraft, ship building, windpower, power generation and heavy machinery. [151, Dirostahl DE 2020], [137, DE 2013]

The batch size of the production is important for choosing the forging method. For a production of one to five workpieces it is not worth producing a die. [148, Euroforge 2021]

However, for small parts, closed-die forging is preferred as higher precision is obtained in the process. It is often used to produce forged fittings, forged flanges, forged automotive parts, etc. Oilfield, automotive, and mining are some of the industries that rely on closed-die forge parts. [157, Grillo 2017] However, mining and oilfield are also typical sectors for open-die forging. [148, Euroforge 2021]

1.2.5.2 Hot, warm and cold forging processes

[137, Herbertz et al., 2013], [148, Euroforge 2021]

The forging process is classified in three process methods according to the temperature of the workpieces immediately prior to the first transformation process:

- hot forging process;
- warm forging process;
- cold forging process.

Hot forging process

In the case of hot forging of steel materials, the transformation process takes place at temperatures of approximately 950 °C to 1 300 °C, i.e. at a temperature where recovery processes and recrystallisation processes take place during and after transformation. The main characteristics of the hot forging process are:

- high energy demand for heating (useable for heat treatment where appropriate);
- low power and energy demand for transformation;
- suitable for nearly all types of metallic materials;
- very large transformation capacity of the materials;
- pronounced scaling in many steels;
- the surfaces have a high roughness;
- possible changes in shape and dimensions due to thermal shrinkage and bending.

Warm forging process

Warm forging of steel materials combines the advantages of the cold forging process and the hot forging process by choosing a material-specific transformation temperature. However, the formation of the scaling has not yet started or has not started significantly. Technically and

economically, it makes sense to have a temperature range of approximately 600 °C to 950 °C. The main characteristics of the warm forging process are:

- average energy demand for heating;
- average power and energy demand during transformation;
- higher alloyed materials can be used than those used in the cold forging process but lower than in warm forging;
- higher material forming capacity than that of the cold forging process but lower than in hot forging;
- higher geometrical flexibility than in the cold forging process but lower than in hot forging;
- low scaling;
- better surface quality than in the hot forging process but lower than in cold forging;
- higher shape and dimension accuracy than in the hot forging process but lower than in cold forging.

It should be noted that some geometries cannot be achieved using the warm forging process. [148, Euroforge 2021]

Cold forging process

In the case of cold forging of steel materials, the transformation process takes place at room temperature or at temperatures up to 300 °C. The main characteristics of cold forging are:

- no or low energy demand for heating;
- large power and energy requirements for transformation;
- low transformation capacity of materials;
- limited geometrical flexibility;
- where appropriate, cold solidification may be used; however, often heat treatment is also necessary;
- no scaling;
- the surfaces have a low roughness;
- high shape and dimensional accuracy, up to and including functional surfaces ready for installation;
- specific pretreatment of the raw material in terms of structural properties and surface area is required.

Prefabrication steps for cold forging

The cold forging of steel requires special pretreatment of the components in order to optimise the structure and surface for the subsequent transformation. The pretreatment consists, for example, of annealing (soft annealing), abrasive blasting and lubrication/coating. The coating of the components is necessary to prevent oxidation and, during subsequent transformation, cold welding between the tool and the workpiece. The pressure-resistant solid lubricants are graphite, molybdenum disulphide, special soaps or waxes. Developments in materials and process technology aim to achieve the desired structure without annealing and to carry out the necessary coating of the raw materials exclusively with more environmentally friendly products.

1.2.5.3 Thermal processes

[137, Herbertz et al., 2013]

As stated previously, the smitheries process is classified in three process methods according to the temperature of the workpieces immediately prior to the first transformation process, i.e. the hot forging process, warm forging process and cold forging process.

In general, the higher the temperature, the higher the transforming capacity of metallic materials. With higher material temperatures, the power and energy required for the transformation decreases. This characteristic/property of the material is used when applying the warm forging process and the hot forging process.

When steel is heated in hot-forging, the temperature is about 950 °C to 1 300 °C, while in the case of the warm-forging process the temperature range is from 600 °C to 950 °C.

1.2.5.3.1 Heating

[137, Herbertz et al., 2013]

The purpose of the heating process is to get a homogeneously heated pre-product/prepared raw material across the pre-product's cross-section and the longitudinal axis in the area of deformation.

A stable production process requires reproducible and energy-efficient heating from one part to another. In order to minimise surface oxidation (scaling) and lateral decarbonisation, heating should take place within the shortest possible time period.

Due to constantly rising energy costs and increased sensitivity to environmental impacts, the aim should be to minimise energy demand and pollutant emissions from heating.

Before shaping, the prepared raw materials can be heated by using indirect or direct heating processes.

Indirect heating
Heating is carried out by convection, heat radiation and heat transmission either in chamber furnaces or in continuous furnaces. The thermal energy is generated by the combustion of natural gas or liquid fuels. Electric heating of the furnaces is also possible.

Advantages	Capable of heating large volume pre-product and transforming intermediates. Low energy costs associated with the use of primary energy. Always applicable irrespectively of the geometry of the prepared raw material.
Disadvantages	Increased scaling and surface decarburisation of the prepared raw material as a result of relatively long warm periods (chemical reaction between the workpiece and the furnace atmosphere).
Applications	Heating of large pre-prepared raw materials; Heating of bulk materials.
Source: [137, Herbertz et al., 2013]	

Direct heating
Direct heating is based on electrical energy and can be carried out by using inductive heating or conductive heating. The heat is produced inside the pre-prepared raw material and does not need to be transmitted by thermal conduction.

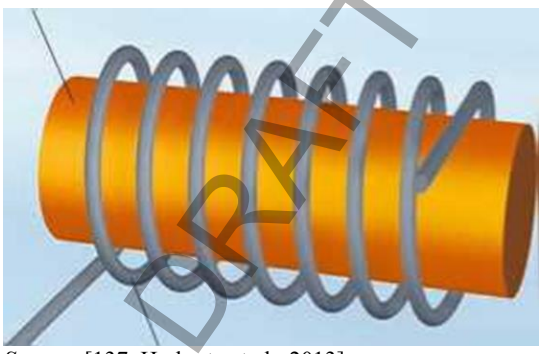
There are two direct heating processes applied:

- inductive heating;
- conductive heating.

Inductive heating

During inductive heating, the prepared raw materials are heated using an induction coil/inductor. A high-frequency alternating current circulates through the induction coil which is generating an electromagnetic alternating field. Within the prepared raw material, this alternating field induces an electrical voltage that leads to the formation of eddy currents. These eddy currents cause heating of the prepared raw material due to the specific electrical resistance of the material.

Advantages	Short heating time of the pre-product. The start-up time of an induction coil after a plant shutdown is relatively short. Good reproducibility of the pre-product temperature. Low space requirement for heater units. 'Tailored' heating possible in some cases. High automation potential of feeding processes.
Disadvantages	In order to ensure optimum heating efficiency and thorough heating of the pre-prepared raw material, the induction coil has to be adapted to the cross-section of the pre-prepared raw materials. When changing the pre-product with a significant cross-sectional change, a change of the induction coil is generally required. The investment costs for various induction coils of different sizes and the time needed to change the coil are a disadvantage.
Applications	Heating of all common circular and square materials with small to medium cross-sectional dimensions.
Source: [137, Herbertz et al., 2013]	



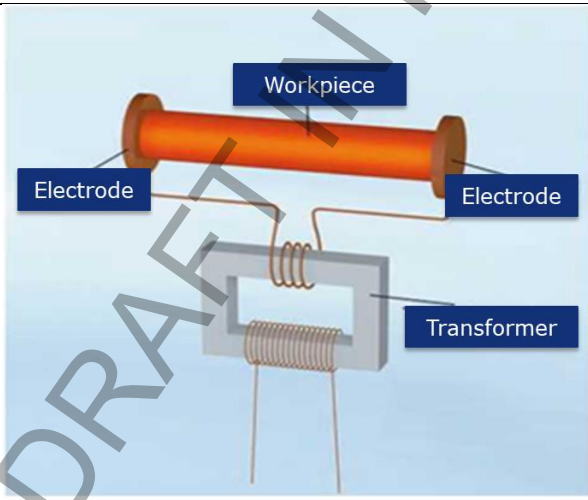
Source: [137, Herbertz et al., 2013]

Figure 1.10: Direct heating by induction

Conductive heating

During conductive heating, the prepared raw material forms part of the electrical circuit. Electricity is directly passed through the product and heats the material because of its electrical resistance. The heat is generated directly in the workpiece by means of a heating current. Conductive heating is therefore also referred to as resistance heating.

Advantages	Very short heating time. Improved energy efficiency compared to inductive warming. No start-up losses.
Disadvantages	Short workpieces should not be heated conductively due to heat losses on the cooled electrodes. The pre-product length-to-diameter-ratio should be higher than 2.5. The transmission of the high current values requires a good surface quality (depth of roughness/surface roughness, rust, scaling, contamination) of the contact surfaces of the pre-prepared raw material, which could require sawing instead of cutting/shearing the material which again needs more energy and process time. Complex/extensive automation, as the pre-prepared raw material must always be fixed individually between the electrodes. The necessary cool parts of the workpiece in the contact area lead to excess material or require specific workpiece shapes/geometries. The heating process leads to extreme peaks in the electrical network. Only applicable up to diameters over approximately 50 mm.
Applications	Heating of long and thin bars. In practice, conductive heating is not often used.
Source: [137, Herbertz et al., 2013]	



Source: [137, Herbertz et al., 2013]

Figure 1.11: Conductive heating by induction

1.2.5.3.2 Furnaces, heating processes, preheating and reheating

[137, Herbertz et al., 2013], [158, IspatGuru 2013]

Heating is needed for hot and warm forging processes.

For both preheating and reheating, both indirect and direct heating processes are applied.

Reheating is necessary when the workpiece is becoming too cold for deforming (due to long forging processes or forging in different steps). Also, some effects in the grain structure can only be achieved in certain defined temperature windows.

In addition to gas furnaces, electric induction and conduction heaters are available for heating the material, which ensure a precise process temperature.

The following energy sources are typically used:

a. propane, butane;
b. natural gas;
c. electricity;
d. oil.

Several furnace types are used to heat the material as well as for preheating, reheating and heat treatment as reported via questionnaires.

Reheating furnaces can be classified by:

- the method of heating;
- the method of charging the furnace;
- the movement of the material in the furnace;
- the heat recovery methods.

[158, IspatGuru 2013]

Furthermore, reheating furnaces can be combustion heating type furnaces using gaseous fuels or electrical heating type furnaces. As batch type or continuous type, the furnaces are classified depending on the charging method [158, IspatGuru 2013]:

- batch type furnace:
  - batch annealing furnace;
- continuous furnace:
  - pusher furnace;
  - walking beam furnace;
  - rotary hearth furnace;
  - walking hearth furnace;
  - roller hearth furnace.
- chamber furnace;
- bogie hearth furnace/shuttle kiln.

<u>Batch type furnace</u>
For preheating and reheating forged products, batch type furnaces are mostly used because the continuous flow of the continuous furnaces does not support the process flow.

This type of furnace can be used with or without direct firing by using natural gas or electricity.

The material is often fed through a single door or a slot into the furnace. [159, McGraw-Hill Dictionary et al. 2003]

However, the use of electrical furnaces is limited by the low flexibility and performance of this type of furnace. [148, Euroforge 2021]

<u>Continuous furnace</u>
The furnaces are usually fed continuously. The stock is pushed through the furnace by the following stock (pusher furnace) or is moved through by walking beams (walking beam furnace), a rotary hearth furnace or on/between rollers. [169, TWG 2021]

For preheating and reheating forged products, continuous furnaces are used less as the continuous flow does not support the process flow. They are more commonly used in the heat treatment. [148, Euroforge 2021]

More information and descriptions of different furnace types can be found in the foundries chapter of this document, Section 2.2.4.

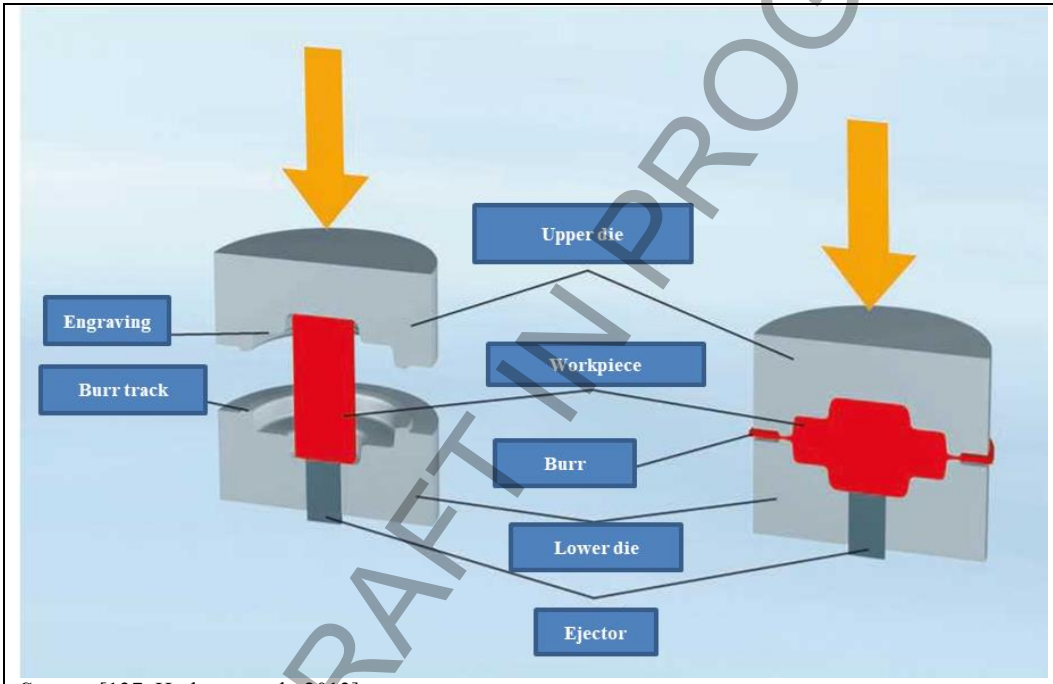
More information, descriptions and details of furnaces can also be found in the FMP BREF.

1.2.5.4 Smithering process using solid forging machinery – hammer mills

[137, Herbertz et al., 2013]

Close-die forging with burr

The process which predominates in industrial practice is close-die forging with burr. In this process, the tool forces the flow of material in both the direction of movement of the tools and in a transversal direction. The workpiece is surrounded almost entirely by the tool, with excess material flowing through the burr gap.



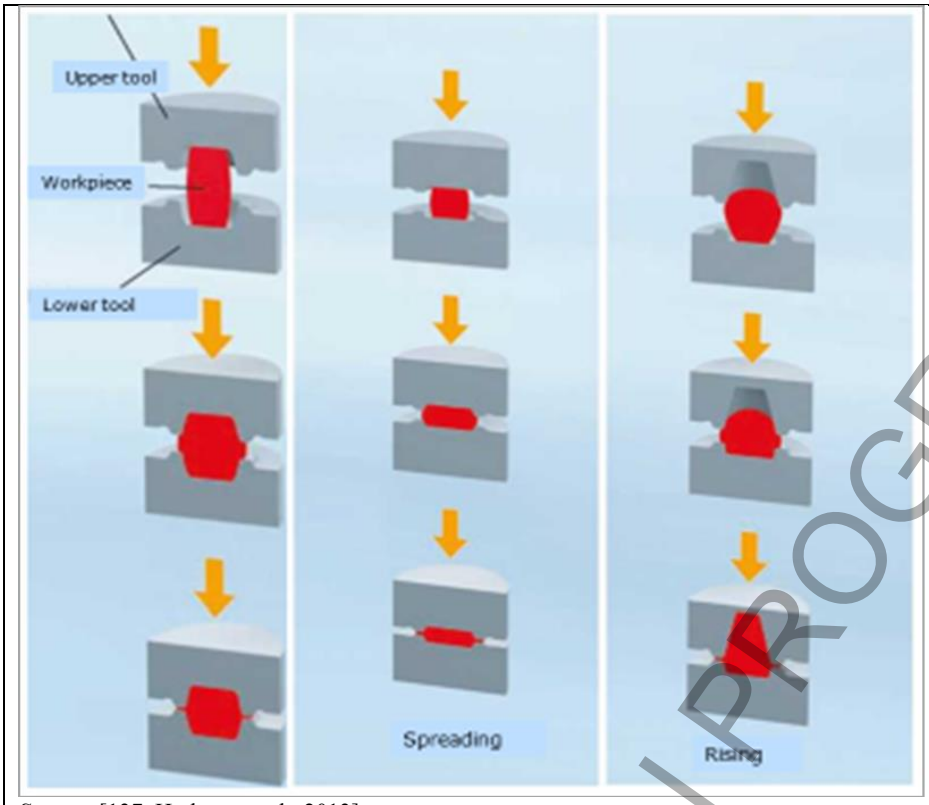
Source: [137, Herbertz et al., 2013]

Figure 1.12: Close-die forging with burr

When filling the moulds, three basic types of filling operations can be distinguished:

1. Heading: Reducing the initial height, in which the significant flow of material is parallel to the movement of the tool.
2. Spread forging: Lateral displacement of the material from the inside to the outside, in which the essential flow of material is perpendicular to the movement of the tool.
3. Increasing: Completion of deep engraving cavities/voids, in which the essential flow of material parallel to tool movement.

The basic types of operations are shown in Figure 1.13. Filling operations during the forging process generally start with the heading of the material. The next phase of the transformation process is the spread forging. The material is in contact with the shaping/moulding engraving walls. During the final transformation phase, the deep engraving cavities and the upper die mould are filled.

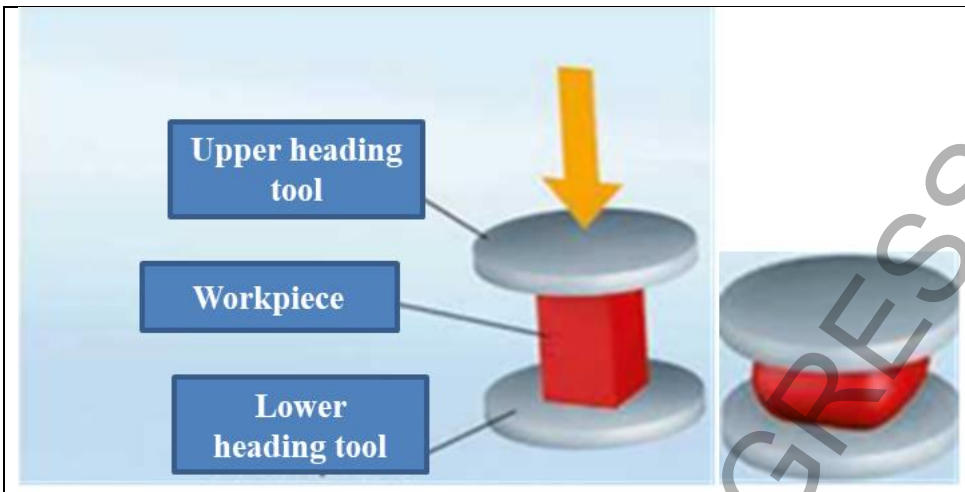


Source: [137, Herbertz et al., 2013]

Figure 1.13: Basic types of operations (heading, spread forging, increasing)

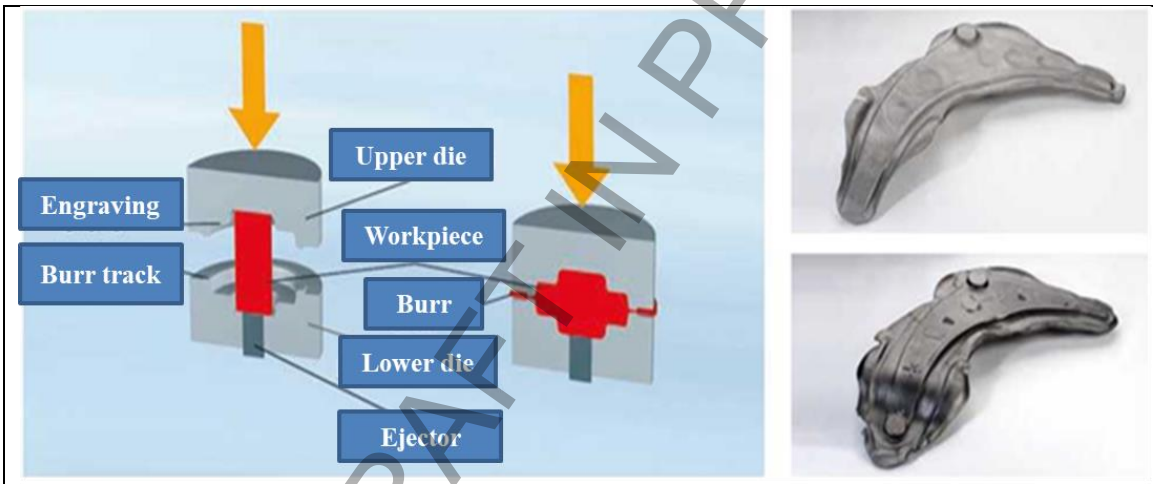
Advantages	Highly productive processes, also applicable for complex geometry. High reproducibility of the manufactured parts.
Disadvantages	Complex tools (dies) are required. Excess material required.
Applications	Hot forging, warm forging and cold forging of steel and non-ferrous alloys. Open-die forging is the most important process in forging/forming and it is used for the production of geometrically complex and highly demanded components, such as: • chassis components supplied to the vehicle and aeronautics industry, • engine and transmission parts such as crankshafts and connecting rods, • turbine blades and compressor blades.
Source: [137, Herbertz et al., 2013]	

As an example, in the case of open-die forging with burr, after forge rolling the pre-prepared product, the heading process (upsetting) is carried out, Furthermore, the pre-product is adjusted by bending the curvature of the end geometry. This is carried out in the same metal forging machine or press equipment.



Source: [137, Herbertz et al., 2013]

Figure 1.14: The heading process (upsetting)



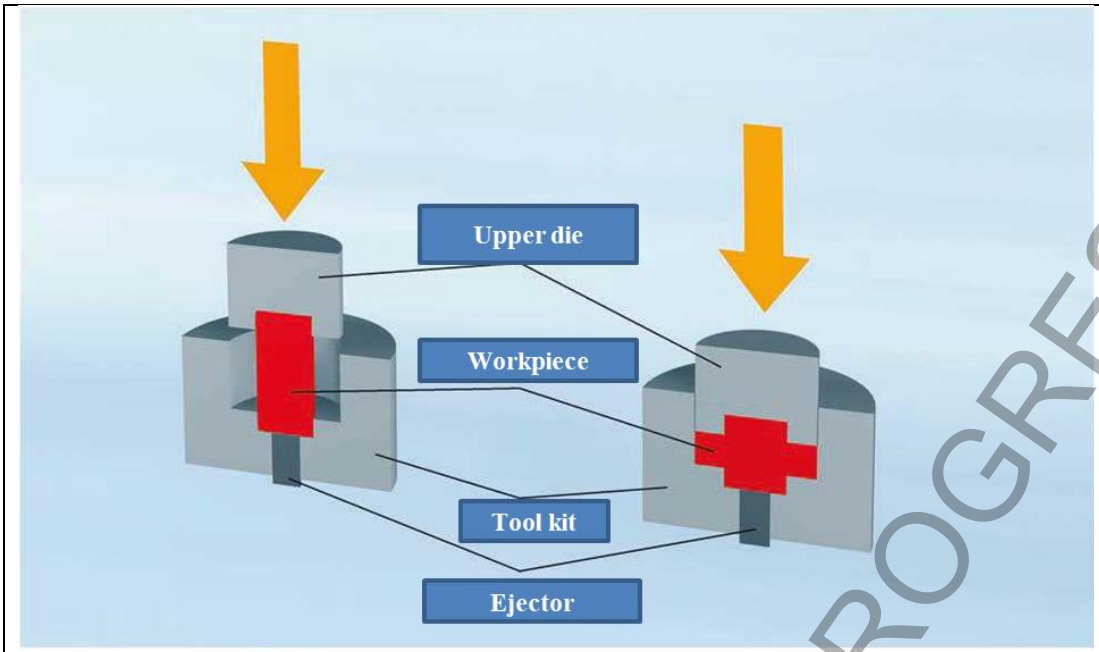
Source: [137, Herbertz et al., 2013]

Figure 1.15: The pre-process and a final forging process

The following process step is separated in a pre-process and a final forging process. During the pre-forging process, an appropriate intermediate form is generated which is used for the subsequent final forging process. [137, Herbertz et al., 2013]

Flashless closed-die forging

In the case of flashless closed-die forging, the work piece is completely enclosed when it is transformed by the tool from which no material escapes. The process of transformation in principle corresponds to the closed-die forging process with burr.



Source: [137, Herbertz et al., 2013]

Figure 1.16: Closed-die forging without burr

Advantages	Highly productive processes. High reproducibility of the manufactured pieces. Compared with open-die forging with burr, material is saved and the deburring process is not necessary.
Disadvantages	Compared with closed-die forging with burr, the tools (dies) are more complex. If no compensatory spaces are provided or the engraving is not fully filled, variations in the volume of the raw materials may lead to overloading of the tools/toolkits. This results in a particularly high requirement for the volume accuracy of the precursors. In the case of long stretched workpieces with complex mass distribution (e.g. suspensions, crankshafts), open-die forging without burr cannot be used.
Applications	Hot forging, warm forging and cold forging of steel and non-ferrous alloys. Open-die forging without burr is mainly used for mass production of components with a rotation symmetrical basic structure and a simple mass distribution, such as: gear wheel blanks/green body, rolling bearing rings, wheel hubs/wheel boss.
Source: [137, Herbertz et al., 2013]	

1.2.5.5 Solid forging machinery – hammer mills

[137, Herbertz et al., 2013]

In addition to the transforming tools, solid-forging machines are the most important equipment for the manufacture of a forging part.

Generally, forming machines are applied to:

- provide high forging forces and high forging energy;
- to accurately manage forging tools against forging forces, the forging momentum and to direct forging tools as precisely as possible to a defined final position.

These requirements require robust and efficient forging machines, leading to high investment costs.

A further requirement is derived from the high investment costs: forming machines need to have high productivity so that the high investment costs are distributed as much as possible to the components produced.

1.2.5.5.1 Classification and types of forging machines

[137, Herbertz et al., 2013]

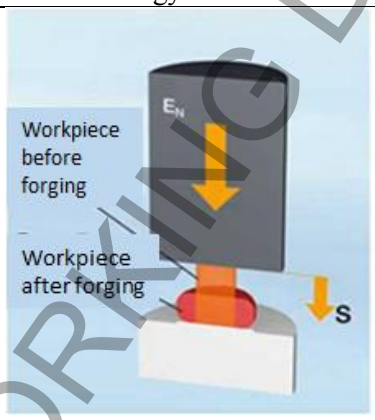
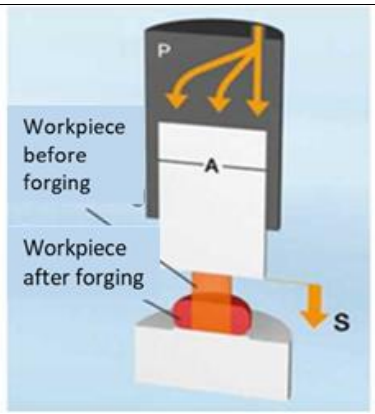
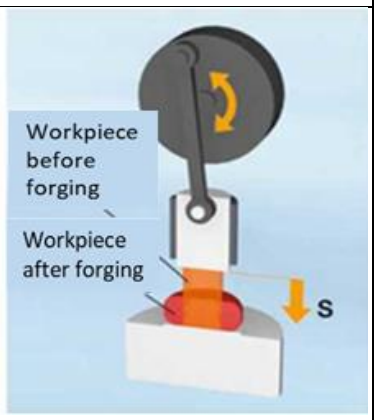
To transform a metallic body, energy is required, known as deformation energy/shaping work. The amount and quantity of the shaping work is determined by the product, the forging force required for the forging operation and the covered forging distance. Usually, the forging force is not a constant number but changes due to the forging distance.

Forging machines vary in their working characteristics. One of the three physical parameters (forging work, forging force, forging distance) is determined by the machine system, while the other two parameters can be freely adjusted within the limits of the design, depending on the type of forming process, i.e.:

- in the case of energy-related machinery, the energy supply/transfer (work) is predetermined as a characteristic measure;
- in the case of power-related machinery, the power is predetermined as a characteristic measure;
- in the case of distance-related machinery, the forming distance is predetermined as a characteristic measure.

The three basic principles derive from the main types of machinery listed in the following table. [137, Herbertz et al., 2013]

Table 1.3: Classification of forging machines with a linear work movement

Working characteristics of forging machines		
Energy-related	Power-related	Distance-related
		

Source: [137, Herbertz et al., 2013]

Table 1.4: Main types of forging machinery

<table>
<tr><td colspan="4">Main types of smitheries machinery</td></tr>
<tr><td rowspan="2">Energy-related IED</td><td rowspan="2">Power-related
Not IED</td><td colspan="2">Distance-related
Not IED</td></tr>
<tr><td>Rotating work movement/machinery</td><td>Linear work movement/machinery</td></tr>
<tr><td>Double-acting hammer</td><td rowspan="4">Hydraulic press</td><td>Eccentric press</td><td>Stretching/forging roll</td></tr>
<tr><td>Counterblow hammer</td><td>Crank press</td><td>Cross wedge roll</td></tr>
<tr><td rowspan="2">Screw press (not IED)</td><td>Wedge press</td><td rowspan="2">Ring roll</td></tr>
<tr><td>Upsetting machine</td></tr>
<tr><td colspan="4">Source: [137, Herbertz et al., 2013]</td></tr>
</table>

Hammers and high-energy-rate forging machines are classified as energy-restricted machines as they deform the workpiece by the kinetic energy of the forging hammer ram. Different types of forging hammers are available, such as gravity-drop hammers, power-drop hammers, die forger hammers, counterblow hammers, and computer-controlled hammers. There are three basic designs of high-energy-rate forging (HERF) machines available: the ram and inner frame, two-ram, and controlled energy flow. [160, Altan et al. 2005]

1.2.5.5.2 Energy-related machinery

Energy-related machines convert the work capacity of the machine into a transforming process at each work cycle, i.e. the formed component is formed until the work capacity provided by the machine is consumed. Typical representatives of energy-related machines are hammers and screw presses. The different types of hammers which can be used are described below. [137, Herbertz et al., 2013]

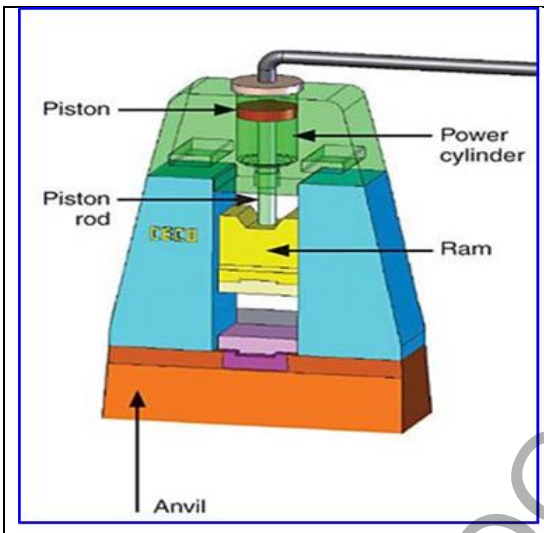
At each working stroke, hammers convert the energy supplied to the ram completely into both forging energy and energy loss. Energy is achieved from the acceleration of the ram (fall height, upper pressure). [139, Probst 2006]

Air- and hydraulically driven hammers

These machines deliver an impact blow and are used for hot forging. Together, the moving parts, lifting system, falling weight (ram) and upper die are returned to the top of the stroke by a mechanical system composed of a piston in a cylinder. This system adds a downwards force to the effect of gravity, at the moment of impact.

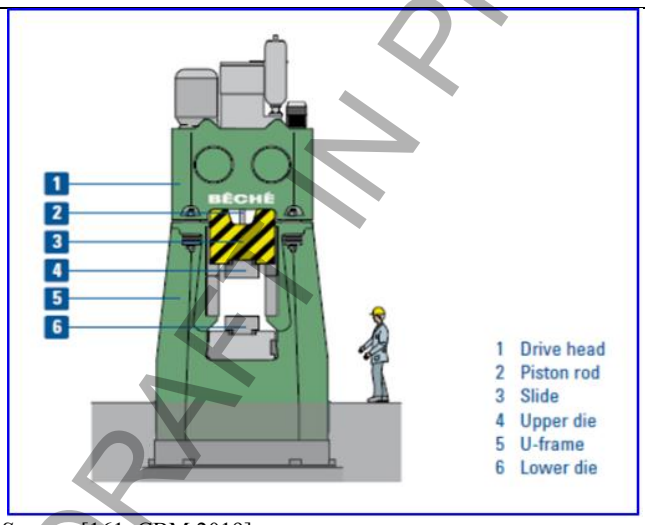
The nature of the process requires rapid mechanical working by deformation of hot metal.

Every air-operated hammer (power driven) should have a means to cushion, or safely arrest, the motion of the piston at the top of the cylinder if the rod should break or pull away from the ram. This device may be of the direct-cushion type integral with the main cylinder or it may be of the separate-cushion type whereby a constant supply of air is applied behind a separate piston adjacent to the main cylinder. A spring, suitably constrained, may also be employed.



Source: [161, CBM 2019]

Figure 1.17: Air-driven hammer



Source: [161, CBM 2019]

Figure 1.18: Hydraulically driven hammer

<u>Double-action hammer/steam-powered accelerated hammer</u>

The energy of hammers consists of hydraulic or pneumatic top pressure energy and drop energy. These energies are converted into kinetic energy and then transferred into forming energy.

The typical characteristics of hammers are:

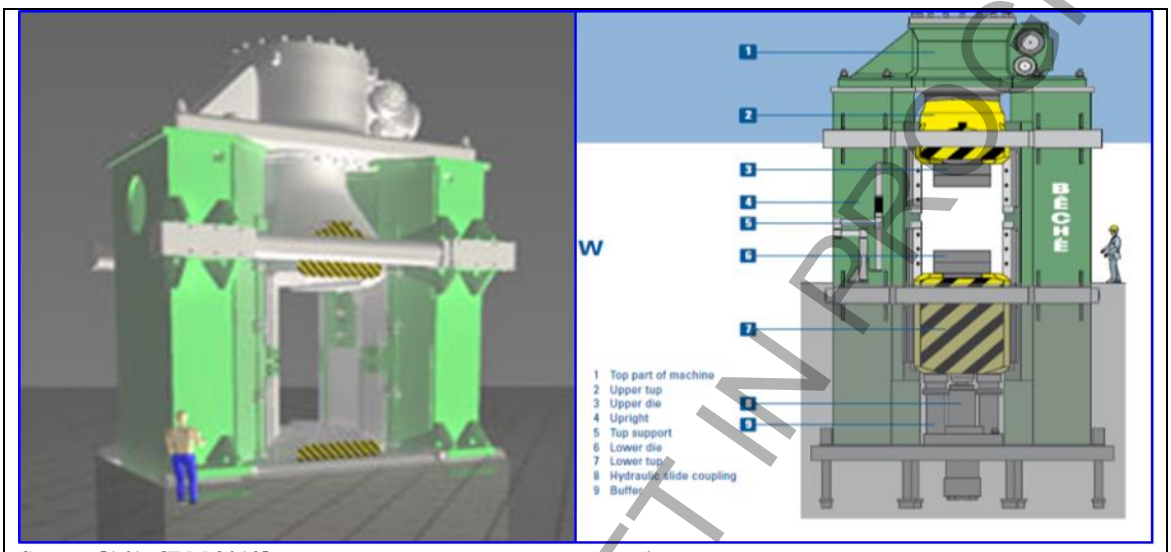
- relatively low investment costs;
- very short stroke sequencing time;
- very short pressure contact time between working tool and workpiece;
- high and well-controlled impact energy which, in the case of short forming distances, is converted into extremely high transformation forces;
- in most cases, several blows/strokes (lifts) are required for completion of the formed component;
- high noise emissions, which need to be reduced by protective measures.

[137, Herbertz et al., 2013]

Counterblow hammer

These machines deliver an impact blow and are used for hot forging. The moving parts are composed of two different subsets of tools that approach each other simultaneously. The links that provide these movements can be mechanical or hydraulic [161, CBM 2019]

The production of very large and heavy forged metal parts requires a correspondingly large amount of forming energy. Double-acting hammers are not suitable for this task. Instead, counterblow hammers do not have scrapheads, but two hammer heads (lower and upper hammer head) that move towards each other. As an advantage, the vibrations of the machinery system are reduced and the hard blows are no longer transferred to the base and from there to the ground. [137, Herbertz et al., 2013]



Source: [161, CBM 2019]

Figure 1.19: Counterblow hammer

As reported in the questionnaire of the SF data collection, the following types of hammers are used in the EU-27:

- freefall hammer;
- counterblow hammer;
- steam hammer;
- double-acting hammer.

1.2.5.6 Treatment processes before, during and after the forging process – machining

Before, during and after the forging process, several additional treatment and machining processes are carried out. These treatment processes are important to achieve a certain pre-product quality for further heat treatment.

1.2.5.6.1 Scale removal

[137, Herbertz et al., 2013]

During the heat transformation, high temperatures of up to 1 300 °C cause surface oxidation of the pre-prepared raw material. It also depends on the duration of the heating process. The resulting scaling layer would result in surface defects in the forged component and increased tool wear. Scaling/scale removal is used in the hot or warm forging process of steel materials.

The purpose is the removal of the loosely adhering layer of the scale from the surface of the heated workpiece. Scale removal can be carried out by shaping/forming, e.g. upsetting or other compression processes, by pressurised water or brushes.

Scale removal (descaling) by upsetting (compression)

As a result of upsetting (compression), the workpiece is slightly transformed, thus paving the brittle/refractory layer of scale/oxide layer as shown in the following figure.

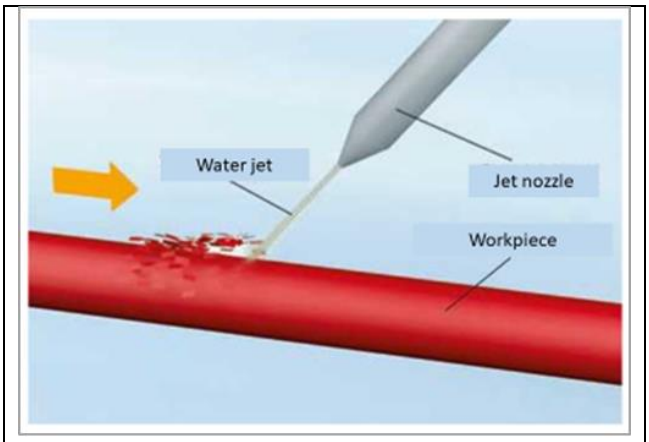
Source: [137, Herbertz et al., 2013]

Figure 1.20: Descaling by upsetting

Advantages	By carrying out a slight forming, scale removal is already possible. At the same time, upsetting can also be used for mass pre-distribution.
Disadvantages	Scale removal is not always fully achieved on the entire workpiece surface.
Applications	Forging processes in which no forging rolls or other pre-forging operations are carried out upstream of the process.
Source: [137, Herbertz et al., 2013]	

Scale removal using pressurised water

When scale removal is carried out with pressurised water, water at a pressure of up to 500 bar is sprayed on the hot workpiece. The evaporating water, the thermal superficial shrinkage and the mechanical energy of the water jet remove the loosely attached oxide layer.



Source: [137, Herbertz et al., 2013]

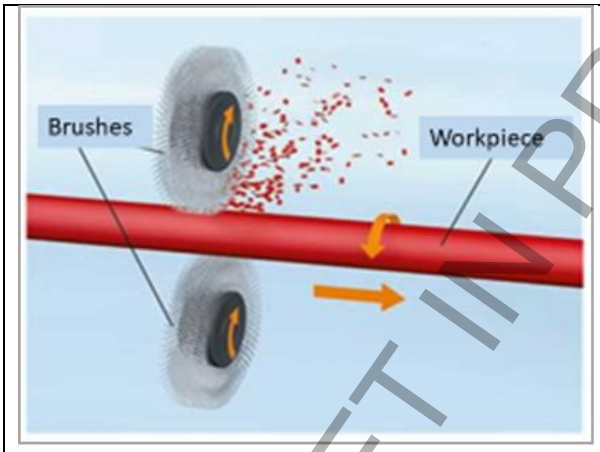
Figure 1.21: Scale removal using pressurised water

Advantages	Scale removal can be well integrated into the process chain.
Disadvantages	In the case of small cross-sections, the workpiece can cool down too much. Applicable only to larger workpieces that can remain stable. The bearing area of the product is only partially descaled.
Applications	Pressurised water scaling is mainly used for workpieces with a high charge weight.
Source: [137, Herbertz et al., 2013]	

Scale removal using brushes

[137, Herbertz et al., 2013]

When scale removal is carried out using brushes, the loose adhering scaling/oxide layer and other impurities on the surface are mechanically removed by rotating steel wire brushes (see figure below).



Source: [137, Herbertz et al., 2013]

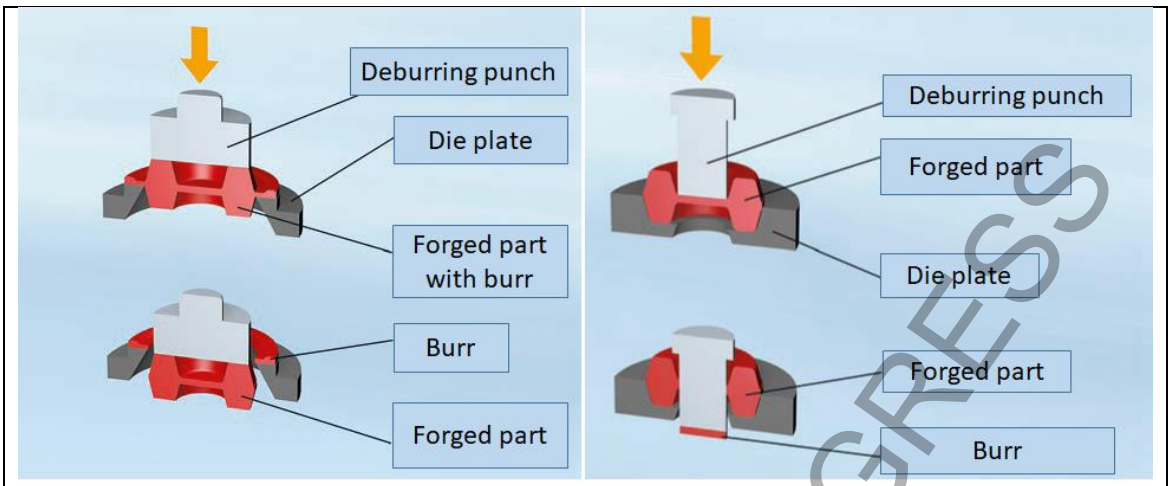
Figure 1.22: Scale removal using brushes

Advantages	Scale removal can be carried out automatically with a continuous process.
Disadvantages	Wear of the brushes which have to be adjusted or replaced depending on the degree of wear.
Applications	Due to the severe wear of the steel wires, the brushes are preferably partially used for the conductive heating process in order to clean the ends of the material sections and to remove slight burrs. In order to avoid current peaks at the electrodes of the conductive unit/system, it is necessary to keep the contact surface clean and free from burrs. In practice, it is not often used. [148, Euroforge 2021]
Source: [137, Herbertz et al., 2013]	

1.2.5.6.2 Deburring and punching

In the case of deburring, the external burrs of the forging are removed. During the punching process, the inner flash (mirror area) is removed. A distinction is made between the cold deburring process and the hot deburring process.

Multi-purpose tools and machinery, e.g. progression tool, are commonly used in order to combine both deburring and punching/piercing processes. [137, Herbertz et al., 2013]



Source: [137, Herbertz et al., 2013]

Figure 1.23: Deburring and punching

Hot and cold deburring process

Hot deburring	Advantages	The hot deburring process is integrated into the production line. The cutting forces are low due to the high temperature.
	Disadvantages	Spread component temperatures cause dimensional variations in component geometry and may have a negative impact on the quality of the deburring and hole cuts. Integration into the production line increases the investment of setting (set-up) efforts and correction efforts during hot operation.
Cold deburring	Advantages	The decoupling of the cold deburring process from the working step within the forging line allows a higher volume output of deburring.
	Disadvantages	The decoupled operation requires intermediate buffering and therefore multiple handling of the components.
Hot and cold deburring	Applications	Forging parts with all types of burrs and punch mirrors.
Source: [137, Herbertz et al., 2013]		

1.2.5.7 Heat treatment

A heat treatment is essential to improve the physical properties of the products. Precisely controlled heat treatment achieves the physical properties that are required by the customer or prescribed by the standard. Modern measuring and control instruments determine the material-appropriate thermal treatments that are required such as normalising, tempering, tempering or soft annealing.
[150, Stooss AG DE 2020]

A supplementary heater is used to keep the material plasticised. During final production, heat treatment gives the component the required mechanical characteristics (hardness, toughness).

The component is then cleaned by surface treatment. The quality check of the workpiece is usually carried out after cleaning, but is also carried out occasionally between the processes.

Depending on the transformation process, the type and number of processes and process steps change.

Regarding surface treatment processes, further information can be found in the Reference Document on Best Available Techniques for the Surface Treatment of Metals and Plastics (STM BREF).

1.2.5.7.1 Heat treatment for raw steel parts

[137, Herbertz et al., 2013]

The material condition of the workpieces after transformation does not generally meet all the requirements for their intended use. It is therefore necessary to modify the state of the material by post-treatment in such a way that, for example, hardness, strength, toughness or wear resistance are optimally adapted to the different conditions of the particular application. This is done by heat treatment. Heat treatment is a time- and temperature-controlled process aimed at achieving certain material properties.

The properties of steel can be deliberately influenced by heat treatment and thus adapted to its intended use. This can be done both by adapting to the functional characteristics of the component, such as tensile strength and toughness, and by preparing for a subsequent handling process/process chain, such as cold forging or machining. The process of heat treatment may be integrated into the production process or separated in time and space from the transformation process.

A number of different procedures/techniques are available depending on the objective of the heat treatment. With some procedures, the material condition is changed across the entire cross-section, e.g. during ignition, hardening, annealing, tempering or austempering (bainit). With other procedures, only a modification of the surface layer is intended, such as surface layer hardening, nitriding or nitrocarburising. While some procedures aim to change the surface layer, there is also an influence on the material condition in the entire cross-section of the material. This applies, for example, to the case of hardening.

The heat treatment processes are essentially defined by the following parameters:

- temperature of heat treatment;
- heating and holding time;
- furnace atmosphere;
- cooling.

The temperature used depends on the material and the heat treatment result that is required. For example, for steel with 0.8 wt-% carbon, a typical heat treatment temperature is about 723 °C (so called Ac_1 temperature). Above this temperature, a structural material condition is formed which can be altered selectively in its properties by an appropriate cooling procedure. Below this temperature, the heat treatment is continued or the relaxation process is started in order to eliminate the brittleness caused by hardening. Depending on the temperature and the material, different tensile strength/toughness ratios of the material/workpieces may be achieved.

The heating time has to be calculated in a way that the increase in temperature occurs as constantly/consistently as possible throughout the entire workpiece. This avoids or reduces the deformation/warping of the workpiece.

The holding/dwell time should be chosen at a specified temperature range in such a way that the desired structural changes occur or the elements carbon (for case/pack hardening) or nitrogen (for nitrogen hardening) can diffuse into the material.

By selecting appropriate furnace conditions, discoloration and scaling on the surfaces of the workpiece during heat treatment can be avoided. In this case, the oxygen which is responsible for discoloration and scaling of the product is replaced by inert cover gases or a vacuum is created.

By quenching or cooling, a change in the structural conditions of the material to a new hard structure (martensite/bainit) is achieved.

The following heat treatment processes act over the entire cross-section of the components:

- normalising (annealing);
- hardening and tempering/heat treatment;
- controlled/monitored cooling from hot forging;
- ferritic-pearlitic annealing /isothermal annealing;
- soft annealing;
- stress-relief annealing;
- recrystallisation annealing;
- solution annealing.

The following processes have an effect on the properties of the component surfaces:

- surface hardening;
- case/pack hardening;
- plasma-nitriding.

Surface hardening/tempering is carried out in order to increase the wear resistance and pressure resistance of the material, for example in the case of components such as gear/toothed wheels, bolts or shafts.

Normalising
The objective is the production of a fine-grained, uniform texture. By normalising, the microstructure produced is of the best combination of strength and toughness properties, at least in the case of non-alloy steels. It refers to a normal structure of a steel. The normal structure is produced by this heat treatment in a targeted and reproducible manner.

Hardening and tempering
For a particular application, a specific combination of strength and toughness should be achieved.

This process is a two-stage heat treatment process consisting of both hardening and subsequent curing/tempering.

A high hardness/tensile strength and low toughness of the product is achieved by hardening.

When tempering after the forging heat stage, hardening is carried out by quenching the workpieces from the forming heat.

The elimination of a separate hardening process offers cost advantages and energy savings. In comparison to the hardening process using a holding time, the energy demand is reduced and energy is saved. This is used to heat the material to a specific hardening temperature.

Controlled/monitored cooling from hot forging
The required strength and toughness should be achieved.

The forged raw parts are cooled down in a controlled manner from the forging heat with a required temperature-time sequence/schedule. This process leads to significant cost advantages,

as heat treatment is carried out exclusively with the forming heat and no additional furnaces are needed.

Ferritic-pearlitic annealing/isothermal annealing
The purpose is the generation of a uniform structure of the product with good grindability/machinability. Ferritic-pearlitic annealing/isothermal annealing means treatment on a ferrite-perlite texture/structure. After heating at the temperature range of the normal annealing temperature, rapid cooling to the isothermal annealing temperature is carried out.

Soft annealing
The purpose is to ensure that the steel is as soft as possible. A soft steel facilitates the machining/metal cutting/chip removal process or the subsequent cold forming of the material.

Stress-relief annealing
Minimising the internal component stress factor without affecting the essential mechanical properties is the purpose of this type of annealing. Internal stresses/tensions may arise as a result of the cold forging process or irregular/non-uniform cooling after the hot forging process or after the heat treatment process.

Recrystallisation annealing
The solidification/hardening of the material caused by the cold forging should be reversed.

The annealing temperature largely depends on the initial structure of the material and the deformation degree during cold forging and it generally ranges from 600 °C to 700 °C. Heating takes place relatively quickly and cooling is usually carried out by stationary/still air.

Solution annealing
This process is carried out in order to obtain uniform and homogeneous structural and material properties. Annealing is carried out at a temperature range of 950 °C to 1 200 °C. Cooling is carried out by quenching in water or, in the case of thin material cross sections, by rapid air cooling.

Surface hardening
The aim is to harden the surface without reducing the toughness of the workpiece.

The near-surface coating is heated to hardening temperature by means of a space-limited heat input and subsequently quenched.

Case/pack hardening
The aim is to harden the surface without reducing the ductility/toughness of the workpiece core. Case/pack hardening is one of the thermochemical processes. As part of this process, the edge layer of components and tools is carburised with a carbon-emitting medium and subsequently quenched.

Plasma-nitriding
Besides hardening of the surface, the improvement of friction properties and sliding properties and the creation of corrosion-resistant coatings are also important. Plasma-nitriding is one of the thermochemical heat treatment processes carried out at temperatures between 350 °C and 600 °C. An increase in hardness is achieved by the formation of very hard nitrogen compounds in the edge layer of the workpiece. Plasma-nitriding takes place in a vacuum chamber under an ionised gas atmosphere, where positively charged ions hit the workpieces connected as cathodes in front of the furnace wall (anode) at high impact speed. It causes extremely intensive cleaning of the workpiece surface, which is then followed by the heating and the nitriding of the surface. [170, REESE 2020]

Surface treatment
The surface treatment of the forging pieces can be divided into two main groups:

- cleaning and descaling of the cold pieces after transformation;
- coating of the surface.

Cleaning/descaling is preferably carried out by blasting technology or blast cleaning, and it is applied in both the prefabrication of the cold-forging process and in the final production process. For technical/procedural reasons, the coating is carried out during the forging process, e.g. applying lubricants during the cold forging process, or anti-corrosion protection of the finished parts in the final production process.

Blasting
Blasting is primarily used to clean the surface of the component, but can also be used to increase the durability of the components.

The workpieces are treated by descaling using balls or cut wire/wire pellets/shots. As a result of the surface solidification associated with descaling and the internal/residual compressive stress of the workpiece, the dynamic resistance of descaling can be increased. The main descaling technique applied is the shot blasting wheel.

During the process of airless blast cleaning the abrasive is accelerated by a high-speed shot blasting wheel and is blasted at high speed to the surface of the component. The kinetic energy of the steel particles destroys the scale or oxide layer and, given that correspondingly high energy is available, it causes local plastic deformation of the workpiece surface. The rotating cylinder of the shot blasting unit ensures continuous movement of the workpieces within the cylinder so that all workpieces and the entire surface of the workpieces are covered by the blasting cone.

The blasting abrasive/agent is selected depending on the surface quality requirements,. The metallic blasting agent mainly used is available in an angular shape or spherical shape, in a variety of particle sizes and in different degrees of hardness.

1.2.5.7.2 Coating

As in the case of cold forging, a coating may be necessary for process reasons or for prevention of corrosion of the prefabricated parts. However, for prefabricated parts, coating can also be carried out for surface finish reasons. The coating application is mainly carried out by the dipping method or spray coat method. The selection of the coating material depends on the purpose of the coating. [137, Herbertz et al., 2013]

1.2.5.8 Mechanical treatment

Mechanical processing methods are characterised by:

- very high accuracy; and
- very good surface quality of the machining surfaces.

A combination of solid-forging processes and mechanical treatment processes enables the specific advantages of both processes to be used in order to economically produce a ready-to-install component with almost any type of geometry and the highest possible quality. Forged products are usually turned into ready-to-install components by subsequent metal-cutting machining.

Source: [137, Herbertz et al., 2013]

Figure 1.24: Forging before (left) and after mechanical processing (right)

Usually, the vast majority of the raw component remains unprocessed; only a few functional surfaces, such as the reference/locating points at bearing positions and the fixing points, are processed by subsequent metal-cutting treatment..

For mechanical treatment, the treatment processes, cutting materials and cutting parameters which are selected depend on:

- the raw material workpiece;
- its composition and heat treatment condition;
- the volume and required quality of the surfaces treated.

Standard treatment methods are applied, such as turning, drilling and milling as well as special processes/technologies. [137, Herbertz et al., 2013]

1.3 Current emission and consumption levels in smitheries

Emissions to air, noise emissions and vibrations arise during the smitheries process. Furthermore, residues/process losses/waste and, in rare cases, emissions to water also occur. In this section, ranges of air pollutant emissions are presented for the smitheries process, including other process steps, such as storage and handling of raw materials, fuels or products.

Emissions to air in the smitheries industry arise in several manufacturing processes. The Industrial Emissions Directive (IED) includes in Annex II a general indicative list of the main polluting substances to air and water to be taken into account, if they are relevant for setting emission limit values. It was concluded at the Kick-off Meeting of the SF BREF review that emissions to air were key environmental issues (KEIs), in particular:

- nitrogen oxides (NO_X);
- carbon monooxide (CO).

It should be noted that, the emission levels presented in this section refer to standard conditions (temperature of 273 K, pressure of 1 013 hPa, dry gas) without correction to a reference oxygen level.

Furthermore, dust emissions and diffuse (fugitive) emissions might also be relevant. These emissions to air were not concluded to be KEIs.

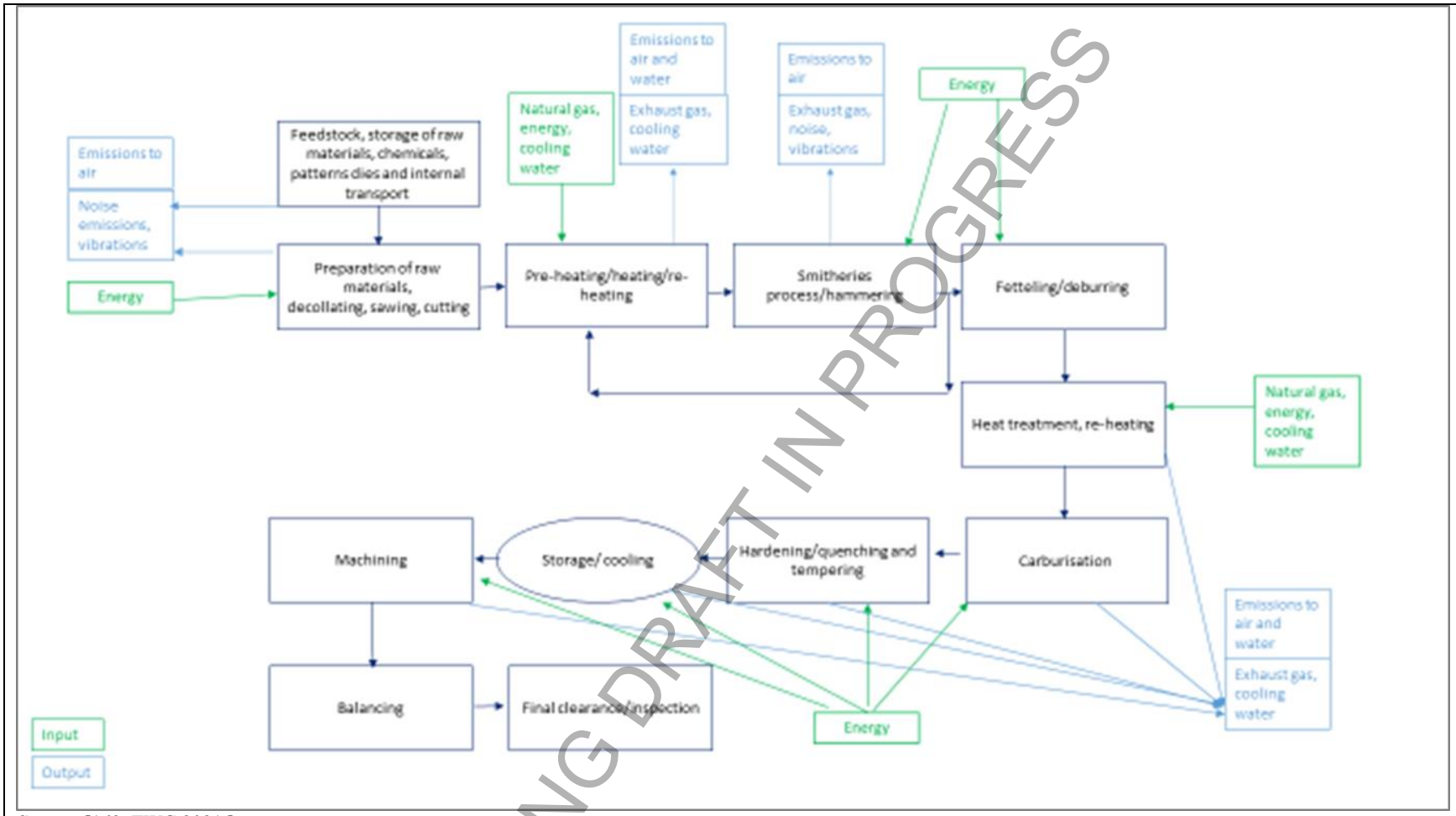
The nature and concentration of the emissions is influenced by several factors, such as:

- type of furnace and design;
- operating or process conditions;
- quality of the raw material;
- the fuels used;
- abatement techniques for emissions reduction.

Other emissions, the effect of which is normally slight and/or local, are noise and vibrations, water and residues/waste.

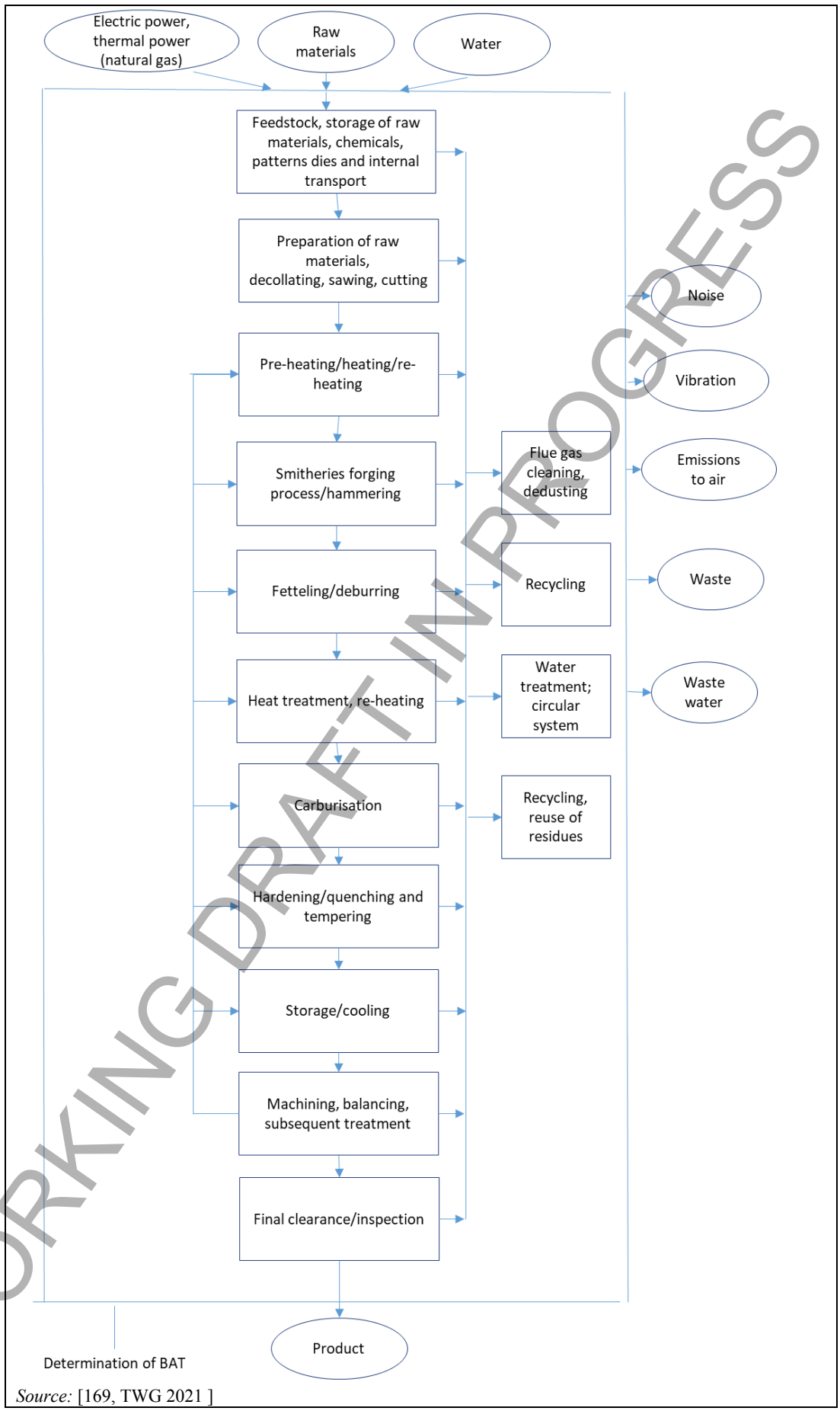
Figure 1.25 and Figure 1.26 show process flow sheets and possible emission points and types of emissions. Energy (electrical and/or heat) is consumed within all steps of the process. Furthermore, the input and output flow is shown in Figure 1.27.

Handling of Confidential Business Information (CBI)
Energy consumption data were considered CBI by the plant operators. In order to maintain data confidentiality, plant names are not directly mentioned in the graphs describing energy consumption but are replaced with anonymised and randomly attributed CBI codes. In addition, no contextual information (e.g. process parameters or techniques applied) is included as this could reveal the identity of the plants. All the consumption figures are presented in ascending order of the maximum specific energy consumption values.



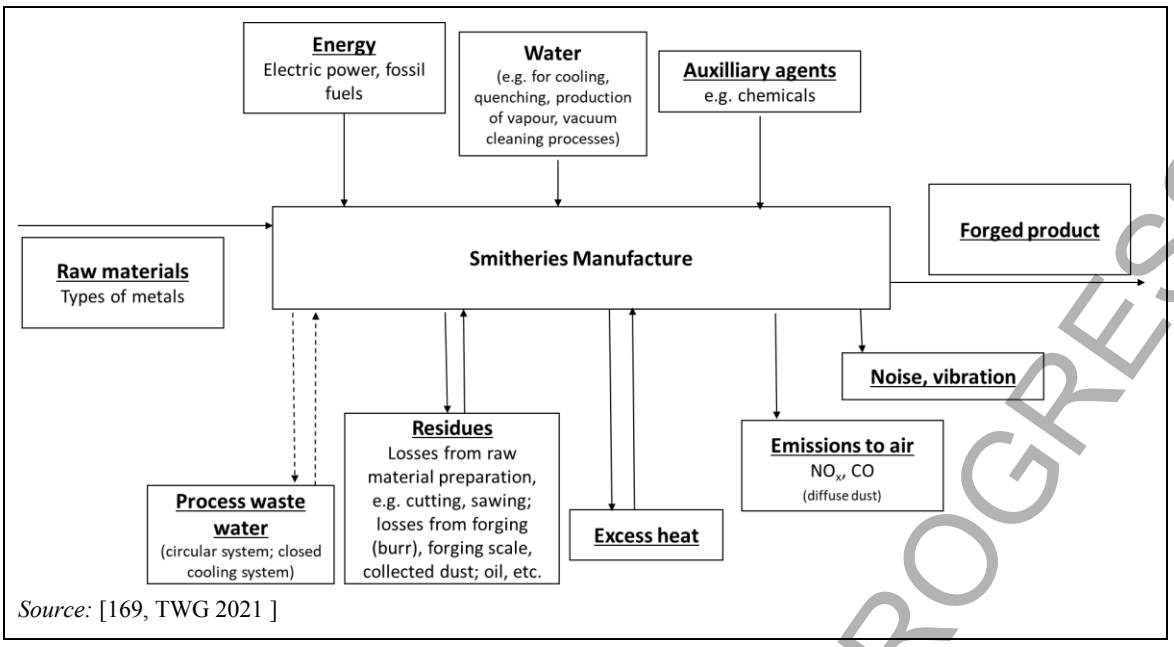
Source: [169, TWG 2021]

Figure 1.25: Example of a simplified flow diagram of a smitheries process along with emissions which may arise and the use of energy at process level



Source: [169, TWG 2021]

Figure 1.26: Smitheries process flow chart including possible types of emissions



Source: [169, TWG 2021]

Figure 1.27: Smitheries input and output flow

1.3.1 Water consumption

Water is used in the production process as well as for cleaning procedures, e.g.:

- for cooling and quenching;
- as auxiliary water, e.g. for the production of vapour and vacuum and the production of steam energy;
- for cleaning processes;
- as sanitary water.

Closed cooling circuits are applied in order to minimise water consumption.

Water consumption is not a key issue in smitheries .

1.3.2 Material consumption – material efficiency

[137, Herbertz et al., 2013]

All non-contaminated and clean metals and metal alloys are suitable for solid forging. A large group of structural steels are used.

The raw material is mainly delivered as circular or square bar material with circular or square cross sections. The length of the bars is up to 12 m.

For small-diameter circular sections, the semi-finished product can be wrapped on coils as continuous material.

The development of the steel material for forging components is ongoing. Improved property profiles will be developed through new alloys and process routes, leading to lower costs or improved performance for specific applications. Both the well-known steel groups, such as heat-treated steels or precipitation-hardening ferritic-pearlitic steels, will be further optimised and new steel groups, such as the bainitic steels, will be developed. Some steel groups essential for solid forging are the following:

- Unalloyed carbon steel (e.g. C35 or C45) (DIN EN 10250-2):
    - If the carbon content is low, these steels can be cold-forged depending on the component geometry. If a slightly higher strength is desired, the carbon content may be increased with higher processing temperatures (semi-hot or hot forging process).
- Case hardening steel (DIN EN 10084):
    - Previously, in case hardening the components were inserted and annealed in coal powder. At the time of writing this document (2021), carbon in gaseous form is preferred for use in hardener furnaces. Case hardening steels allow the surface to be hardened without reducing the toughness of the component core. These steels have a carbon content of about 0.1 % to 0.3 %. Depending on the application, hardenability-enhancing elements such as chromium or molybdenum may be alloyed if higher strength is required just below the hard edge layer to support the edge pan or, in the case of joints, to increase the strength at the tooth-root. Elements such as nickel also increase the viscosity/toughness of the workpiece, especially at low temperatures. Typical fields of application are for transmission parts and drive parts with surface hardening, such as rack wheels, shafts and toothed components.

The use of a computer-aided design (CAD) system can optimise the amount of raw materials used.

Material efficiency is a very important element due to material cost issues since the material costs are around half of the product costs. Further options to reduce material input are:

- avoidance of excess material after forging process that has to be removed by machining process (near net shape);
- minimisation of burrs;
- application of lightweight construction (sometimes requires special steels) to minimise the material weight in the final product. [148, Euroforge 2021]

1.3.3 Energy consumption – energy efficiency

The smitheries industry is a high-energy-consuming industry, depending on the process used. Fuels and electricity are the two main types of energy used in smitheries manufacture. Energy efficiency (both thermal and electrical) has always been a priority for the European smitheries industry as part of the overall business decisions which are driven by economic and technological needs.

Smitheries require electrical and thermal energy for virtually every step of the process, e.g. raw material preparation, heating, hammering. Electricity is needed for process control of the installation, for heating and as the driving power for machinery including forging and (induction) heating equipment as well as for lighting. Also, machining following the forging process uses electrical energy. [148, Euroforge 2021]

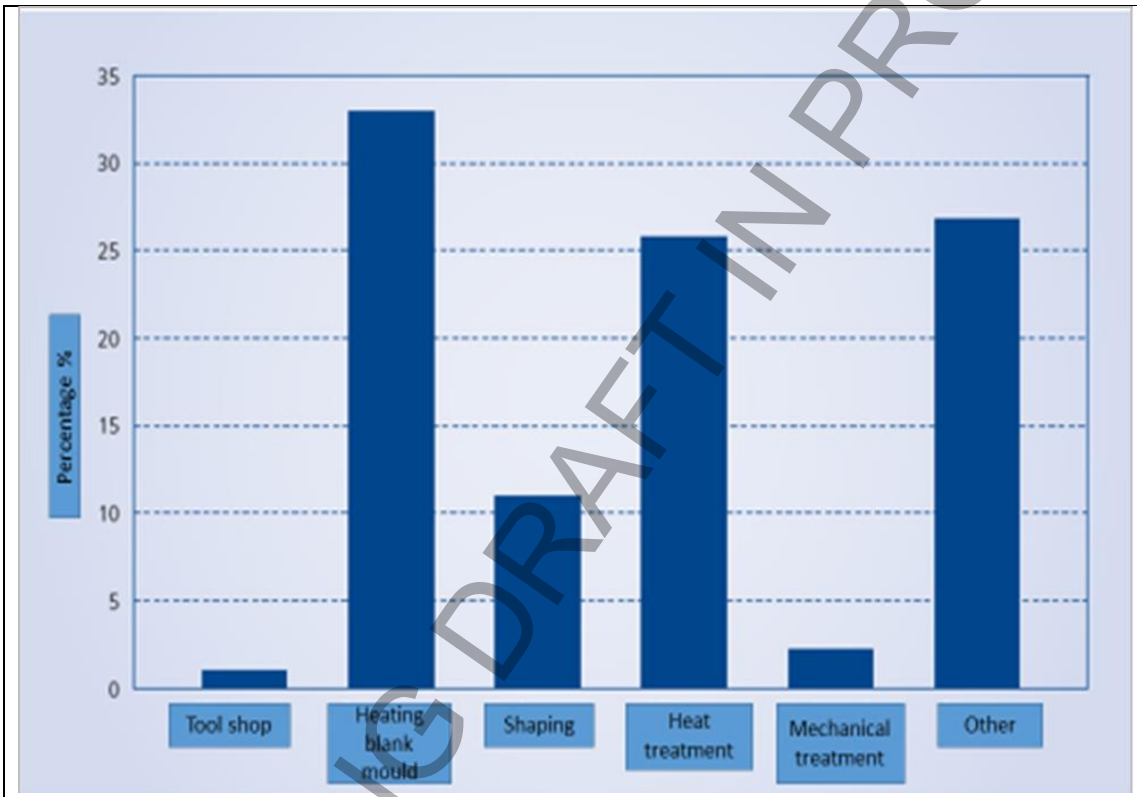
Electricity is usually generated and supplied by utility companies. When steam and electricity are generated on site, the efficiency factor can be considerably higher. Fuel-basedoperations energy is needed for heating processing lines/forging furnaces and buildings. [168, COM 2021]

The energy consumption of the furnaces depends on several parameters such as:

- the furnace design (pusher-type, bogie hearth, chamber-type, walking beam, etc.);
- throughput and shift patterns (operating time);
- the burner design;
- the use of a regenerating system;
- the production capacity of the furnace;

- the heating zone arrangement;
- the charging temperature of the stock;
- the heating and discharging temperature;
- the accuracy of the thermal regulation;
- the degree of insulation of the furnace;
- the operation point in relation to the design point;
- the O_2 content in the furnace atmosphere. [168, COM 2021]
- the size and type of hammer;
- the numbers of hammers used;
- the size of product and the amount of products

In relation to the process steps for hot forging, almost 33 % of the total energy input is used for the heating process, 11 % for the forging process, 26 % for heat treatment, 1 % for toolmaking, 2 % for mechanical processing as well as 27 % on other installation areas and processes, e.g. heating of production halls. [146, Ade 2017]



Source: [146, Ade 2017]

Figure 1.28: Percentage of energy consumption for process steps in hot forging

The use of energy varies considerably with regard to the heating energy, but the different energy flows in connection with the manufacture of the raw material and the need for post-processing also have to be taken into account when considering the total energy requirement.

The main users of electricity are the heating furnaces used to heat and reheat the prepared raw materials by inductive or conductive heating.
To heat a tonne of steel to the forging temperature of 1 200 °C using electrical inductive heating, electrical energy consumption of 400 kWh to 500 kWh is required.

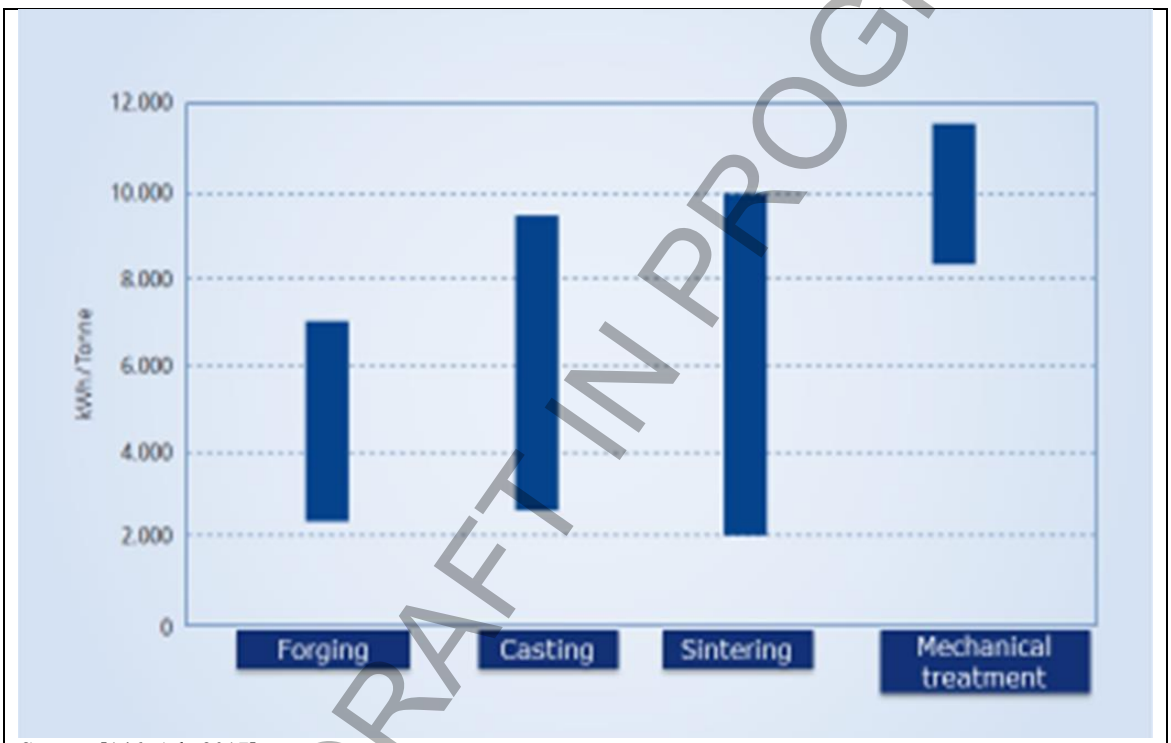
Currently, electricity consumption accounts for around two thirds of the total energy requirement, although the energy mix has remained largely unchanged over the past 20 years (since about 1997). [146, Ade 2017]

Electrical furnaces are used for producing 75% of preliminary products.

For hot forging, energy consumption of 900 kWh to 4 500 kWh per tonne of finished product is needed, depending on the component produced.

An energy consumption of 3 400 kWh to 7 000 kWh per tonne of forged component is used for the production processes, such as for heating, reheating, several forging steps and heat treatment processes. When using electric steel, the lower level is 2 400 kWh/t. Furthermore, energy is also bound in the preliminary product. [146, Ade 2017]

Figure 1.29 compares energy consumption of different smitheries processes.



Source: [146, Ade 2017]

Figure 1.29: Energy consumption of different processes in kWh/tonne

Smitheries plants (IED and non-IED) reported the use of between one and six hammers with a calorific power of between 1.4 MW and 47.2 MW. IED smitheries plants reported the use of between two and four hammers with a calorific power of 15.7 MW and 47.2 MW.

The following specific energy consumption data at plant as well as at process level were reported:

- specific net energy consumption (kW/tonne of liquid metal);
- specific electricity consumption (kW/tonne of liquid metal);
- specific net heat (e.g. added steam) consumption (kW/tonne of liquid metal).

In Table 1.5 below, the reported specific energy consumption parameters (at plant level) per plant are shown.

Table 1.5: Reported (R) and non-reported (NR) specific energy consumption parameters

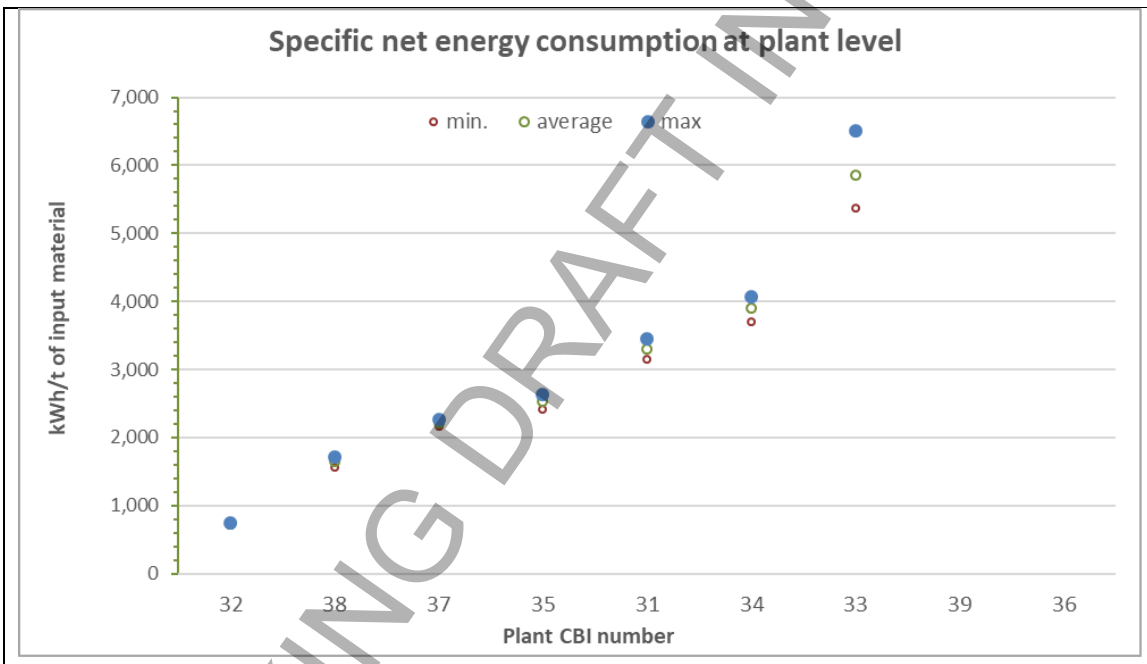
Plant CBI code	Net energy	Electri-city	Net heat	Plant number	Net energy	Electri-city	Net heat	Plant number	Net energy	Electri-city	Net heat
31	R	R	R	34	R	R	NR	37	R	R	R
32	R	R	R	35	R	R	NR	38	R	R	NR
33	R	R	R	36	NR	NR	NR	39	NR	NR	NR
Source: [169, TWG 2021]											

Energy consumption data were reported for the years 2017, 2018 and 2019. [169, TWG 2021]

1.3.3.1 Specific energy consumption at plant level

The theoretical thermal (fuel and electricity) energy demand for the smitheries process is determined by the energy required for heating the prepared raw material, heat treatment and the smitheries process itself by using hammers.

The reported levels for specific net energy consumption at plant level are presented in Figure 1.30.

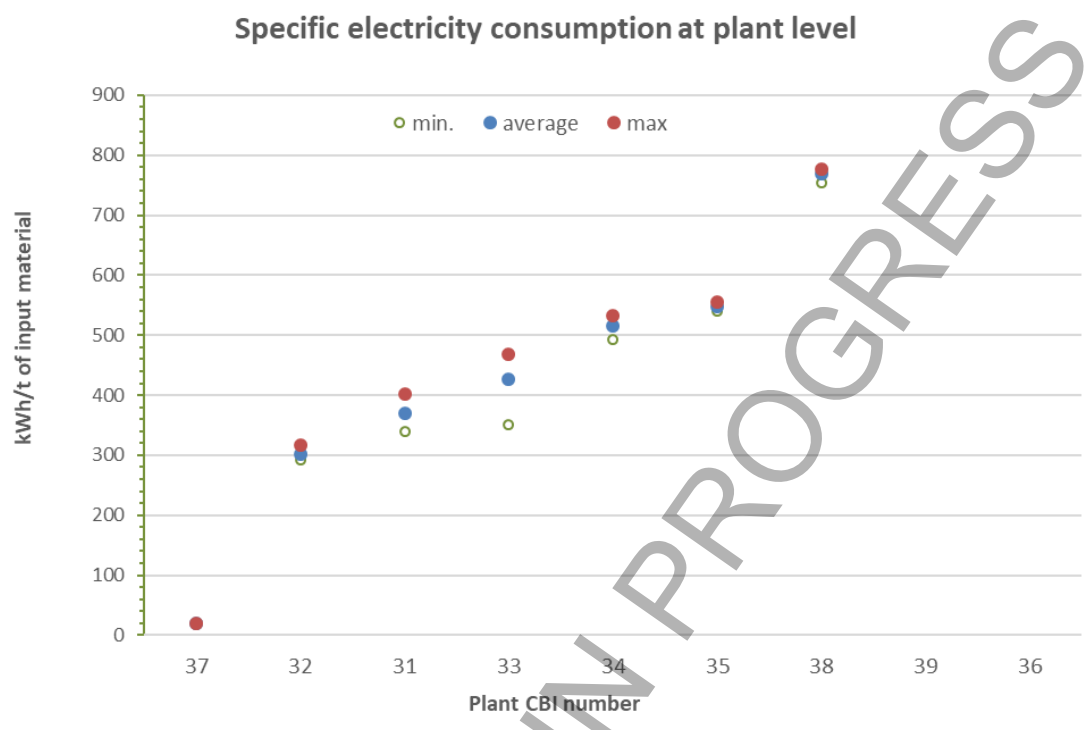


Source: [169, TWG 2021]

Figure 1.30: Reported levels of specific net energy consumption at plant level (in kWh/t of input material)

The main users of electricity are the heating furnaces to heat the pre-prepared raw materials by inductive or conductive heating.

The reported specific electricity consumption at plant level are presented in Figure 1.31.



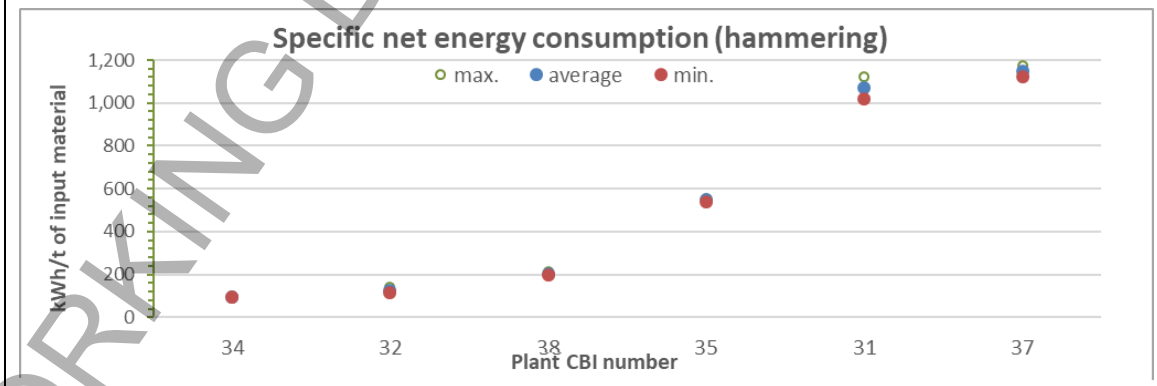
Source: [169, TWG 2021]

Figure 1.31: Reported specific electricity consumption at plant level (in kWh/t of input material)

1.3.3.2 Specific energy consumption at process level

Hammering

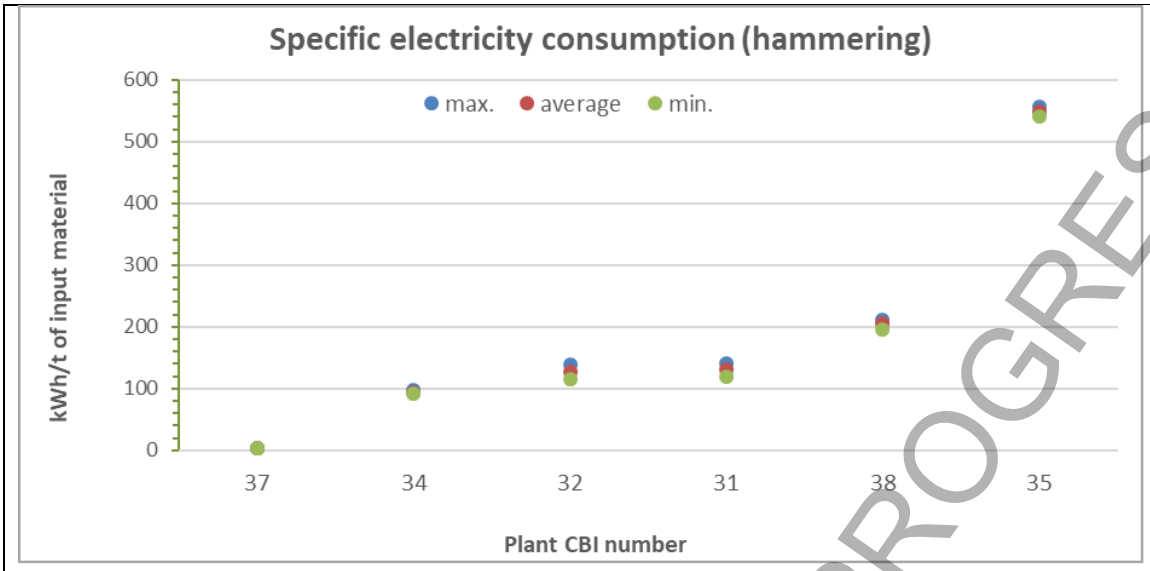
The reported specific net energy consumption for hammering are presented in Figure 1.32.



Source: [169, TWG 2021]

Figure 1.32: Reported specific net energy consumption for hammering (in kWh/t of input material)

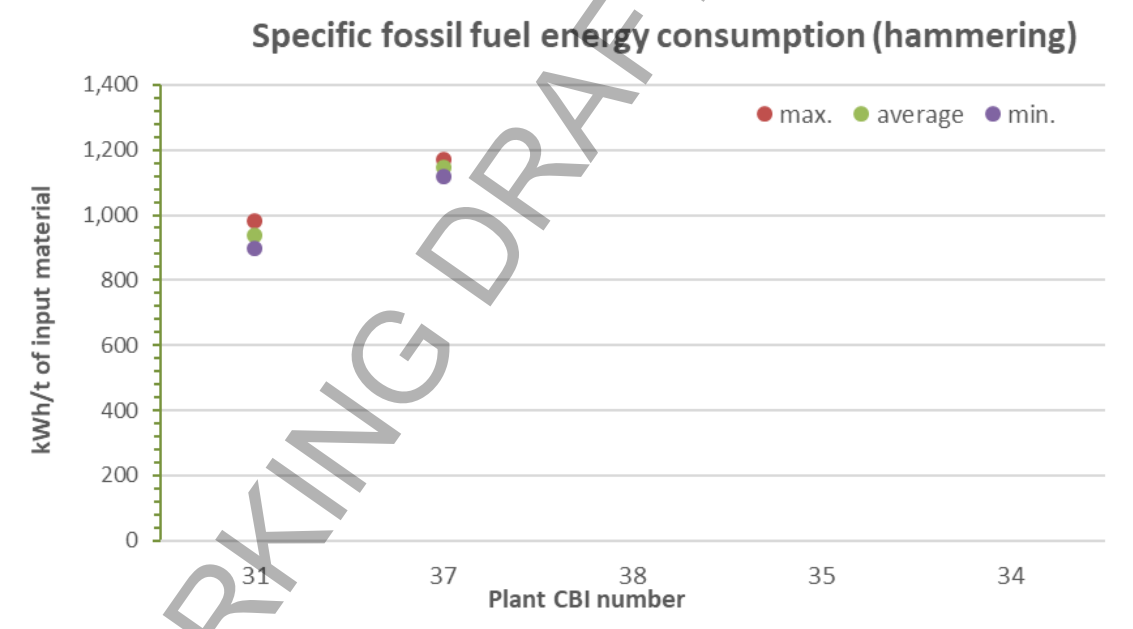
The reported specific electricity consumption for hammering are presented in Figure 1.33.



Source: [169, TWG 2021]

Figure 1.33: Reported specific electricity consumption for hammering (in kWh/t of input material)

The reported specific fossil fuel energy consumption for hammering are presented in Figure 1.34.

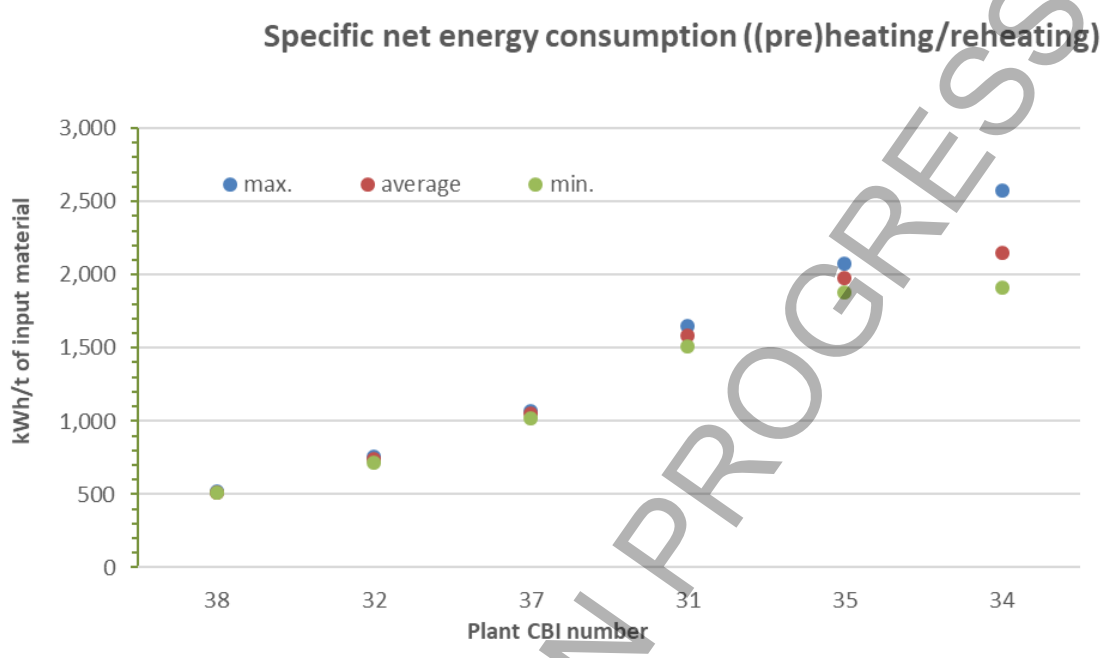


Source: [169, TWG 2021]

Figure 1.34: Reported specific fossil fuel energy consumption for hammering (in kWh/t of input material)

Preheating/reheating

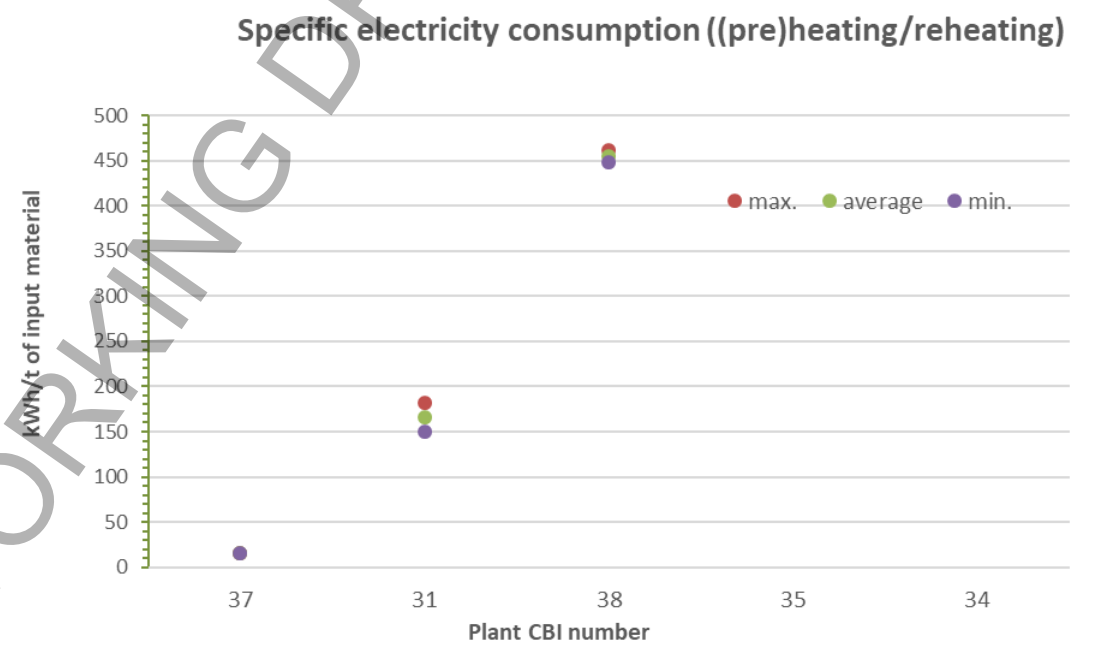
The reported specific net energy consumption for preheating/reheating are presented in Figure 1.35.



Source: [169, TWG 2021]

Figure 1.35: Reported specific net energy consumption for preheating/reheating (in kWh/t of input material)

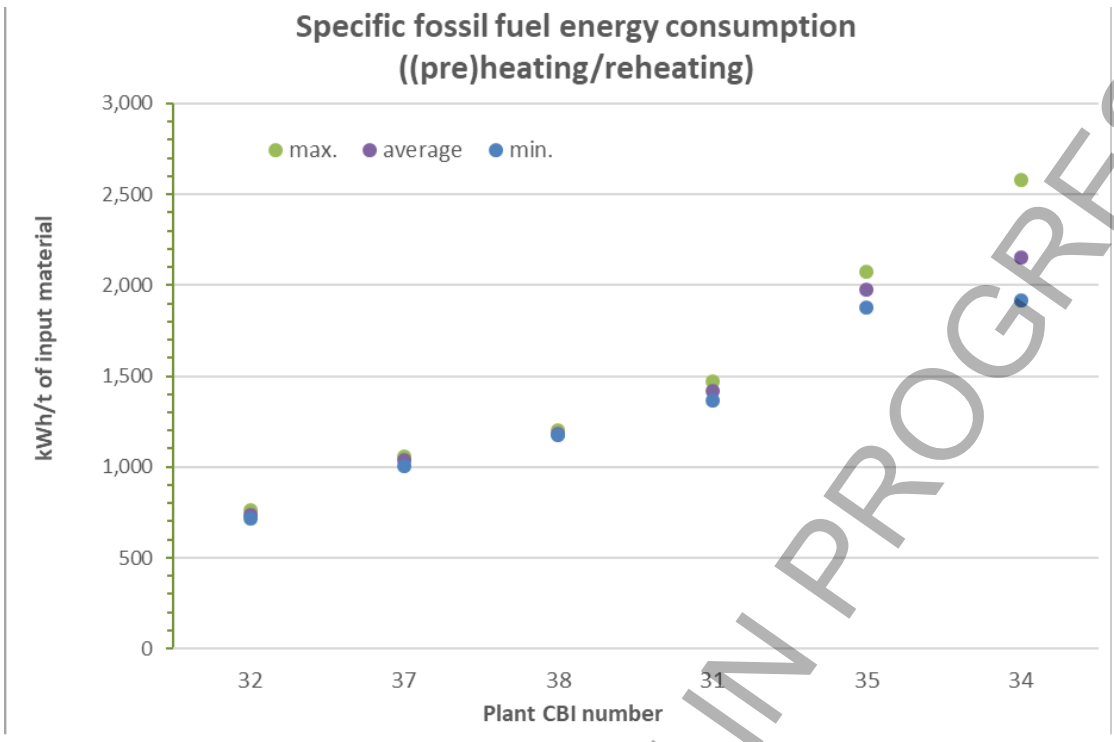
The reported specific electricity consumption for preheating/reheating are presented in Figure 1.36.



Source: [169, TWG 2021]

Figure 1.36: Reported specific electricity consumption for preheating/reheating (in kWh/t of input material)

The reported specific fossil fuel energy consumption for preheating/reheating are presented in Figure 1.37.



Source: [169, TWG 2021]

Figure 1.37: Reported specific fossil fuel energy consumption for preheating/reheating (in kWh/t of input material)

The reported specific fossil fuel energy consumption for thermal treatment are presented in Table 1.6.

Table 1.6 : Reported specific energy consumption for thermal treatment

	Net energy			Electricity			Fossil fuel energy		
Plant CBI number	Max.	Average	Min.	Max.	Average	Min.	Max.	Average	Min.
38	863	836	814	56	51	46	807	785	767
34	672	662	651	-	-	-	672	662	651
32	1 700	1 624	1 560	-	-	-	1 700	1 624	1 560
31	684	655	627	80	74	68	604	581	559
Source: [169, TWG 2021]									

For thermal treatment, the values reported for net energy are within the range 627 kWh/t to 1 700 kWh/t of input material (min-max), the values reported regarding electricity are within the range 46 kWh/t to 80 kWh/t of input material (min-max) and the values reported regarding fossil fuel energy are within the range 559 kWh/t to 1 700 kWh/t of input material (min-max). [169, TWG 2021]

1.3.3.3 Hammer and furnace energy consumption

Energy consumption for hammers was reported during the SF BREF data collection via questionnaires 2020/2021. [169, TWG 2021]

For non IED-plants, the reported energy consumption per hammer ranged from 25 kJ to 630 kJ. One plant reported a calorific power of 15.21 MWth.

For IED plants, the reported energy per hammer ranged from 25 kJ to 400 kJ. The plant calorific power for the IED smitheries range from 15.75 MWth to 47 MWth.

Table 1.7: Reported hammer energy and calorific power of plants which participated in the data collection

Plant	Number of hammers	Energy per hammer (kJ)	Calorific power of the plant
DE001	1	No information	The thermal output corresponds to 3 t/h = 3 850 KW
DE002	2	80; 160	No information
DE003	4	179; 84; 54; 53	No information
DE004	2	630; 450	No information
DE005	2	55; 50	No information
DE006	6	350; 350; 250; 200; 200; 100	15.21 MWth
DE007	2	360; 400	25.59 MWth
ES008	2	313; 313	15.75 MWth
PL009	4	68; 51; 34; 25	47 MWth
Source: [169, TWG 2021]			

Thermal capacities and electrical power of types of furnaces used were reported by plant. Usually and in most cases, natural gas is used as fuel. Electricity was also reported to be used.

Table 1.8: Reported data on total calorific power of all furnaces for the plants participated in the data collection

Type of furnace	Natural gas (NG) / electricity (E)	Thermal capacity MWth	Electrical power MWel
Pusher furnace, preheating	NG	0.46 – 4.26	0.021 – 0.034
Batch type furnace, preheating	NG	0.87 – 3	0.018 – 0.023
Rotary hearth furnace, preheating	NG	1.6 – 3.185	0.030 – 0.04
Continuous furnace, preheating	NG	NI	0.8
Induction heater, preheating	E	0.42 – 1.35	1.12 – 3
Batch annealing furnace	NG	1.11 – 2.54	NI
Heating furnace/furnace	NG	0.65 – 1.17	NI
Bogie hearth furnace, post-heat treatment	NG	0.75 – 3.71	0.019 – 0.03
Pusher furnace, post-heat treatment	NG	0.523 – 1.15	NI
Continuous furnace, post-heat treatment	NG	1.45	NI
Source: [169, TWG 2021]			

The reported data show a thermal capacity of the heating furnaces ranging between 0.42 MWth and 4.26 MWth.

The following table shows reported data on the total calorific power calculated as the sum of calorific power of all furnaces by plant. Furthermore, the electrical power of furnaces is shown as it was reported by the TWG via questionnaires in 2020.

Table 1.9: Reported data as sum of calorific power of all furnaces by plants which participated in the data collection

Plant number	Number of furnaces	Total calorific power (MWth) calculated as the sum of calorific power of all furnaces	Reported total calorific power	Reported total electrical power of all furnaces (MWel)
DE001	1	0	-	0
DE002	3	3.45	-	3.2
DE003	11	21.82	-	0
DE004	6	14.84	14.84 MW	0
DE005	2	1.37	1.37 MW	0
DE006	6	13.152	15.21 MW	0.6446
DE007	15	25.59	26.51 MW	1.428
Source: [169, TWG 2021]				

1.3.4 Emissions to air

Emissions to air arise during the smitheries manufacture. In this section, ranges of air pollutant emissions are presented for the forging process, especially for heating furnaces using exclusively natural gas. Thermal processes are associated with the reported emissions to air. The IED includes a general list indicating the main air-polluting substances to be taken into account, if they are relevant for setting emission limit values. As concluded at the KoM, the following are relevant to smitheries manufacture:

- oxides of nitrogen (NO_X) and other nitrogen compounds;
- carbon monoxide (CO) as an indicator for combustion efficiency for furnaces using natural gas.

CO emissions may result from poor combustion and improper burning conditions in the firing process of furnaces. Emissions of CO were concluded at the KoM not to be a KEI. However, it was concluded that contextual information about combustion efficiency could be obtained. This type of emissions can be considered an indicator for combustion efficiency.

There is potential for noise emissions and vibrations from different forging processes as well as from any outdoor storage of raw materials and from transportation of raw materials. The magnitude of these emissions can be significant if these aspects are not well engineered or maintained and noise emission can lead to local nuisance problems.

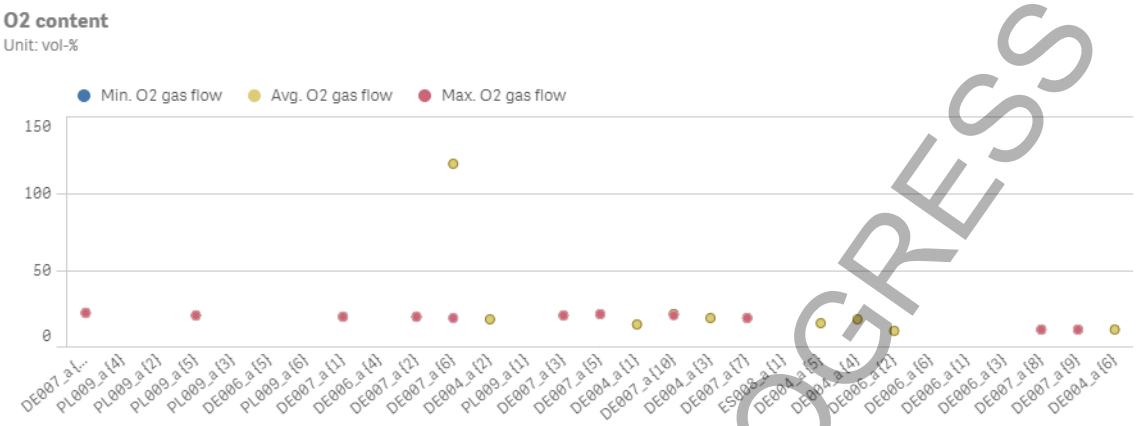
Emission data and bulk information were collected via questionnaires from three IED plants and also from six non-IED plants located in the EU-27. Data have been reported for the most recent 3-year reporting period, e.g. the years 2019, 2018 and 2017, if available. If data were not available for these years, data for other years could be reported. [169, TWG 2021]

Emission data on dust emissions have not been reported via questionnaires because, at the KoM, it was concluded that they were not KEIs.

Waste gas characteristics – O_2 content/level

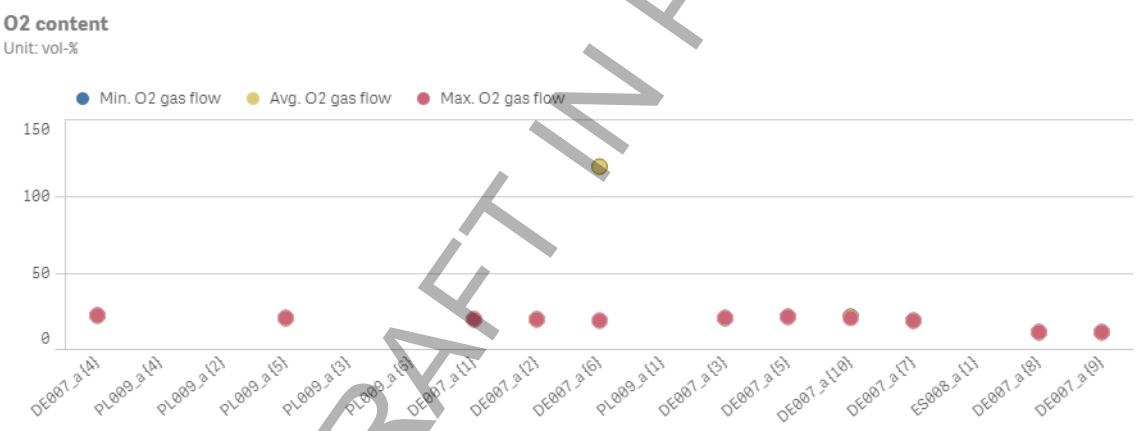
A variety of reported O_2 content/level values is given. Reported O_2 conditions (O_2 content in waste gases and O_2 level corresponding to the reported values) are in the range of 5 % to around 20 %. For all plants but one, the reported O_2 level associated with the reported emission levels is

the same as the O_2 content in waste gases. Therefore, reported emission levels were also associated with a reference O_2 level in the range of 5 % to 20 %. [169, TWG 2021]



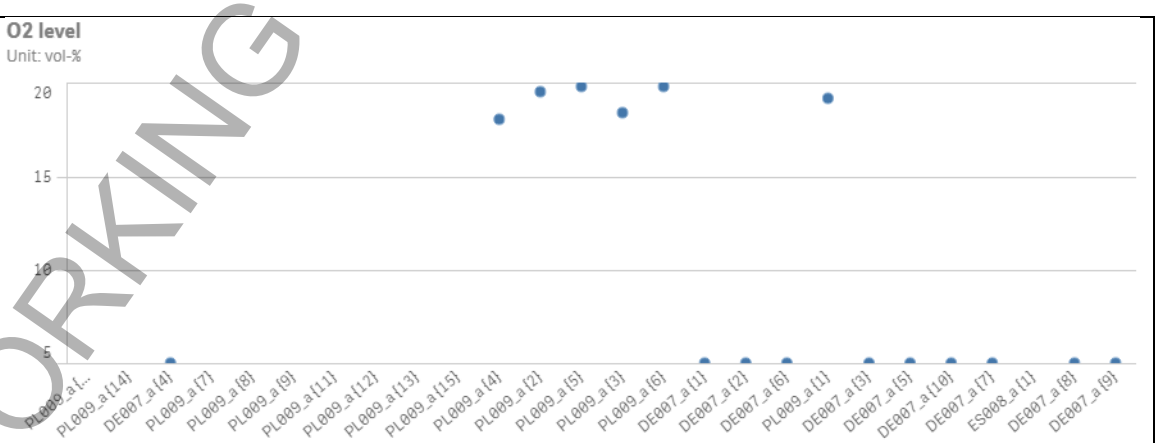
Source: [169, TWG 2021]

Figure 1.38: Reported O_2 content per EP – IED and non-IED plants



Source: [169, TWG 2021]

Figure 1.39: Reported O_2 content per EP – IED plants



Source: [169, TWG 2021]

Figure 1.40: Reported O_2 level per EP – IED plants

1.3.4.1 Emissions of nitrogen oxides (NO_X)

IED and non-IED plants reported data on NO_X emissions via questionnaires. The data are shown in Figure 1.41. [169, TWG 2021]

About 86 % of the reported NO_X emissions data are below 100 mg/Nm^3 and about 52 % of the reported NO_X emissions data are below 50 mg/Nm^3. Maximum NO_X emissions of 308 mg/Nm^3 were reported from one IED plant.

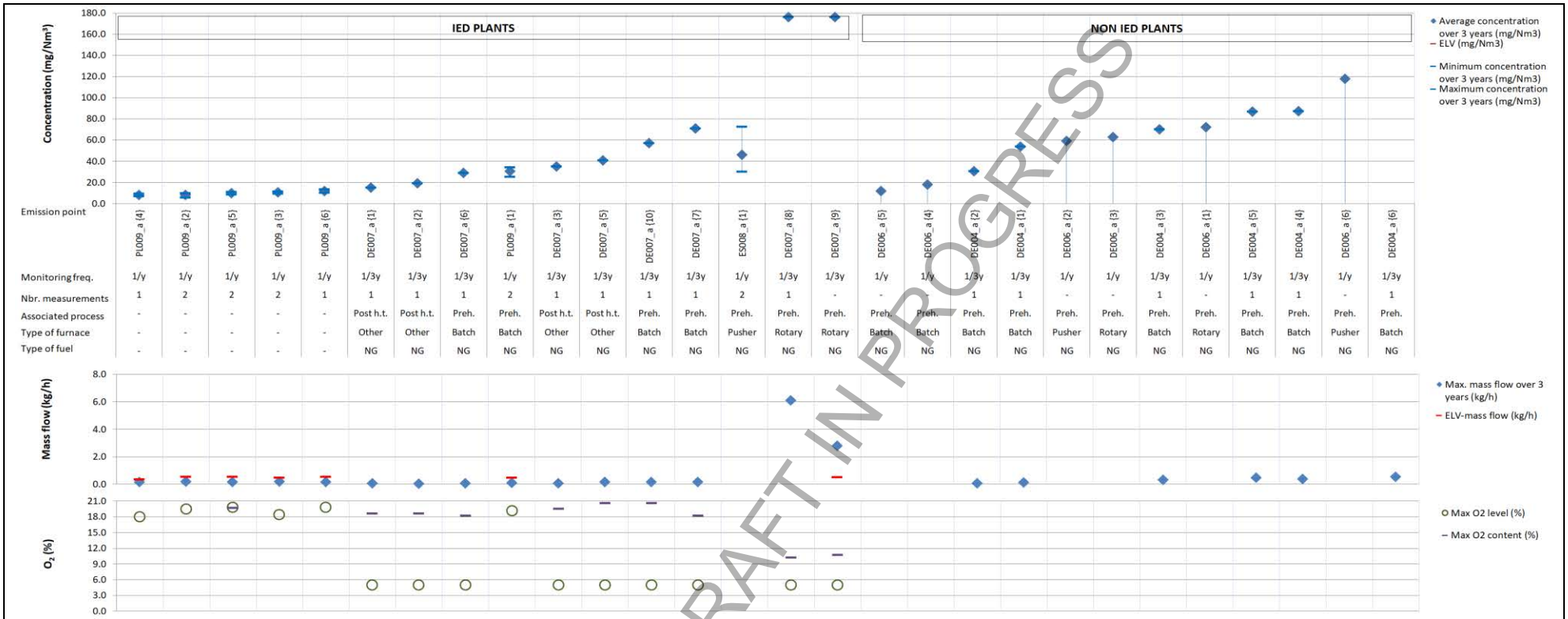
All data refer to heating furnaces using natural gas.

Monitoring frequencies of once every year (1/yr) and once every 3 years (1/3yr) were reported for IED and non-IED plants.

1.3.4.2 Emissions of carbon monoxide (CO)

During combustion processes, the exhaust gas contains CO emissions.

CO emission data were reported for IED and non-IED plants. The reported data on CO emissions to air from feedstock heating (heating, reheating) using 100 % natural gas are shown in Figure 1.42 (IED and non-IED plants). The data were reported from four plants (two IED plants and two non-IED plants). A total of 7 out of 19 emission points are related to IED plants. CO emission concentrations varying from 3 mg/Nm^3 to 23 mg/Nm^3 were reported for the IED plants.



Source: [169, TWG 2021]

Figure 1.41: Reported NO_X emissions per EP (in mg/Nm³) – IED and non-IED plants

NB: Values not shown in the figure: EP DE006_a {2}: 110 mg/Nm^3
Source: [169, TWG 2021]

Figure 1.42: Reported CO emissions per EP – IED and non-IED plants

1.3.4.3 Diffuse emissions to air

Diffuse emissions (mainly diffuse dust emissions) may arise during the smitheries process, from heating and machining processes. Diffuse emissions may also occur from the descaling process to remove the metal oxide layer and other impurities from the surface of the prepared material, from the deburring process, punching, etc.

If applicable, diffuse (non-channelled) dust emissions may also arise during the storage and handling of materials, e.g. from open storage and also from road surfaces because of road transport. The impact of diffuse emissions can be a local increase in the ambient concentration of particulates.

Since dust emissions and diffuse dust emissions were not identified and concluded to be a key environmental issue (KEI) at the KoM, there are no data on dust emissions to air reported.

However, several techniques for reducing diffuse emissions were reported. [169, TWG 2021]

The techniques shown in Table 1.10 below were reported.

Table 1.10: Reported techniques for reducing diffuse emissions by plants (IED and non-IED)

Techniques applied	Additional information regarding diffuse emissions
Enclosure of production equipment	• Exhaust air from the forging process is led outside through natural thermals in the hall via ridge turrets. • Working environment in the area of the hammer plants secured by measurements taken by the employers' liability insurance association: air quality in the working area conforms to the limit values. • Field test for exhaust air collection and cleaning carried out: Collection challenging (surrounding construction, vibrations, entry of sparks and flammable sawdust, used as separating agent). Technically only conditionally feasible with wet scrubber systems. • High technical expenditure for the legally compliant operation of such a large plant according to national legislation.
Enclosure of storage areas	• Storage areas only partially asphalted or concreted. Therefore, in the summer months low dust development due to dry floor covering. Factory roads are cleaned weekly. • Warm exhaust air from outdoor storage of hot forgings used.
Paving and cleaning of roads used by lorries or forklifts.	• Roads used by lorries or forklifts are paved and cleaned periodically in order to avoid diffuse dust emissions.
Capture of off-gases from heating furnaces	• Collection of furnace off-gases.
Cooling line encapsulation	• No information provided.
Appropriate material handling	• Reduction of diffuse emissions from material handling. Outdoor areas are cleaned periodically (i.e. weekly), such as roads, paths, and squares, especially in dry season.
Collection and treatment of waste gases from finishing processes	• Reuse of heat from off-gases by using recuperators.
Source: [169, TWG 2021]	

Additional useful information, e.g. regarding definitions of diffuse dust emissions, EN standards, measurement methods, can be found in the JRC Reference Report on Monitoring of Emissions to Air and Water from IED Installations (ROM). [174, COM 2018]

1.3.4.4 Noise emissions and vibrations

In smitheries, noisy machinery is used. The impact hammering noise occurs in the several steps during the smitheries process, mainly by operating noise-generating machinery and by carrying out noisy working procedures.

During smitheries operation, noise emissions and vibrations specifically occur from the forging process, the hammering process and the operation of the hammers, the cutting and sawing processes, and material transport, as reported via questionnaires. [169, TWG 2021]

Additionally, noise emissions occur during the pouring of scrap from containers of the plant into containers of the scrap disposal companies. [169, TWG 2021]

Furthermore, noise emissions may occur throughout the whole smitheries process, from preparing and processing raw materials, from material feeding to the sawing machines (billet feeder), from the heating process and the metal treatment process, from the machining and finishing processes, from material storage as well as from the dispatch and shipping of the final products. The heavy machinery and large fans used in various parts of the smitheries manufacturing process can give rise to noise and/or vibration emissions, particularly from:

- forging/hammering and any operations involving hammering;
- exhaust fans;
- blowers;
- roof ventilators;
- material storage, sorting and transportation;
- transportation equipment.

Plants are required to comply with reduction standards in compliance with national legislation, and noise surveys are conducted and evaluated in the context of immission control and workplace safety. At the process/hammering hall, the windows and doors are closed during operation. Natural noise barriers, such as office buildings, walls, trees or bushes are used in the smitheries industry to reduce noise emissions.

For the on-site transportation, noise-reduced equipment is used, such as noise-reduced forklifts.

In the data collection, permitted noise emission levels but no measured noise emission data were provided via questionnaire. However, techniques that are applied in the plants in order to reduce noise emissions and vibrations were reported.

Forging hammers produce powerful short-period impact loads. This type of shock-producing machine generates powerful dynamic effects that are relatively short in duration and can be characterised as pulses. Only a part of the shock energy is utilised in the intended machine function and the rest is dissipated in the foundation, causing intense vibration. Heavy shocks imparted to the foundation can cause alignment problems (i.e. reduce operating life), neighbour complaints and prohibit proper operation of adjacent equipment. The main objectives are to reduce the vibration amplitudes and the forces transmitted to the soil and/or to minimise any disturbance to the neighbourhood and surroundings. [164, Heidari et al. 2011]

Where residential areas are located close to a plant, the planning of new buildings at the smitheries site is connected with a necessity to reduce noise emissions and vibrations.

1.3.4.5 Monitoring of parameters and emissions

To control the heating processes of the furnaces, continuous measurements are recommended for the following parameters:

- pressure,
- temperature.

Regular periodic monitoring is appropriately carried out for the following substances:

- O_2,
- NO_X,
- CO.

Additional useful information, e.g. regarding monitoring, monitoring regimes, measurements, EN standards, can be found in the JRC Reference Report on Monitoring of Emissions to Air and Water from IED Installations (ROM REF). [174, COM 2018]

1.3.5 Emissions to water

For smitheries, water is used in small quantities, e.g. for cooling and quenching processes as well as for cleaning processes. In general, smitheries production does not generate significant amounts of waste water effluent.

Water which is used in cooling and quenching processes is directly vaporised because of the high temperatures of the product material. Furthermore, cooling using a closed cooling circuit is applied in order to avoid waste water generation.

As decided at the KoM, emissions to water is not a key environmental issue (KEI) in smitheries operations.

1.3.6 Process losses – residues

Process losses/residues originating from the smitheries manufacturing processes mainly consist of metallic residues like crop ends, burrs from the hammering process, dust arising from the manufacturing processes and collected via cleaning, oil and grease resulting from several stages of the manufacturing process as well as packaging waste.

Recycling and internal reuse of process residues generated from the hammering processes for example are applied in smitheries. [169, TWG 2021]

2 FOUNDRIES

2.1 General information on foundries

2.1.1 Sector overview

2.1.1.1 Foundry industry

TWG please update the information in this section – Please provide updated Tables and Figures with up-to-date information

Foundries melt ferrous and non-ferrous metals and alloys and reshape them into products at or near their finished shape through the pouring and solidification of the molten metal or alloy into a mould. The foundry industry is a differentiated and diverse industry. It consists of a wide range of installations, from small to very large; each with a combination of technologies and unit operations selected to suit the input, size of series and types of product produced in the specific installation. The organisation within the sector is based on the type of metal input, with the main distinction being made between ferrous and non-ferrous foundries.

The European foundry industry is the third largest in the world for ferrous castings and the second largest for non-ferrous. The total production of castings in various European countries are given in Table 2.1 and Table 2.2. Data for Northern Ireland, Luxembourg and some of the Accession Countries have not been provided, however it is known that activity in these regions is low compared to the listed regions. Germany, France and Italy are the top three production countries in Europe, with a total annual production of over two million tonnes of castings each. In recent years Spain has taken over the fourth position from Great Britain, with both having a production of over one million tonnes of castings. Together, the top five countries produce more than 80 % of the total European production.

The total European production tonnage of ferrous castings has been stable over the past five years, although some fluctuations have occurred for individual countries. For instance, the figures for Great Britain indicate a general declining trend in production output, whereas the trend for Spain is one of growth. The non-ferrous foundry sector has undergone steady growth since 1998. The total figure for 2001 is obscured by the lack of data from Great Britain. In general, it can be seen from Table 1.2 that in most countries production has risen. This holds not just for the major producing countries but also for those countries with low amounts of production.

Table 2.1: European production data for ferrous castings, i.e. iron, steel and malleable iron castings (in kilotonnes)

Country	1998	1999	2000	2001	2002	2000:2001	2001:2002
						% change	
Austria	190.1	181.7	191.4	192.4	181.2	0.5	-5.8
Belgium	144.4	149.3	149.8	149.5	143.7	-0.2	-3.9
Czech Republic	493	379.1	390.3	415.3	381.6	6.4	-8.1
Denmark	85.8	86	96.4	85.7	87.3	-11.1	1.9
Estonia	n.d	n.d	0.94	1.07	1.1	13.8	2.8
Finland	122.6	109	117.6	119.5	112.5	1.6	-5.8
France	2250.8	2146.6	2283.1	2147.4	2128.6	-5.9	-0.9
Germany	3662.9	3555.2	3758.2	3801.4	3749.7	1.1	-1.4
Great Britain	1076.3[a]	949.2[a]	968.2[a]	906.3[a]	886.3[a]	-6.4	-2.2
Hungary	78.1	68.7	74.8	62.8	67.9	-16.0	8.2
Ireland	450	480	520	275	n.d	-47.1	
Italy	1508.4	1492.6	1516.4	1433.3	1460.9	-5.5	1.9
Netherlands	140.6	121	136	132.3	123.7	-2.7	-6.5
Norway	65.3	67.7	70.1	73.4	67.3	4.7	-8.3
Poland	675	610.2	671.2	673	598.0	0.3	-11.1
Portugal	98.6	97.7	102.3	100	96.7	-2.2	-3.3
Slovakia	n.d	n.d	n.d	47.5	n.d		
Slovenia	89.8	81.9	86.9	96.3	n.d	10.8	
Spain	706.6	759.3	950.5	955.7	992.9	0.5	3.9
Sweden	264.2	253.2	266.7	244.7	234.6	-8.2	-4.1
Switzerland	122.8[b]	122[b]	119.9[b]	105.5[b]	81.8[b]	-12.0	-22.5
Total	**12225**	**11710**	**12471**	**12018**	**11396**		
Full total [c]				***12018***	***11815***		

a) Without steel castings
b) Without steel and malleable iron castings
c) Full total calculated by taking most recent available number for the years for which no data are given
NB: nd: no data
Source: [67, CAEF 2002], [100, TWG 2002]

For ferrous foundries, the progress of material substitution in recent years has caused the share of iron castings in the output total to decline slightly, dropping from 58.9 % in 2001 to 58.2 % in 2002. At the same time, producers of nodular-iron castings held a share of 34.3 % in the production total in 2002, marking an increase of 0.5 percentage points compared to 2001. Producers of malleable castings were able to expand their share from 1.1 % in 2001 to 1.3 % in 2002, while the share of steel castings in the output total ranged around 5.8 % in 2002 (5.9 % in 2001).

Table 2.2: European production data for non-ferrous metal castings (in kilotonnes)

Country	1998	1999	2000	2001	2002	2000:2001	2001:2002
						% change	
Austria	90.4	92.4	105.9	113.3	116.2	7.0	2.6
Belgium	25.3	23.8	27.2	26.3	26.7	-3.3	1.6
Czech Republic	44.8	48	57.7	58.1	59.6	0.7	2.6
Denmark	1.7[a]	4	4	4.8	4.6	20.0	-3.2
Estonia	n.d	n.d	0	0	0		
Finland	10.5	10	10	10	9.7	0.0	-3.3
France	338.2	343.8	373.9	394.7	390.3	5.6	-1.1
Germany	783.9	777	842.1	849.6	845.8	0.9	-0.4
Great Britain	121[a]	n.d	n.d	n.d	n.d		
Hungary	24.8	35	44.8	58.4	68.3	30.4	16.9
Ireland [b]	25.8	25.8	26	26.6	n.d	2.3	
Italy	832.3	832.1	959.1	960	979.7	0.1	2.1
Netherlands	n.d	n.d	n.d	n.d	n.d		
Norway	22.2	25.2	26.4	30.9	26.7	17.0	-13.5
Poland	66.5	84	84	72.2	76.3	-14.0	5.7
Portugal	17.5	21.2	22.6	25.4	25.6	12.4	0.6
Slovakia	n.d	n.d	n.d	7.6	n.d		
Slovenia	15.9	17.3	23.6	24.8	n.d	5.1	
Spain	140.7	153.6	121.1	142.1	149.9	17.3	5.5
Sweden	51.8	55.7	58.5	53.3	52.9	-8.9	-0.8
Switzerland	22.3	22.9	25.1	24.1	21.1	-4.0	-12.3
Total	**2636**	**2572**	**2812**	**2481**	**2853**		
Full total [c]				***2602***	***3033***		

a) Only aluminium
b) Only lead sheet production
c) Full total calculated by taking most recent available number for the years for which no data are given
NB: nd: no data
Source: [67, CAEF 2002], [100, TWG 2002]

The output of non-ferrous metal alloys is still dominated by light metal castings at a share of 75.1 %, despite a decline by 3.5 percentage points compared to the year before. The share of copper alloys went down from 10.1 % to 9.8 %, and the share held by the producers of zinc alloys similarly shrank from 8.7 % to 7.3 %. The difference was absorbed by miscellaneous non-ferrous metals and processes that are not detailed in the statistics.

Data on the number of foundries are given in Table 2.3 and Table 2.4. These data show that there has been a general decline in the number of foundries since 1998, with the loss of about 5 % of the existing foundries each year. This decline is also reflected in the employment numbers, as given in Table 2.5 and Table 2.6.

Table 2.3: Number of foundries (production units) for iron, steel and malleable iron casting

Country	1998	1999	2000	2001	2002	2000:2001	2001:2002
						% change	
Austria	28	26	25	24	41	-4.0	70.8
Belgium	40[a]	25	24	21	21	-12.5	0.0
Czech Rep.	n.d	n.d	n.d	140	143		2.1
Denmark	n.d	n.d	12	12	12	0.0	0.0
Estonia	n.d	n.d	1	1	1	0.0	0.0
Finland	19	23	20	19	19	-5.0	0.0
France	169	167	167	163	159	-2.4	-2.5
Germany	324	310	299	288	273	-3.7	-5.2
Great Britain	228[b]	214[b]	198[b]	188[b]	179[b]	-5.1	-4.8
Hungary	34	34	32	33	n.d	3.1	
Ireland	n.d	n.d	n.d	1	n.d		
Italy	310	307	293	291	281	-0.7	-3.4
Netherlands	22	n.d	n.d	28	n.d		
Norway	12	12	12	11	11	-8.3	0.0
Poland	234	230	230	220	190	-4.3	-13.6
Portugal	62	61	61	61	61	0.0	0.0
Slovakia	n.d	n.d	n.d	12	n.d		
Slovenia	n.d	n.d	n.d	n.d	n.d		
Spain	224	221	105	102	98	-2.9	-3.9
Sweden	48	49	49	49	50	0.0	2.0
Switzerland	23	23	23	22	20	-4.3	-9.1
Total	**1777**	**1702**	**1551**	**1686**	**1559**		
Full total [c]			***1732***	***1686***	***1633***		

a) Only members
b) Without steel castings
c) Full total calculated by taking most recent available number for the years for which no data are given
NB: nd: no data
Source: [67, CAEF 2002], [100, TWG 2002]

Table 2.4: Number of foundries (production units) for non-ferrous metal casting

Country	Total		Pressure Die Casting		Other Light casting		Other Heavy metal alloy casting	
	2001	2002	2001	2002	2001	2002	2001	2002
Austria	63	61	20	21	28	25	15	15
Belgium	12	10	3	3	6	5	3	2
Czech Rep.	58	63	39[a]	40	n.d	n.d	n.d	23
Denmark	8	8	n.d	n.d	n.d	n.d	n.d	
Estonia	0	0	0	0	0	0	0	0
Finland	22	25	4	6	11	12	7	7
France	288	283	n.d	n.d	n.d	n.d	n.d	n.d
Germany	414	400	n.d	n.d	n.d	n.d	n.d	n.d
Great Britain	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Hungary	78	n.d	23	n.d	35	n.d	20	n.d
Italy	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Netherlands	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Norway	10	13	3	3	7	6		4
Poland	290	280	n.d	n.d	n.d	n.d	n.d	n.d
Portugal	67	54	38	32	12	9	17	13
Slovakia	7	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Slovenia	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Spain	55[b]	57	n.d	n.d	n.d	n.d	n.d	n.d
Sweden	84	84	43	n.d	29	n.d	12	n.d
Switzerland	49	48	15	14	23	23	11	11
Total	**1505**	**1386**	**149**	**119**	**151**	**80**	**85**	**75**

a) Incl. all light casting
b) Only members
NB: nd: no data
Source: [67, CAEF 2002], [100, TWG 2002]

Table 2.5: Employment in the foundry industry for iron, steel and malleable iron casting

Country	1998	1999	2000	2001	2002	2000:2001	2001:2002
						% change	
Austria	3465	3314	3342	3936	3067	17.8	-22.1
Belgium	2823	2299	3260	1847	1936	-43.3	4.8
Czech Republic	n.d	n.d	n.d	17536	14847		-15.3
Denmark	n.d	n.d	1481	1393	1290	-5.9	-7.4
Estonia	n.d	n.d	125	133	129	6.4	-3.0
Finland	2326	2058	2027	2090	2045	3.1	-2.2
France	26407[a]	25714	25613	24871	24651	-2.9	-0.9
Germany	46944	45157	44896	44796	42748	-0.2	-4.6
Great Britain	24000[b]	20000[b]	18000[b]	16500[b]	15900[b]	-8.3	-3.6
Hungary	3485	3285	3175	2734	n.d	-13.9	
Ireland	502	503	509	309	n.d	-39.3	
Italy	22050	22200	22100	21400	20630	-3.2	-3.6
Netherlands	2462	2122	2119	2148	1830	1.4	-14.8
Norway	1864	1706	1730	1754	1564	1.4	-10.8
Poland	33600	28500	26800	26370	24500	-1.6	-7.1
Portugal	2649	2800	2782	2780	2710	-0.1	-2.5
Slovakia	n.d	n.d	n.d	1925	n.d		
Slovenia	n.d	n.d	n.d	n.d	n.d		
Spain	13860	14040	11803	11006	11385	-6.8	3.4
Sweden	3650	3650	3650	3800	3800	4.1	0.0
Switzerland	2400	2300	2400	2400	1930	0.0	-19.6
Total	**192487**	**179648**	**175812**	**189728**	**174962**		
Full total [c]			***195273***	***189728***	***179930***		

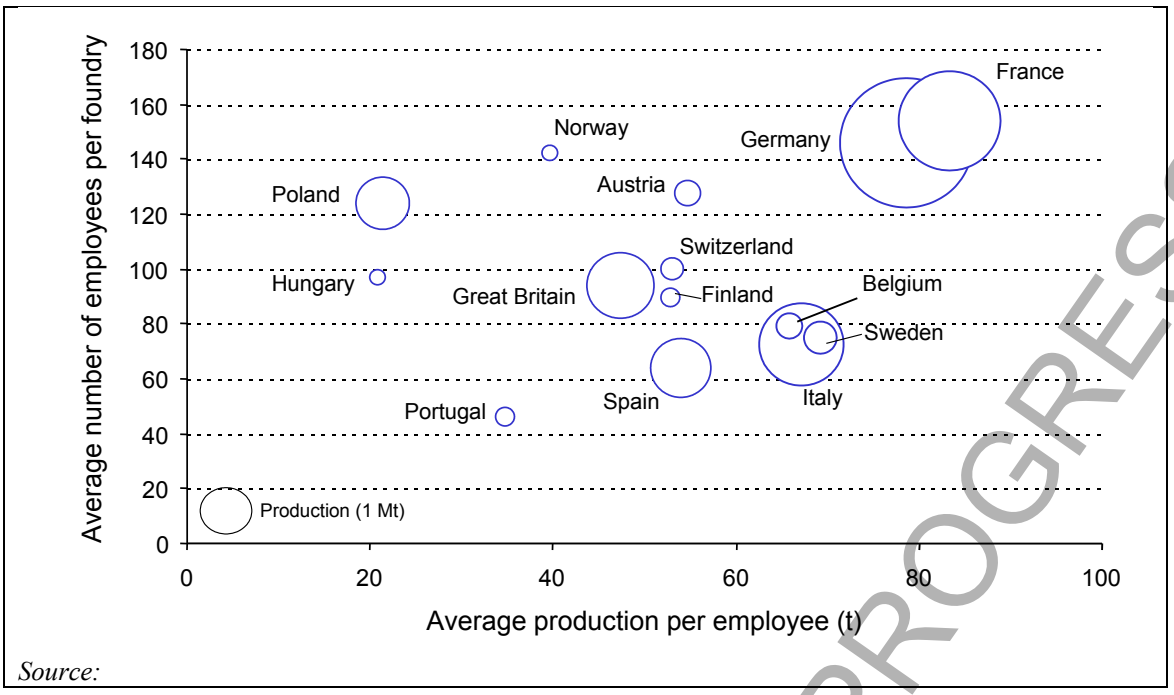
a) Break in continuity of series
b) Without steel castings
c) Full total calculated by taking most recent available number for the years for which no data are given
NB: nd: no data
Source: [67, CAEF 2002], [100, TWG 2002]

Table 2.6: Employment in the foundry industry for non-ferrous casting

Country	1998	1999	2000	2001	2002	2000:2001	2001:2002
						% change	
Austria	4029	4179	4349	4585	4398	5.4	-4.1
Belgium	1824	803	800	n.d	558		
Czech Republic	n.d	n.d	n.d	5083	5374		5.7
Denmark	n.d	n.d	377	372	349	-1.3	-6.2
Estonia	n.d	n.d	0	0	0		
Finland	708	744	884	718	730	-18.8	1.7
France	17926	17821	17651	17932	17720	1.6	-1.2
Germany	32000	33000	33000	34500	34390	4.5	-0.3
Great Britain	n.d	n.d	n.d	n.d	n.d		
Hungary	3208	3941	5503	4702	n.d	-14.6	
Ireland[a]	70	70	70	70	n.d	0.0	
Italy	n.d	n.d	n.d	n.d	n.d		
Netherlands	n.d	n.d	n.d	n.d	n.d		
Norway	1271	1411	1483	1491	1307	0.5	-12.3
Poland	4433	6500	6200	4130	4100	-33.4	-0.7
Portugal	1200	1230	1280	1380	1350	7.8	-2.2
Slovakia	n.d	n.d	n.d	845	n.d		
Slovenia	n.d	n.d	n.d	n.d	n.d		
Spain	5650	5620	4810	5034	4994	4.7	-0.8
Sweden	3700	3700	3700	3700	3700	0.0	0.0
Switzerland	1900	2000	2100	2200	1900	4.8	-13.6
Total	**77919**	**81019**	**82207**	**86742**	**80870**		
Full Total [b]			***88135***	***87300***	***86487***		

a) Only lead
b) Full total calculated by taking most recent available number for the years for which no data are given
NB: nd: no data
Source: [67, CAEF 2002], [100, TWG 2002]

The tables show that European production levels are relatively stable or are slightly rising but that this production now results from fewer units and less employees. This can be explained by progressive upscaling and automation in the foundry units. The relationship between unit size, production and employment is well illustrated in Figure 2.1. This shows that the larger West-European producers (Germany, France) are attaining higher productivities with fewer people. The more labour-intensive units are found in the Eastern and Southern part of Europe (Poland, Hungary, Portugal).



Source:

Figure 2.1: Ferrous foundry productivity data for various European countries the size of the circle represents the total production in the specified country

The casting of metal is an ancient activity, dating back to more than 3000 BC. The development of the European foundry industry is linked with the development of both the metal and the automotive industries. Present foundries often have a history dating back to the beginning of the 20th century. Originally they were usually located on the outskirts of towns, but as villages and cities have grown around them they are now often surrounded by habitation. The foundry industry is basically an SME industry, with 80 % of companies employing less than 250 people. Since castings in general are semi-finished products, foundries are located close to their customers.

2.1.1.2 Foundry markets

TWG please update the information in this section – Please provide updated Figures with up-to-date information

The main markets served by the foundry industry are the automotive, general engineering and construction sectors. The relative shares of these sectors as markets for the foundry industry are given in Figure 2.2. The high dependence on the automotive sector has a major influence on activities in the foundry sector, and concerns various aspects, such as economy, location, quality standards, environmental standards, new developments, etc. One example of this dependency is that the automotive industry's shift towards lighter vehicles, is reflected in the foundry industry by an increased demand (and thus market) for aluminium and magnesium casting, thus enabling the growth of these sectors.

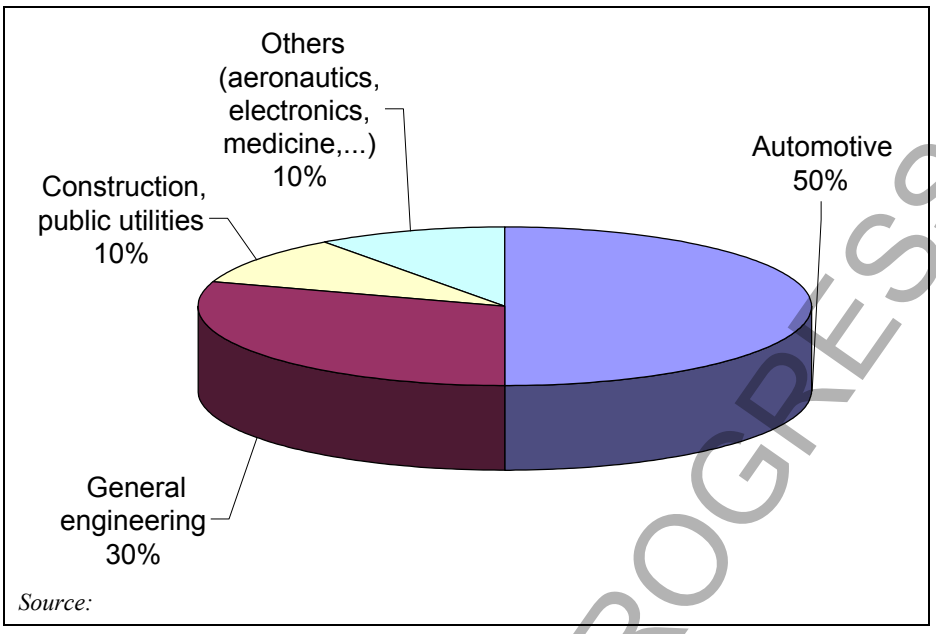


Figure 2.2: Relative sectoral market shares

The market shares differ according to the type of metal. This is illustrated by data from the Spanish foundry market, as shown in Figure 2.3 and Figure 2.4. The automotive sector takes up more than 60 % of all iron castings from Spanish foundries. Steel castings on the other hand (including low alloyed as well as stainless and other alloys) are used for machine parts and in valve making, and therefore serve a broader range of sectors. Indeed, the largest share of the market for valve making is taken up by stainless castings.

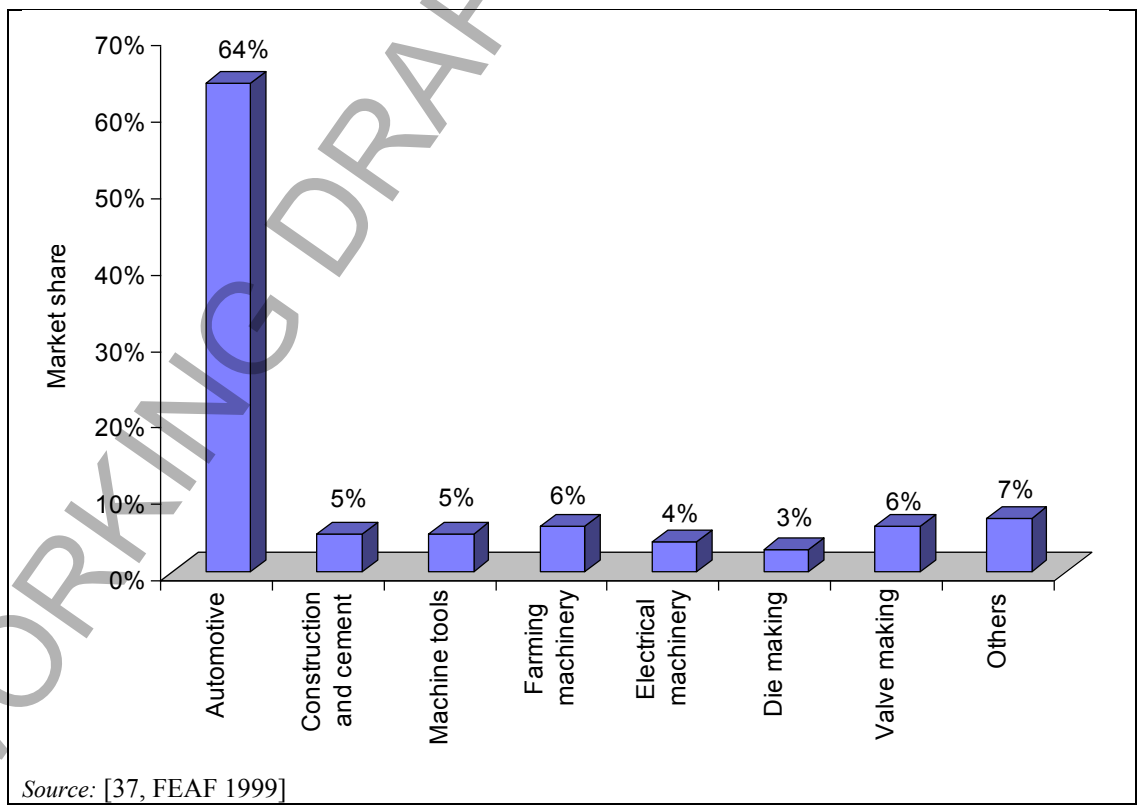
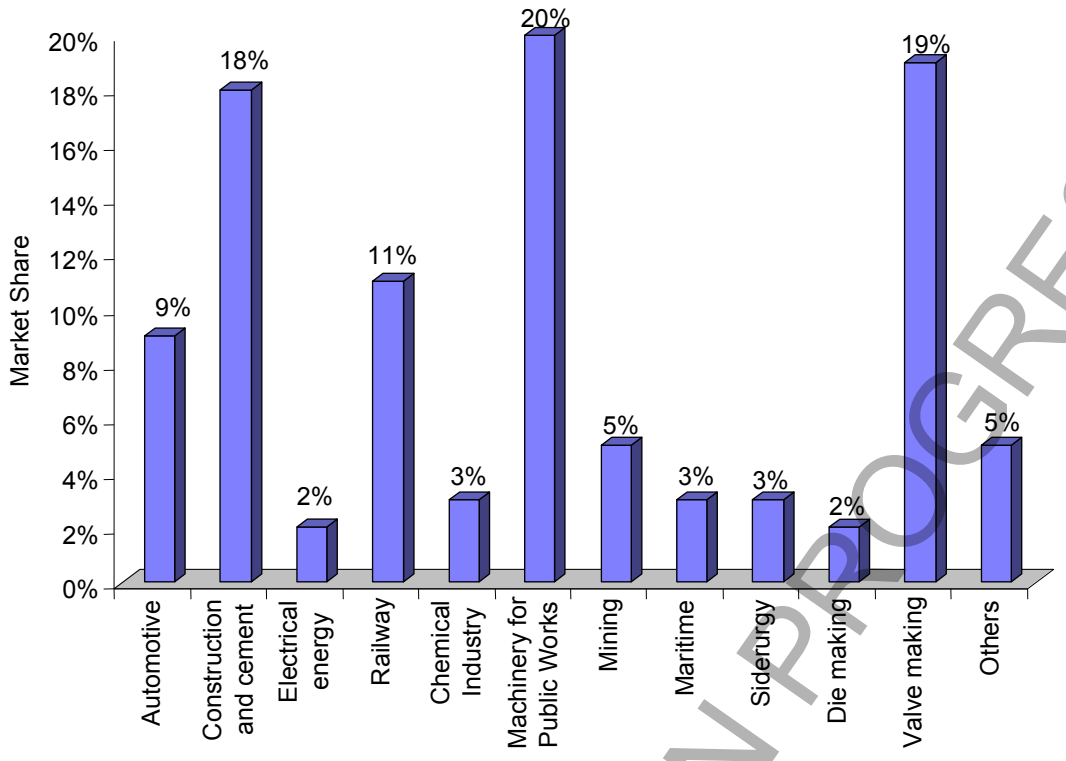


Figure 2.3: Market shares for iron castings (data for Spanish market)



Source: [37, FEAF 1999]

Figure 2.4: Market shares for steel castings (data for Spanish market)

The opening of Europe towards the East has led to the big European producers showing a growing interest in the existing foundry activity in countries such as Poland, the Czech Republic and Hungary. Some of the big European companies have invested in these regions. For the East European countries, the opening of their markets combined with inward foreign investment has allowed the implementation of new techniques, thereby increasing productivity and reducing their effects on the environment. Due to the low labour costs in these countries, their competitive strength lies in jobbing foundries, mainly producing large castings, and in foundries producing a broad range of products. To compete on the world market, West-European foundries now focus on their technological skills, selecting niche markets which require complex castings with high precision, specific quality requirements, or those that require quick or just-in-time delivery.

2.1.1.3 Foundry types

Besides the metal type (i.e. ferrous/non-ferrous) the foundry layout is largely dependent on the size of castings and the series size. ~~A small series foundry is termed a 'jobbing foundry' and a large series one is termed a 'series foundry'.~~ Foundries may be also be classified according to the type of metal manufactured, i.e. either a ferrous or a non-ferrous foundry. There is a large difference between a zinc foundry producing a large series of frames for toy cars and a cast iron foundry producing rotor housings for wind turbines. Foundries apply different degrees of automation according to their series size and the repeatability of the work. Concerning applied techniques, the main distinction is made by the type of melting furnace used (e.g. cupola, electrical, rotary) and the type of mould (e.g. sand moulding, die-casting). These will be described and discussed further in Chapter 3.

A classification of the different foundry types has been developed by the industry's foundry sector and consists of five different clusters including:

- iron foundries for serial production (including centrifucal casting): these foundries usually employ automatic moulding techniques and manufacture small castings;
- iron foundries for single castings (including continuous casting): these foundries usually employ manual moulding techniques and manufacture large castings;
- steel foundries;
- non-ferrous metal foundries employing sand casting technqiues;
- non-ferrous metal foundries employing gravity casting or low-pressure die casting (including continuous or centrifugal casting);
- non-ferrous metal foundries employing high-pressure die casting.

The different foundry types according to the cluster classification and information on their respective operations and specificities are presented in Table 2.7.

Table 2.7: Typical types of foundries – cluster classification

Criteria	Iron foundry, serial production (incl. centrifugal casting)	Iron foundry, single castings (incl. continuous casting)	Steel foundry	Non-ferrous foundry, sand casting	Non-ferrous foundry, gravity casting or low-pressure die casting (incl. continuous and centrifugal casting)	Non-ferrous foundry, high-pressure die casting
Casting material	Grey iron, nodular iron, white iron	Grey iron, nodular iron	Alloyed or non-alloyed steel	Alloys based on aluminium, copper or magnesium	Alloys based on aluminium, copper or lead	Alloys based on aluminium, magnesium, zinc or copper
Typical products	Automotive parts, e.g. brake disc. Parts for mechanichal engineering, Wear resistance parts	Machine parts, e.g. wind turbine parts, rolls, engineblocks	High strength or corrosion resistant castings, e.g. pump components, heat resistant parts, wear resistance parts	Automotive or other use, e.g. fittings. Bushings, bearings, marine parts, engineering parts	Automotive parts, e.g. cylinder heads. Counterweights, bushings, bearings, marine parts	Automotive and machine parts, e.g. motor blocks. Handles, enclosures, marine parts, couplings, valves
Melting furnace; raw materials	Cupola or induction furnaces; pig iron and clean scrap	Cupola or induction furnaces; pig iron and clean scrap	Arc air furnace or induction furnaces; clean scrap	Induction furnaces, resistance furnaces, gas or oil fired furnaces; refined alloys, clean scrap	Induction furnaces, resistance furnaces, gas or oil fired furnaces; refined alloys, clean scrap	Induction furnaces, resistance furnaces, gas or oil fired furnaces; refined alloys, clean scrap
Foundry tooling (repairing)	Pattern and core box material: metal	Pattern and core box material: wood or plastic	Pattern and core box material: wood, plastic or metal	Pattern and core box material: wood, plastic or metal	Core box material: metal; die material: steel	Die material: steel
Sand moulds, sand system or permanent moulds (dies)	Automatic moulding plant, green sands	Hand moulding or mechanised moulding plant, Self curing organic- or in-organic binder	Hand moulding or mechanized moulding plant, self curing organic binder	Automatic moulding plant, green sands, self curing organic- or in-organic binder	Gravity or low-pressure die casting machines	High-pressure die casting machines
Core-making, sand system	Core shooting machines, organic sand binders, gas curing binder	Hand moulding, self curing organic binder	Hand moulding, self curing organic binder or core shooting machines, gas curing organic binder	Core shooting machines, self curing organic or in-organic binders, gas or heat curing organic binder	Core shooting machines, inorganic or organic binders, gas or heat curing	No core-making
Fettling	Automatic shot blasting and mechanised grinding	Shot blasting and grinding mechanised or by hand	Shot blasting and grinding, mechanised or by hand	Shot blasting, automatic or mechanised grinding, mechanised or by hand	Automatic sawing and mechanised grinding	Automatic cutting

Source: [173, CAEF et al. 2020]

2.1.2 Environmental issues

The foundry industry is a major player in the recycling of metals. Steel, cast iron and aluminium scrap can all be remelted into new products. The possible negative environmental effects of foundries result from the presence of a thermal process and the use of mineral additives. The environmental effects of a foundry process therefore mainly relate to the exhaust and off-gases and to the reuse or disposal of mineral residues.

2.1.2.1 Air

Noxious emissions from the melting and treatment of metals are generally related to the use of additives and fuels or to impurities in the feed. The use of cokes as fuels or the heating of crucibles with gas or oil-fired burners can cause emissions of combustion products. Also, the application of additives in metal treatment processes generates reaction products. The presence of impurities (e.g. oil, paint) in scrap used for remelting can potentially cause the production of the products of incomplete combustion or recombination and dust. Also any dust generated may contain metal and metal oxides. The evaporation of elements with a high vapour pressure occurs during melting and small particles of metal escape from the bath. Metallic particles are also generated during grinding and finishing operations.

In the making of moulds and cores, various additives are used to bind the sand. In the binding of the sand and pouring of the metal, reaction and decomposition products are generated. These include both inorganic and organic products. The generation of decomposition products further continues during the casting, cooling and de-moulding operations.

Dust and particle releases are a general issue in all stages of the foundry process, and for all processes used. Dust is generated in the production and processing of sand moulds and cores, as well as in the finishing of the castings (both from lost moulds and permanent moulds).

In the foundry process, emissions to air are not limited to one (or several) fixed point(s). The process involves various emission sources (e.g. from hot castings, sand, hot metal). ~~A key issue~~ A key issue for a sustainable reduction of emissions are primary measures integrated in the processes, e.g. the usage of clean scrap or of emission-reduced binders in combination with secondary measures, i.e. techniques for capturing and treating the exhaust and off-gas flow.~~in emission reduction is not only to treat the exhaust and off-gas flow, but also to capture it.~~

2.1.2.2 Residues

Sand moulding involves the use of large sand volumes, with sand-to-liquid-metal weight ratios generally ranging from 1:1 up to 20:1. At the end of the moulding process the used sand can be regenerated, reused or disposed of. Modern techniques for sand preparation and regeneration lead to reuse rates of more than 90 %. Additional mineral residues such as slag and dross are generated in the melting stage when removing impurities from the melt. These should also be considered for either recycling~~use~~ or disposal.

2.1.2.3 Energy

Since foundries deal with a thermal process, energy efficiency and management of the generated heat are important environmental aspects. There are a lot of techniques applied in foundries for energy saving and heat recovery. However, due to the high amount of transport and handling of the heat carrier (i.e. the metal) and due to its slow cooling, the recovery of heat is not always straightforward.

2.1.2.4 Water

In most foundries, water management involves an internal circulation of water, but a major part of the water still evaporates. The water is generally used in the cooling systems of electric furnaces (induction or arc) and cupola furnaces. In general, the outgoing waste water stream is therefore very small. For (high-)pressure die-casting, a waste water stream is formed, which needs treatment to remove organic (phenol, oil) compounds before disposal.

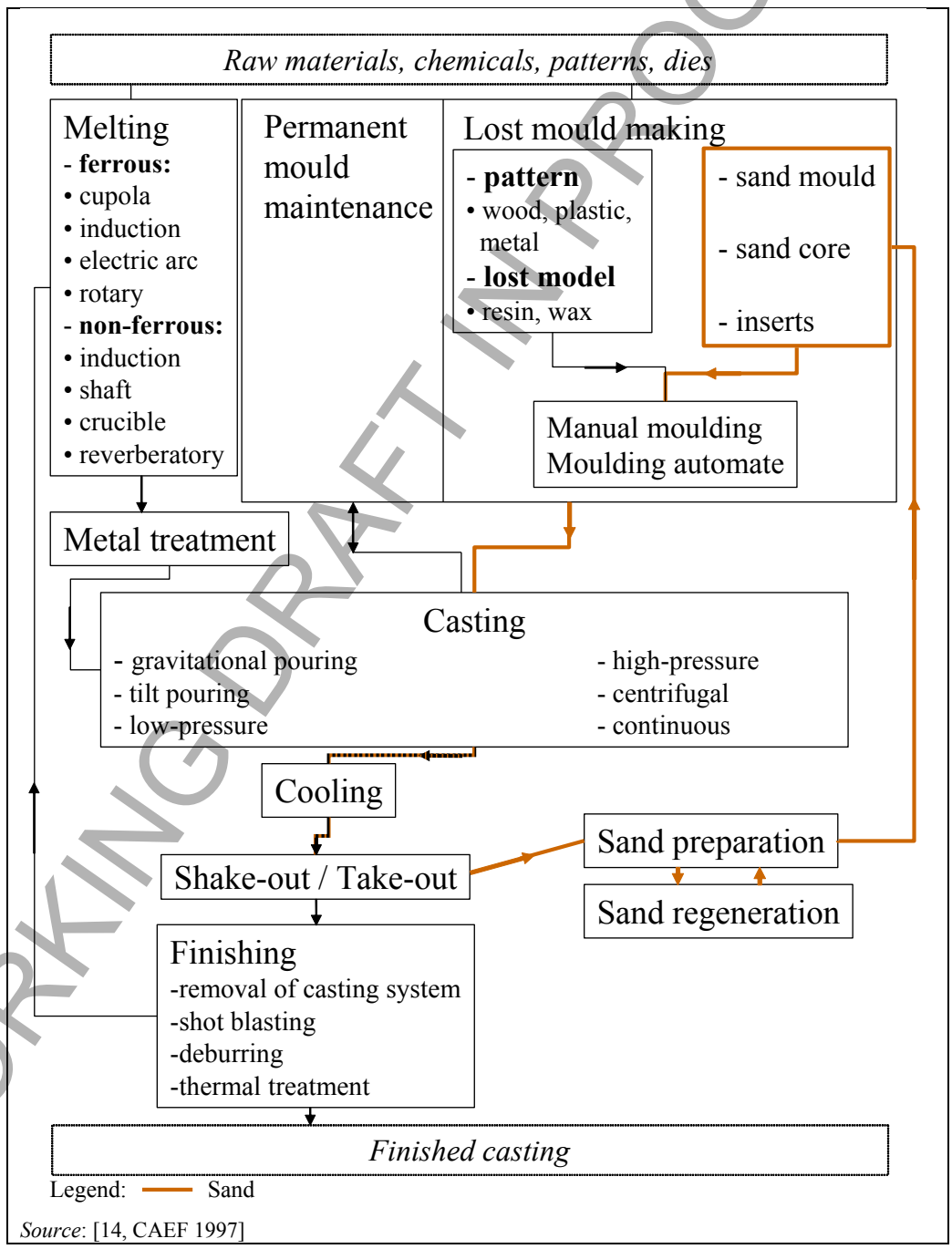
2.2 Applied processes and techniques in foundries

2.2.1 Overview

2.2.1.1 The foundry process

A general flow chart of the foundry process is depicted in Figure 2.5. The process can be divided into the following major activities:

- melting and metal treatment: the melting shop;
- preparation of moulds: the moulding shop;
- casting of the molten metal into the mould, cooling for solidification and removing the casting from the mould: the casting shop;
- finishing of the raw casting: the finishing shop.



Source: [14, CAEF 1997]

Figure 2.5: The foundry process

Starting from foundry scrap (selected scrap according to a certain chemical composition) or ingots, the foundry produces finished castings. Usually these are components which will require further treatment or assembly to yield a final product.

On the moulding side, a basic distinction is made between permanent and lost moulds. Foundries casting in permanent moulds buy these metal moulds (dies) externally, but typically operate an in-house mould repair and maintenance shop. Foundries casting in lost moulds often buy wooden, metal or plastic patterns (for their mould design) and operate an in-house pattern maintenance and repair shop. Moulds, cores and lost models are generally produced as part of the foundry process.

Traditionally in the foundry sector the main distinction made is between ferrous and non-ferrous foundries. This is mainly because the applied processes in both sectors differ. Non-ferrous foundries often apply die-casting techniques. These allow a better surface finish, which is important for many of the aluminium and brass applications. Due to the high cooling rate, castings with a high mechanical strength are produced. However, this technique does not allow the production of massive or large pieces, which require sand casting techniques. Sand casting techniques are applied in non-ferrous foundries for those products that are not produced in large series. The non-ferrous metals (and their alloys) discussed in this document are:

- aluminium;
- magnesium;
- copper;
- zinc;
- lead.

Ferrous foundries generally apply the lost mould techniques. Due to their greater stiffness and strength, ferrous alloys are used in different applications to non-ferrous alloys. The size of the products that can be produced is almost unlimited. Ferrous metals have a higher melting point and therefore require different melting techniques. The ferrous metals and alloys discussed in this document are the various types of cast iron (which may be classified according to their properties or by the graphite type) and cast steel.

Superalloys with a high content of alloying elements, such as nickel, will also be discussed.

Foundries utilise mechanisation and automation depending on the need for reproductivity and on the series sizes. The most flexible installation is typically the ‘single castings’ foundry (small series foundry ~~is termed a~~ also called ‘jobbing foundry’). This produces a variety of products in small numbers (< 100). In general, this type of foundry applies manual moulding techniques with resin-bonded sand moulds. The melting furnace works batch wise to allow an easy change of alloy. This implies the use of induction or rotary furnaces.

For medium-sized series (< 1 000 parts), mechanised moulding and casting lines are used. Lost mould foundries utilise mould making machines. This implies the use of green sand, which allows fast mould making. The size of the mould making machine limits the maximum size of the castings. Casting can be performed manually or by using a pouring machine. Auxiliary side processes, such as sand preparation, are operated in a semi-automated way with remote control. Both continuous furnaces (cupola, shaft) and batch furnaces are used. For non-ferrous alloys, die-casting techniques are applied.

Large series of small castings are often made in flaskless green sand moulding. For specific applications, die-casting also can be used in ferrous foundries if the final casting quality requires it, although in reality the technique finds only limited implementation. The main difference for medium-sized series is the further automation of the finishing, the quality control and the mould assembly. For die-casting in non-ferrous alloy facilities, further automation is often applied, this is especially the case in pressure die-casting shops.

Specific casting techniques, such as full mould casting, centrifugal casting and continuous casting are applied where the product type requires it.

Regarding emissions to air, various process steps in the foundry have the potential to produce dust, fume and other gases, e.g. material storage, handling and processing. Techniques to reduce emissions to air involve prevention, minimisation and ~~fume~~ off-gas collection and treatment.

~~Furnace sealing (or the use of sealed furnaces) combined with process control may be applied to prevent or contain emissions from a process plant. Sections 4.5.2 – 4.5.6 covering furnaces indicate where furnace sealing is possible and where other collection techniques may be used to provide integral gas collection.~~

~~Other techniques are available to collect the emissions that cannot be prevented or contained. Gases and fumes that escape from the processes are released into the working area and then escape into the surrounding environment. They may affect operator health and safety and contribute to the environmental impact of the process. Process gas collection techniques are used to prevent and minimise these fugitive emissions. Hoods are designed to be as close as possible to the source emission while leaving room for process operations. Movable hoods are used in some applications. Some processes use hoods to collect primary and secondary fumes.~~

~~Fugitive emissions may be very important, but are hard to measure and quantify. Methods of estimating ventilation volumes or deposition rates can be used to estimate them. One reliable method, which has been applied to primary copper smelting, shows that the magnitude of fugitive emissions can be much more significant than collected and abated emissions. Fugitive emissions can be more than two to three times the quantity of controlled emissions. [1, COM, 2017]~~

The melting shop, core-making shop, sand plant and post-casting shop are considerable sources of emissions. The emitted air pollutants are mainly dust (possibly with heavy metal particles), sulphur dioxide, carbon monoxide and odorous organic compounds. Table 2.8 gives the results of a survey of the pollutants generated in the different parts of the ferrous foundry process. Both inorganic and organic compounds are listed as individual and group compounds. Dust emissions are of specific importance, since thermal processes can generate considerable amounts of heavy metals.

Table 2.8: Survey of air emissions from different ferrous foundry stages

SOURCE ⇨ / RELEASES ⇩	Raw material storage and handling	Furnace operations	Desulphurisation of molten iron	Nodularisation	Preparation of cores and moulds	Casting	Shake-out, reclamation	Fettling, dressing and finishing of castings
Oxides of sulphur		X	X		X	X	X	
Oxides of nitrogen		X			X	X	X	
Carbon dioxide		X	X	X	X	X	X	
Carbon monoxide		X	X	X	X	X	X	
Hydrogen sulphide					X	X	X	
Ammonia					X	X	X	
Oxides of iron		X	X	X		X	X	X
Alkali metal compounds		X	X					
Alkaline-earth metal compounds		X	X	X		X		
Metal oxide particulates		X	X	X		X	X	X
Non-metallic particulates	X	X	X		X	X	X	X
Metallic iron		X						X
Hydrogen cyanide					X			
Sulphur			X					
Amines/amides					X	X		
Dioxins		X						
Volatile organic compounds		X			X	X	X	
Acid vapours		X			X	X		
Noise		X			X		X	X

Substances include their compounds, except where separate reference to the compound is made.

Releases to air may also be released to land or water, depending upon the abatement technology employed, e.g. via collected dusts, sludges or liquors.
Some releases are specific to a particular binder system
Source: [62, UK Environment Agency 2002]

Techniques to minimise emissions are discussed in Section 3.

~~The principles and techniques for waste gas collection and treatment are the same for foundries and (primary) non-ferrous metal industries, therefore for a full discussion of the principles the reader is referred to the BREF document on non-ferrous metal industries. Section details a short survey of the techniques that apply.~~

2.2.1.2 Iron casting

Cast iron is an iron-carbon alloy, containing usually between 2.4 % and 4 % carbon. The minimum carbon content is 1.8 %. Silicon, manganese, sulphur and phosphorus are also present in various amounts. Special grades of iron are produced which contain various levels of nickel, chrome and other metals. Due to its high carbon content, cast iron has a low melting point and a good casting ability as compared to steel. Its ductility is low and does not allow rolling or

forging. Variations in properties can be achieved by varying the ratio of carbon to silicon, by alloying, and by heat treatment.

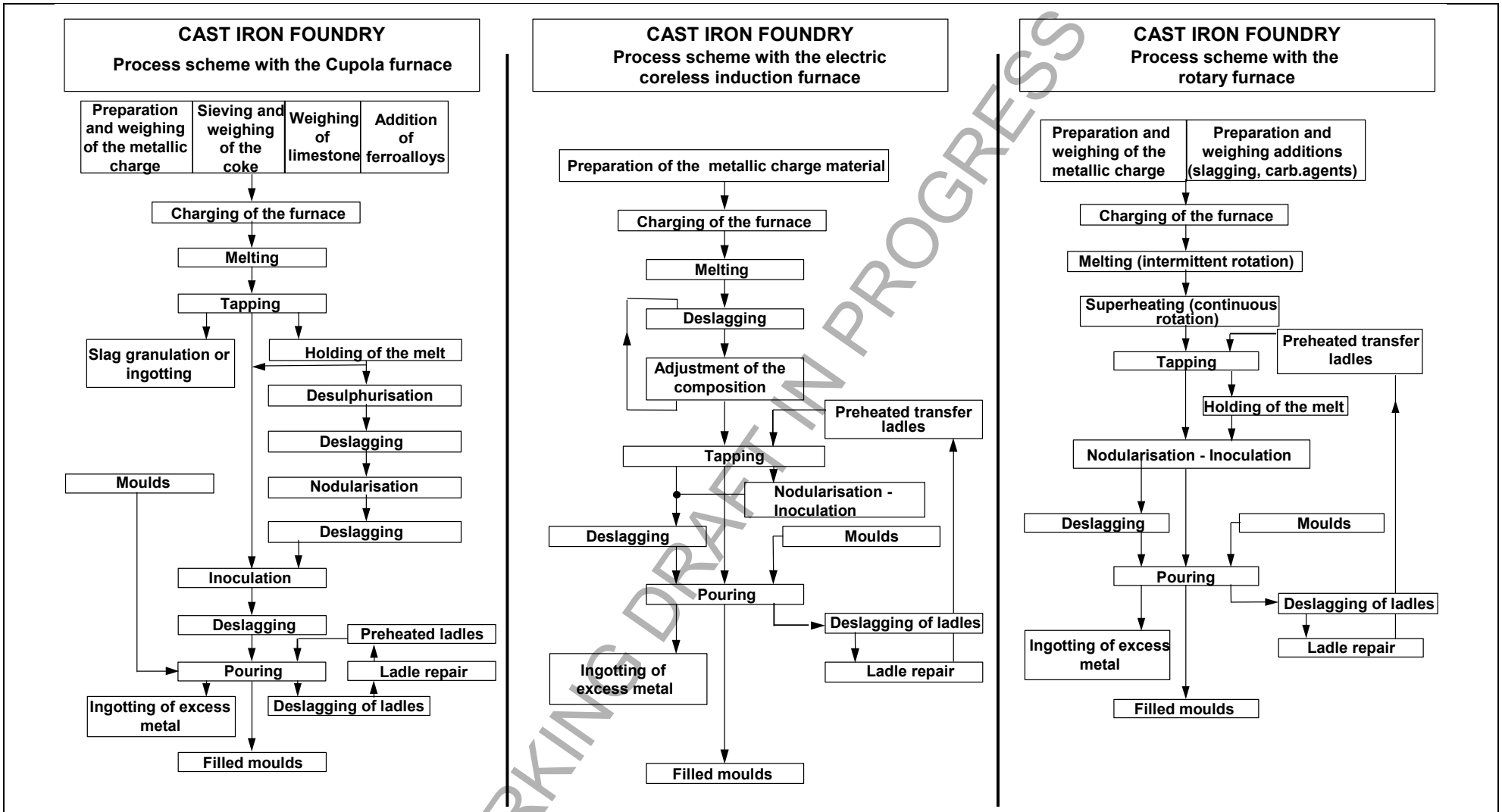
Depending on the concentration and form of the carbon (lamellar, spheroidal or compact), various types of cast iron may be defined:

- lamellar iron: carbon in the form of flakes;
- nodular iron: carbon in spheroidal form;
- compact graphite iron: carbon in bonded form.

The classification of cast iron is often made according to its material properties:

- Grey iron: iron with a grey fracture surface. Although this applies for lamellar, nodular and compact graphite iron, the term is commonly used as a synonym for lamellar iron.
- Ductile iron: cast iron with an increased ductility. This is one of the effects caused by nodularisation, but it also applies to malleable iron. The term is commonly used as a synonym for nodular iron.
- Malleable iron: typical technical properties of malleable iron are increased ductility and weldability. A special kind of heat treatment is required to produce white or black malleable iron. ~~iron that is capable of extension or of being shaped under the hammer. This property is related to a low carbon content, which leaves most of the carbon in bonded form.~~

Cast iron can be melted in the cupola furnace, induction furnace (generally of coreless type, but very occasionally can be the channel type) or in the rotary furnace. The electric arc furnace is only very rarely used for the preparation of cast iron. Figure 2.6 gives process flow diagrams for the melting and metal treatment of cast iron in the three different furnace types. The process generally consists of melting – tapping – metal treatment – pouring. The various aspects of melting and metal treatment are discussed in the following sections. Metal treatment involves various steps such as desulphurisation, nodularisation, inoculation and deslagging. The desulphurisation step in cupola melting may also be incorporated into the nodularisation, e.g. by using a nodularisation process which simultaneously takes up the sulphur, such as the core wired process.



Source: [14, CAEF 1997]

Figure 2.6: Process flow diagrams for the melting and metal treatment of cast iron

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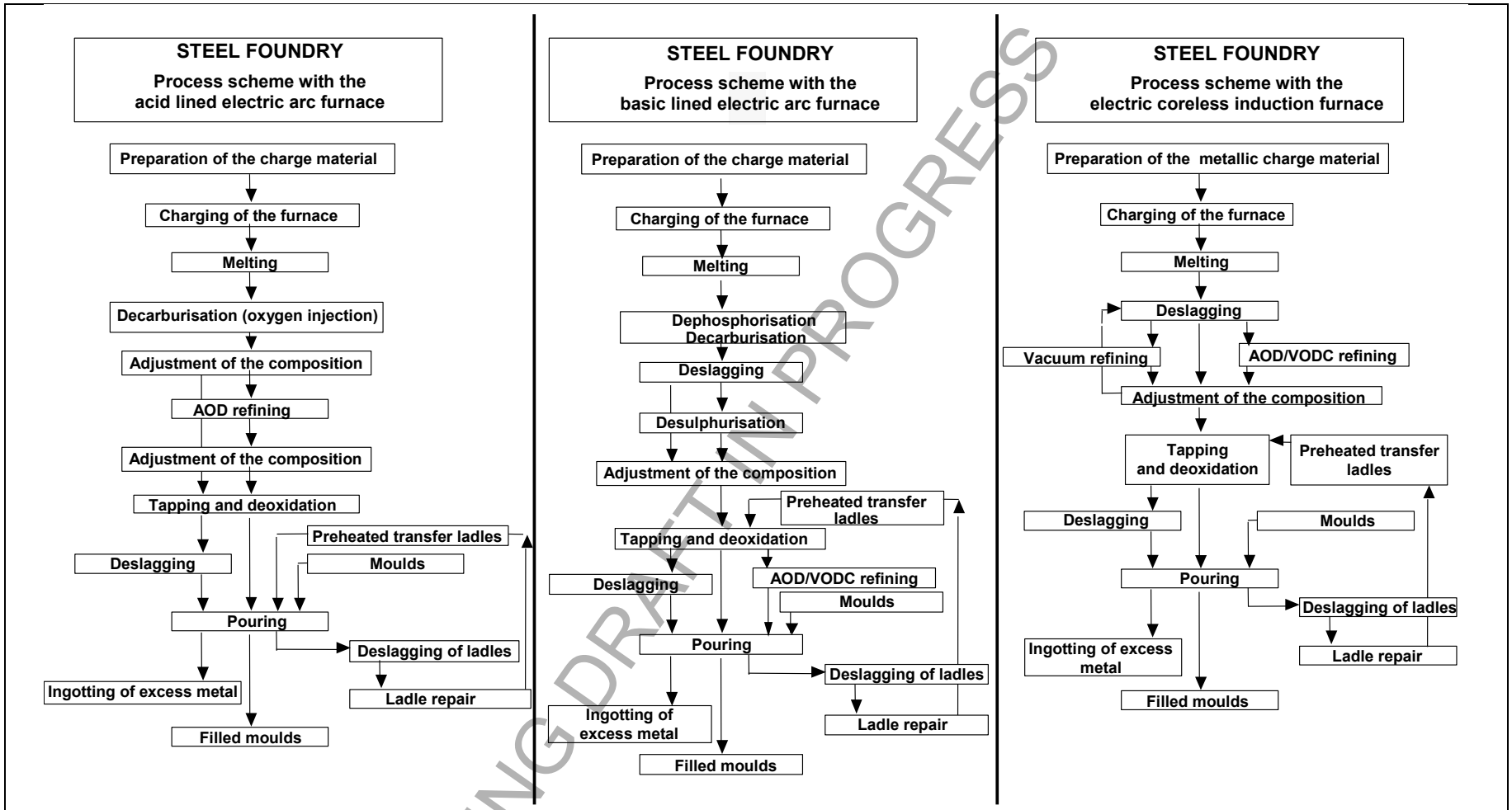
The cupola is the leading device for remelting iron in Europe. It is responsible for about half ~~some 55 %~~ of the tonnage of iron castings produced in western Europe. Nowadays, the cupola is increasingly facing major challenges to its market domination. This is partially due to its flue-gas quality, which requires treatment. Faced with the possible financial burden of investing in, and then depreciating, a stack gas treatment installation, many small and medium sized units have turned to electric or ~~oxygas~~ melting units with oxy-fuel combustion. Thus the number of cupolas used in foundries is falling, but their average size is increasing. There have been major changes in the market for cupolas in Europe~~ in recent years~~, particularly due to the restructuring of the coke industry, leading to a decreased number of suppliers and a need to import coke into Europe. Another major change is the smaller number of cupola manufacturers, with one German firm having a quasi-monopoly in the hot blast type.

The majority of repetitive iron castings are made in green sand moulds with resin-bonded cores. The cold-box amine ~~and hot-box~~ technique~~s are~~ is most widely used. The 'Croning resin shell' moulding process is used where a high precision and good surface finish are needed. The Lost Foam process is used to a limited extent, for repetition castings. Castings made in smaller numbers (e.g. big castings) are made in chemically bonded sand moulds. Special sand processes, such as vacuum moulding and full moulding are used for certain iron castings. There are also a few permanent moulding (die-casting) foundries making iron castings, but the high temperature of the iron melt ~~short die-life of a mould~~ limits its production capacity to ~~making~~ only a few thousand components and therefore has restricted the use of ferrous die-casting.
[59, Godinot 2001], [73, Brown, J. R. 2000], [133, DE UBA 2014]

2.2.1.3 Steel casting

Steel is a material of which the (mass) content of iron is bigger than that of any other element, with a carbon content generally lower than 2%, and which also usually contains other elements. A limited number of chromium steel types may contain over 2 % carbon, but 2 % is the usual cut-off limit used to distinguish steel from cast iron [201, CEN, 2000]. One particularly useful aspect of steel is that it can be hot worked. Low alloy cast steel contains elements such as Mn, Cr, Ni, and Mo in amounts less than 5 %. High alloy steel includes more than 5 % of alloying elements, e.g. 12 % Cr and 8 % Ni. Special steel grades are produced with enhanced properties, such as higher strength; higher magnetic permeability; better resistance to corrosion, fatigue or wear; and improved behaviour during welding or at high or low temperatures.

Cast steel is normally melted in electric arc furnaces (EAF) or in coreless induction furnaces (IF). Once melted, the liquid metal can be refined (i.e. removal of carbon, silicon, sulphur and or phosphorus) and deoxidised (i.e. reduction of metallic oxides), depending on the base material and the quality requirement of the finished product . Figure 2.7 gives process flow diagrams for the melting and metal treatment of cast steel in the different furnace types.
[14, CAEF 1997]



Source: [14, CAEF 1997]

Figure 2.7: Process flow diagrams for the melting and metal treatment of steel

2.2.1.4 Aluminium casting

TWG please update the information below

About two thirds of all aluminium castings are used in the ~~automotive~~ transportation industry, e.g. in cars, buses, lorries, trains and aircraft. The need to reduce vehicle fuel consumption and weight has increased the interest in aluminium. the amount of aluminium used per car produced in Europe almost tripled between 1990 and 2012, ,The total mass of aluminium in a European car roughly tripled ~~doubled~~ between 1990 and 2012~~00~~, increasing from 50 kg to 140 kg. Information from industry (European Aluminium, 2019) stated that this amount was predicted to rise to 160 kg by 2020. This growing use of aluminium in its major user sector clearly has an effect on the overall number of castings produced.

Aluminium is mainly cast into permanent moulds. The relative share of applied casting techniques for aluminium are given in Table 2.9.

Table 2.9: Relative shares of applied casting techniques for Al

Casting type	Relative share (%)
Pressure die-casting	59
Low-pressure die-casting & gravity casting	37
Sand casting	3
Others	1
Source: [49, Inasmet and CTIF 2002], [120, TWG 2003], [134, CAEF 2020]	

Many different types of melting furnaces are used in aluminium foundries the choice depending on individual requirements. Directly and indirectly heated furnaces, using fuel and electricity, are applied. The fossil fuels currently used are natural gas, liquid petroleum gas (LPG) and oil. Natural gas is favoured by most foundries on convenience grounds. Electrical heating may be provided by either resistance elements or by induction. Capacity is one of the most important parameters for melting and holding furnaces. Today induction furnaces are normally used when a high melting capacity, e.g. above 10 tonnes/hour, is needed. Shaft melting and holding furnaces, as well as crucible furnaces, are often used when the melting capacity is less than five tonnes/hour. Small and medium crucible furnaces are often used when it might be necessary to be able to change the alloy easily or if the production rate is low.

For holding, electric furnaces have the advantage of not producing burner off-gases and being able to sustain a homogeneous temperature over the whole molten volume, at a relatively low energy expense.

Aluminium melting in foundries generally uses alloyed ingots as a starting material, although in some cases the metal is delivered already as a liquid. The secondary melting of aluminium scrap is usually not performed in foundries and falls outside the scope of this document. It is discussed in the BAT reference document for the non-ferrous metals industries.
[24, ETSU 1994] [52, Eurofine 2002], ~~[155, EuropeanIPPC Bureau, 2001]~~ [1, COM 2017]

2.2.1.5 Magnesium casting

Magnesium alloy castings are used for aerospace, automotive and electronic applications. The main advantage for using them is their light weight; typically magnesium alloys have a density of 1.8 g/ml compared with 2.7 g/ml for aluminium alloys. Aluminium is the principle alloying constituent of magnesium-based casting alloys, with zinc and manganese also present in small amounts. Pressure die-casting is the most commonly used casting process, due to the low casting temperature (650-700 ºC); both hot chamber and cold chamber die-casting machines are used. Sand moulding is applied to a lesser extent. Magnesium die-castings can be made with thinner walls than aluminium, but their use is limited by stiffness problems. The thinner walls allow the overall weight of the components to be substantially reduced, thus compensating for

the higher alloy cost per kilogram. Gravity die-casting and sand casting are also used, particularly for more highly stressed castings. The use of magnesium alloy die-castings in automotive components is growing rapidly, with some vehicles already containing 10-20 kg of Mg components. The most popular parts made at present are instrument panel substrates, cross car beams, wheeldrives and seat frames.

Molten magnesium alloys attack firebrick and refractory furnace linings, resulting in harmful silicon contamination. Therefore steel crucibles are used. Iron is also slightly soluble in magnesium but it has a much less harmful effect than silicon. Scrap is usually cleaned and if possible shot blasted to remove any adhering sand as a further precaution against silicon pick-up. To eliminate ladling, the molten alloy is, if possible, poured direct from the melting pot.

Due to its very easy oxidation, magnesium alloys are melted under a cover using a cleansing flux or cover gas, to avoid oxidation losses and to prevent inclusions. Inhibitor powders are used to cover any exposed metal during holding and pouring, and are added to moulding-sand to prevent chemical reactions. The fluxless melting of Mg alloys requires another form of melt protection. For this purpose, SO_2 or mixtures of nitrogen and 1,1,1,2-tetrafluoroethane (R134a) or of nitrogen, CO_2 and/or SO_2 or of sulphur and argon is used in magnesium die-casting foundries as inert gas. Magnesium shielding gases usually consist of a reactive and carrier gas. The use of R134a (1,1,1,2-tetrafluorourethane) results in the formation of a MgF_2 protective layer. It is also noted that R134a has a high Global Warming Potential (GWP) of the order of 1 430. The use of SO_2 results in protective $MgSO_4$, MgS and MgO phases ~~sulphur hexafluoride (SF_6) is used, as it promotes the formation of a protective film on liquid magnesium,~~ which prevent oxidation. The use of sulphur hexafluoride (SF_6) in magnesium die-casting and in the recycling of magnesium die-casting alloys is prohibited by Regulation (EU) No 517/2014 on fluorinated greenhouse gases as of 1 January 2018. ~~It is used at low concentration (<0.3 vol %) in a mix with air or air/CO_2. SF_6 is a greenhouse gas, considered harmful to the atmosphere and falls under the Kyoto protocol, which requires its use to be minimised. Austria and Denmark have issued regulations to ban the use of SF_6 by 2003 and 2006, respectively.~~

Magnesium alloys benefit from grain refinement, which is carried out by inoculation with carbonaceous materials. This used to be done with hexachloroethane, but since 1 July 2003 this product is banned in Europe generally to ensure environmental protection and for health and safety reasons. This applies both for magnesium and aluminium alloys.
[74, Brown 1999], [120, TWG 2003] [134, CAEF 2020]

2.2.1.6 Copper casting

Copper is cast in the form of various groups of alloys, each having copper as the main element. Short descriptions of some of these are given below:

- *High conductivity coppers*: These are used mainly for their high electrical and thermal conductivities. Applications include tuyères for blast furnaces and hot blast cupolas, water-cooled electrode clamps, switchgear, etc.
- *Brasses*: Cu-Zn alloys, where zinc is the major alloying element. These are easy to cast, with excellent machinability and good resistance to corrosion in air and fresh water. They are widely used for plumbing fittings. High tensile brasses are more highly alloyed and find uses in marine engineering. Brasses are cast both in sand and in permanent moulds.
- *Tin bronzes*: Cu-Sn alloys, where tin is the major alloying element. With tin contents of 10-12 %, tin bronze castings are more expensive than brass. They have high corrosion resistance and are suitable for handling acidic waters, boiler feed-waters, etc. High tin alloys are also used in wear-resistant applications. Their applied casting techniques are sand and centrifugal casting.

- *Phosphor bronzes*: Cu-Sn alloys, with an addition of about 0.4-1.0 % P. These are harder than tin bronzes but have lower ductility. They are used for bearings where loads and running speeds are high and for gears such as worm wheels.
- *Lead bronzes*: Cu-Sn-Pb alloys. These are used almost exclusively for bearings, where loads and speeds are moderate.
- *Gunmetals*: Cu-Sn-Zn-Pb alloys. These are the optimal alloys for sand casting. They have a good combination of castability, machinability and strength, and good corrosion resistance. They are used for intricate, pressure-tight castings, such as valves and pumps. They are also used for bearings, where loads and speeds are moderate.
- *Aluminium bronzes*: Cu-Al alloys, where Al is the major alloying element. These combine a high strength with high resistance to corrosion. Their applications range from decorative architectural features to highly stressed engineering components. They have many marine uses, including propellers, pumps, valves. They are also used for the manufacture of non-sparking tools. Al casting techniques are applied.
- *Copper-Nickels*: Cu-Ni alloys, where Ni is the major alloying element. These are used for e.g. pipework for marine applications in severe conditions.
- *Copper-beryllium alloys*: Beryllium is cast as a copper-beryllium alloy for the production of parts that require resistance to corrosion and very high mechanical characteristics. These include plunger tips for die-casting machines, precision parts for the electrical and mechanics industry, in watchmaking, for tooling, and for measurements instruments. Two alloy types are used: a copper-beryllium alloy with 2 % Be, and a copper-cobalt-beryllium alloy with 0.5 % Be. There is a tendency to reduce or exclude beryllium in alloys due to its known carcinogenic character. Casting is done in permanent moulds using pressure or gravity die-casting. For precision parts casting, the investment casting technique is used. [74, Brown 1999]

2.2.1.7 Zinc casting

Zinc casting almost exclusively uses the pressure die-casting technique. In the EU, there are mainly two alloys in use; their compositions are given in Table 2.10. They are also referred to as Zamac, which in origin is a trade name. The basis of these alloys is pure zinc.

Table 2.10: Most common zinc alloys, contents in %

Symbol	Alloy number	Al (%)	Cu (%)	Mg (%)
$ZnAl_4Cu_1$	ZP0410	3.7 – 4.3	0.7 – 1.2	0.025 – 0.06
$ZnAl_4$	ZP0400	3.7 – 4.3	0.25	0.025 – 0.06

The zinc alloy is almost exclusively melted in a casting machine, of the hot chamber type. In rare cases, and only when high production capacity is needed, centralised melting may be applied.

Zinc alloys have comparable material properties to aluminium. The main differences are the lower melting point and the higher density of the zinc alloys (6.7 g/cm^3 versus 2.6-2.7 g/cm^3). They are mostly used for small pieces requiring high precision and a low wall thickness. They also allow a higher casting speed to be utilised and result in a 10 times longer die life (800 000 to 1 200 000 shots), which makes them more suitable for large series (of small pieces). The zinc alloys are melted in an electrically or fuel heated cast iron crucible and cast using hot-chamber die-casting machines. The products are used in e.g. automotive and electronics components and in machine construction applications.

2.2.1.8 Lead casting

Lead is a low melting (melting point 327 ºC) heavy metal. Lead is relatively soft, corrosion-resistant and has good self-lubricating properties. The uses of lead castings include

accumulator sheets, shielding material for X-rays and nuclear applications, and in ballast and counterweight materials. Mainly pressure and gravity die-casting techniques are applied.

2.2.1.9 Casting of superalloys

The superalloys are typically Ni, Ni-Fe, and Co based alloys with Cr, Ti, W, Al additions. They were originally used for high temperature applications (over 810 ºC) or in severe corrosive media. Superalloys can be distinguished from high alloyed steels (see definition in Section 2.2.1.3). Since iron is not the major compound (as defined in [201, CEN, 2000]), they are considered non-ferrous materials. The casting of superalloys may occur in certain investment casting foundries, as well as partly in foundries which specialise in high alloyed steel qualities.

The nickel base alloys are produced from a group of alloys which have chemical compositions generally over 50 % nickel and less than 10 % iron. They are mainly strengthened by intermetallic precipitation in an austenitic matrix. The cobalt base alloys have a high Co content (40 % to 70 %), high Cr (over 20 %), high W (7 % to 15 %) and they are strengthened by a combination of carbides and solid solution hardeners.

Some superalloys, particularly Ni-Fe and Cobased alloys, are directly melted in electric furnaces by classical methods usually applicable to stainless steels. However for Ni and special Ni-Fe superalloys, vacuum induction melting is required in order to reduce the content of interstitial gases (O, H, N) to a very low level. This enables foundries to achieve high and controlled contents of oxidisable elements such as Ti or Al.

The control of interstitial gases and oxidisable elements is very important for the product's mechanical properties, the corrosion resistance and its reliability. In general, superalloys are cast into complex final shapes where machining is not possible. Therefore, they are mainly produced by investment casting (i.e. using a ceramic mould). This casting process produces a product of very precise dimensions with a very smooth surface. Additional processes, such as HIP (hot isostatic pressing), can be used to eliminate the internal porosity that can appear in large castings. In aircraft gas turbine manifolds, directional casting technology is commonly applied. This technology eliminates the grain boundaries and greatly increases the strength of the material.

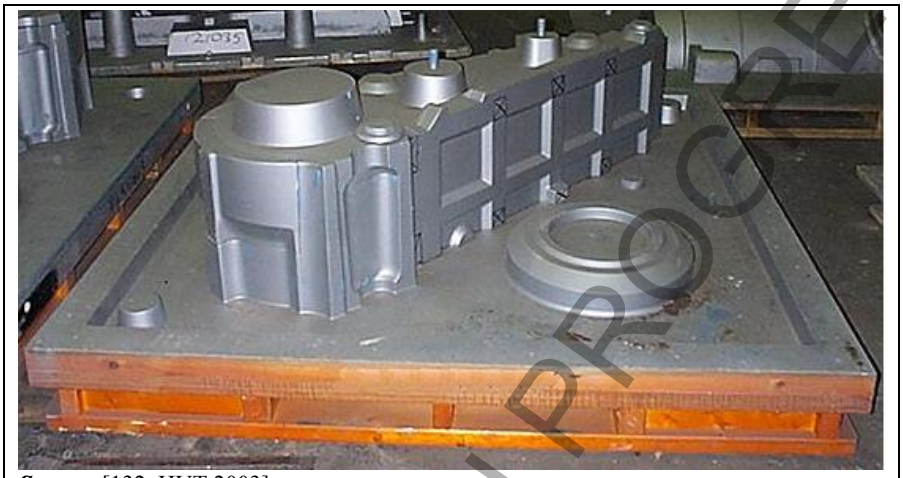
Initially superalloys were developed for high temperature applications. However, their field of application continues to expand and now covers areas such as cryogenic temperature appliances and orthopaedic and dental prostheses. In general, superalloys are mainly used in aircraft and industrial gas turbines, in nuclear reactors, in aircraft and spacecraft structures, in petrochemical production and in medical applications.
[100, TWG 2002]

2.2.2 Pattern making

2.2.2.1 General pattern making

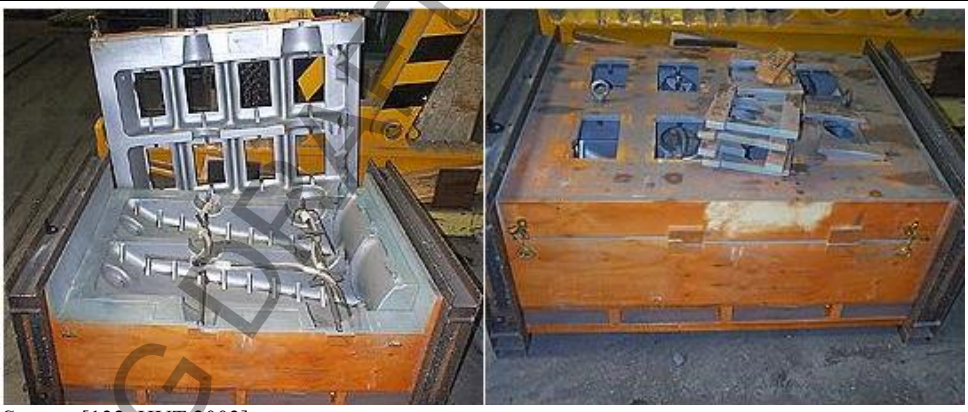
Pattern making, or foundry tooling as it is also called, requires a high level of skill to achieve the close tolerances required of the patterns and core boxes. This step is critical in the casting process since the castings produced can be no better than the patterns used to make them. Patterns are made by means of hand tools, universal machines, or by a CAD/CAM system on computer-numerical-controlled (CNC) machines. In some pattern making shops, computer-aided design (CAD) is used in the design of patterns. Cutter tool paths are designed with computer-aided manufacturing (CAM). The numerical output from these computers is conveyed to CNC machine tools, which then cut the production patterns to shape. Such computer-aided systems have better dimensional accuracy and consistency than manual methods.

Patterns (Figure 2.8) and core box materials (Figure 2.9) are typically metal, plastic, wood or plaster. Wax and polystyrene are used in the investment and Lost Foam casting processes, respectively. Pattern makers have a wide range of tools available to them, including woodworking and metal machining tools. Mechanical connectors and glues are used to join pattern pieces together. Wax, plastic or polyester putty is used as a filler to fill or round the inside of square corners.
[18, US EPA 1998]



Source: [132, HUT 2003]

Figure 2.8: Wooden pattern



Source: [132, HUT 2003]

Figure 2.9: Core boxes

2.2.2.2 Rapid prototyping (RP)

Rapid prototyping is a technique to pass very quickly from a product concept to a cast prototype. The term 'rapid prototyping' (RP) includes all technical and organisational measures from the formulation of the concept of a product to the manufacture of the product. Rapid prototyping can be used for every stage of product development, i.e. for concept models, geometrical prototypes, functional prototypes or for technical or sales prototypes. All the currently available techniques allow the fabrication of a prototype part from a three-dimensional drawing. Most of the RP processes create a casting, a sand mould or a sand core without a pattern or a core box, e.g.there is ~~They are also used for the~~ direct sintering of sands for the production of moulds or cores. Another kind of RP processes is called sand printing. The 3D sand printing method uses a layer-by-layer printing process that allows the creation of parts with complex internal and external geometries. The sand particles are bound together by a binder

'glue' that solidifies the particles into the 3D shape. ~~The~~ RP technique consists of building an object to a design pattern by joining particles or layers of raw material such as polymer resin, wax, paper, ~~or~~ ceramic powder or sands. In Figure 2.10 an example picture of a wax pattern is given.

Source: [132, HUT 2003]

Figure 2.10: Thermopolymer (wax) patterns in an RP machine

There are four basic steps to rapid prototyping:

1. the creation of a 3D-CAD model;
2. making the interface between the 3D-CAD system and the rapid prototyping system. For example the CAD data may be converted to the STL (Standard transformation format) file format;
3. slicing the STL file into thin cross-sectional layers;
4. realisation of the RP-model.

The advantages of Rapid Prototyping, particularly for complex forms, include:

- shorter development time and the possibility of rapid modifications during the development;
- saving of costs, materials and time;
- early error detection.

[100, TWG 2002], [101, Linxe 2002]

An overview ~~survey~~ of available techniques is given in Table 2.11.

Table 2.11: Description of rapid prototyping techniques

Process	Principle	Materials	Special features
Liquid – solid	Polymerisation by local UV exposure of a photosensitive resin	Photosensitive resins Acrylates, epoxydes	- shrinkage and deformation - model needs support
Solid – solid	Contours of a layer are cut out from a foil	Paper, metals, polymers	- no supports - consumption of base material
	Deposition of a material showing thermal fusion	ABS, wax, elastomers	- model needs support
	Material jet	Waxes, polymers	- model needs support
Powder – solid	Agglomeration of powder by sintering	Metals, ceramics, sand, polystyrene, nylon, polyamide, wax	- no support - porosity - shrinkage
	Agglomeration of powder by binder projection	Alumina; sand	- no support - porosity
Source: [101, Linxe 2002], [134, CAEF 2020]			

2.2.3 Raw materials and raw material handling

The main flows of raw materials entering the foundry are metal ingots, foundry scrap and sand. A distinction can be made between ferrous and non-ferrous foundries. Non-ferrous foundries generally melt only internal return material and alloy ingots (Figure 2.11). The remelting of external scrap is generally considered a separate activity, usually forming part of the secondary metal production. If external scrap is acquired, it is first subjected to a spectroscopy analysis in order to determine the alloy type. Ferrous foundries use pig iron and selected iron and steel scrap as starting materials, besides internal return material. The various qualities of metal feeds are stored in separate areas in order to allow the controlled feeding of the melting furnace.

Source: [132, HUT 2003]

Figure 2.11: Aluminium scrap (l.) and ingots (R)

Raw materials, including fluxes in lump and powder form; foundry cokes for cupola furnaces; deoxidants; and refractories are normally stored under cover. Following delivery, handling is kept to a minimum. Powdered materials may be stored in sealed silos and conveyed pneumatically or kept and handled in sealed bags, as displayed in Figure 2.12.

Source: [132, HUT 2003]

Figure 2.12: Pneumatic conveyors and silos for powdered materials

Sand is normally delivered in bulk and discharged directly to a silo via a pneumatic conveyor, conveyor belt or grab. Specialist sands may arrive in bags or by tanker. Used sands are stored in silos for preparation or regeneration and in silos or heaps for transport for external reuse or disposal.

Liquid binders and oil products are delivered in drums, by bulk container or by road tanker. They are stored in their delivery containers or, in the case of rail tankers, discharged direct into a dedicated storage. The containers are connected by pipe directly to the sand/resin/catalyst-mixing unit. Some catalysts and co-reactants are used in a gaseous form, but these are also delivered as liquids and handled in a similar fashion before being vaporised and mixed with a carrier gas. Evaporation is enclosed and may be carried out by a variety of methods.

Refractories, release agents and other minor deliveries are stored indoors.

Coarse solid residues, such as used refractories and slags, are stored on separate heaps, in a subdivided storage area or in boxes. They are moved and handled using small lift trucks. Fine solid residues are collected at the filter unit into big bags or containers, which may be stored intermediately before transport for disposal. In order to avoid soil contamination from the various classes of materials, specific measures are taken. Potential impacts are listed in Table 2.12.

The metal charged in the melting furnace is carefully selected and weighed to ensure the correct composition. The charge composition is calculated based on the average chemical composition of each component, the oxidation losses during melting and the required final composition of the casting. The different charge elements are combined into a charging device (e.g. drop bottom skip, vibrating feeder, skip hoist) with a tilting magnet, usually equipped with a weighing system, to allow collection of the correct amount.

Additional alloying elements can be added to the charge as ferro-alloys such as FeSi, FeMn, FeCr, or pure such as Cu, C, Ni. However most alloys are added to the molten metal to prevent metallic losses due to oxidation. Alloying elements are usually present in the foundry in small quantities and are always stored inside the building, preferably close to the melting installation. [14, CAEF 1997].

Table 2.12: Potential soil contamination from ferrous foundry raw materials

Activities	Contaminants of Concern		Potential Impact
Raw materials storage			
Scrap storage – external, often on soil	Loose materials from scrap - metals and coatings		Localised contamination of soil surface
	Oils - may include: - PAH from combustion engine oils - PCBs from capacitors (mainly in shredded scrap, unless PCB phase-out has taken place successfully)		Leaching into groundwater and nearby surface waters
	Cutting fluids - may be chlorinated		
Liquids in underground tanks	Petroleum products, e.g. fuel oil diesel		Leakage into soil with leaching into ground and surface waters
Raw materials handling, transfer and use			
Chemical binder products – accidental spillage or leaks	Phenolic resins	Free phenol content of 0.5 to 5 %	Water-soluble; can leach into groundwater. Rapid degradation if less than 400 ppm. Concentrated larger volume spills will be slower to degrade due to toxicity to bacteria
	Furan resins	Furfuryl alcohol	Water-soluble
	Solvent carriers in resins	e.g. methanol, up to 20 % volume	Mostly water-soluble, can leach into groundwater
	Urethane resins	Aromatic solvents[1]	Solvents could leach into groundwater
	~~Furan~~ No bake sand hardeners	e.g. Toluene-, Xylene-, Benzene-sulphonic acids	Could leach into groundwater or alter soil properties, e.g. mobilisation of metals
	Urea-based resins	Ammonia	Can leach into ground and surface waters
	Silicate resins	Alkaline pH	Could leach into groundwater or alter soil properties, e.g. mobilisation of metals
Mould coatings	Isopropyl alcohol (IPA)		Water-soluble, can leach into groundwater
Fuels, maintenance products: - accidental spillage or leaks (particularly around filling points) - deliberate disposal to ground	Fuel oils, diesel, petrol with PAH & SO_4^{2-} post-combustion; Lubrication & hydraulic oils; Quench oils; Transformer oils (potential for PCBs)		Oils can leach into ground and surface waters. Air deposition of PAH and SO_4^{2-} from the combustion of fuel oils. SO_4^{2-} will leach down soil profile. PAH, PCBs will tend to absorb onto soils

[1] Former formulations contained PAH (mainly naphthalene), but naphthalene depleted formulations have been developed, which have eliminated this contaminant.
Source: [47, EU Thematic Network Foundry Wastes 2001], [120, TWG 2003], [134, CAEF 2020]

2.2.4 Melting and metal treatment

The selection of a melting furnace is an important aspect in the setting up of a foundry process. Each furnace type has its own properties concerning feed requirements and alloying possibilities, which in turn will have repercussions on the full foundry process. On the other hand, the type of metal to be melted determines which furnace may or may not be used. The applicability of the various furnace types is given in Table 2.13.

Table 2.13: Applicability of furnace types, for melting (m) and holding (h)

	Cupola	Electric arc	Channel induction	Coreless induction	Rotary	Hearth type	Shaft	Crucible/ Ladle
Iron	m	m*	h	m, h	m*	m		h
Steel		m		m				h
Aluminium			m, h	m, h	m	m	m	m, h
Magnesium								m, h
Copper			h	m, h		m		m, h
Lead				m, h				m, h
Zinc				m, h				m, h
* Less common								

Iron foundries require metal of a controlled composition and temperature, supplied at a rate sufficient to match the varying demand of the moulding line. The metallic charge to be melted usually consists of foundry returns, iron and steel foundry scrap and pig iron, with alloying additions such as e.g. ferrosilicon, ferrophosphorus or ferromanganese. The charge is usually melted in a cupola or in an electric induction furnace. Induction furnaces are gradually gaining higher market preference compared to the cupola type. Coreless induction furnaces are used for melting. Channel induction furnaces are only used for holding, their main application being in combination with the cupola furnace, in the so-called duplex configuration. Gas-fired and oil-fired rotary furnaces can also be used, although their use is less common. Short-term holding, transport and metal treatment are performed in ladles.

Steel is melted in both electric arc and induction furnaces. Large steel foundries may use electric arc furnaces, but induction furnaces are more commonly used. Arc furnaces are capable of using low cost scrap charges, since refining takes place in the furnace. However, they have the limitation that there is always some carbon pick-up from the graphite electrodes, so very low carbon stainless steels (< 0.03 % content in carbon) cannot be made. In the induction furnace, refining is not possible, so a carefully selected charge must be used. However, any type of steel may be melted. Short-term holding, transport and metal treatment are performed in ladles.

The melting furnace used in non-ferrous melting is dependent on the foundry size. Non-ferrous foundries often use a variety of different alloys and/or have a limited melting capacity. Melting is done in small volume furnaces, for which the crucible furnace is most suited. Additionally, die-casting is the major casting technique. In this case, there often is no need for a centralised melting, as the melting (and holding) furnace is integrated into the casting machine. Non-ferrous foundries with a higher capacity and a need (or reason) for centralised melting typically use induction, hearth type or shaft furnaces for melting, and then distribute the molten metal to holding furnaces and casting crucibles.
[73, Brown, J. R. 2000], [120, TWG 2003]

2.2.4.1 Cupola furnaces

2.2.4.1.1 Cold blast cupola furnace

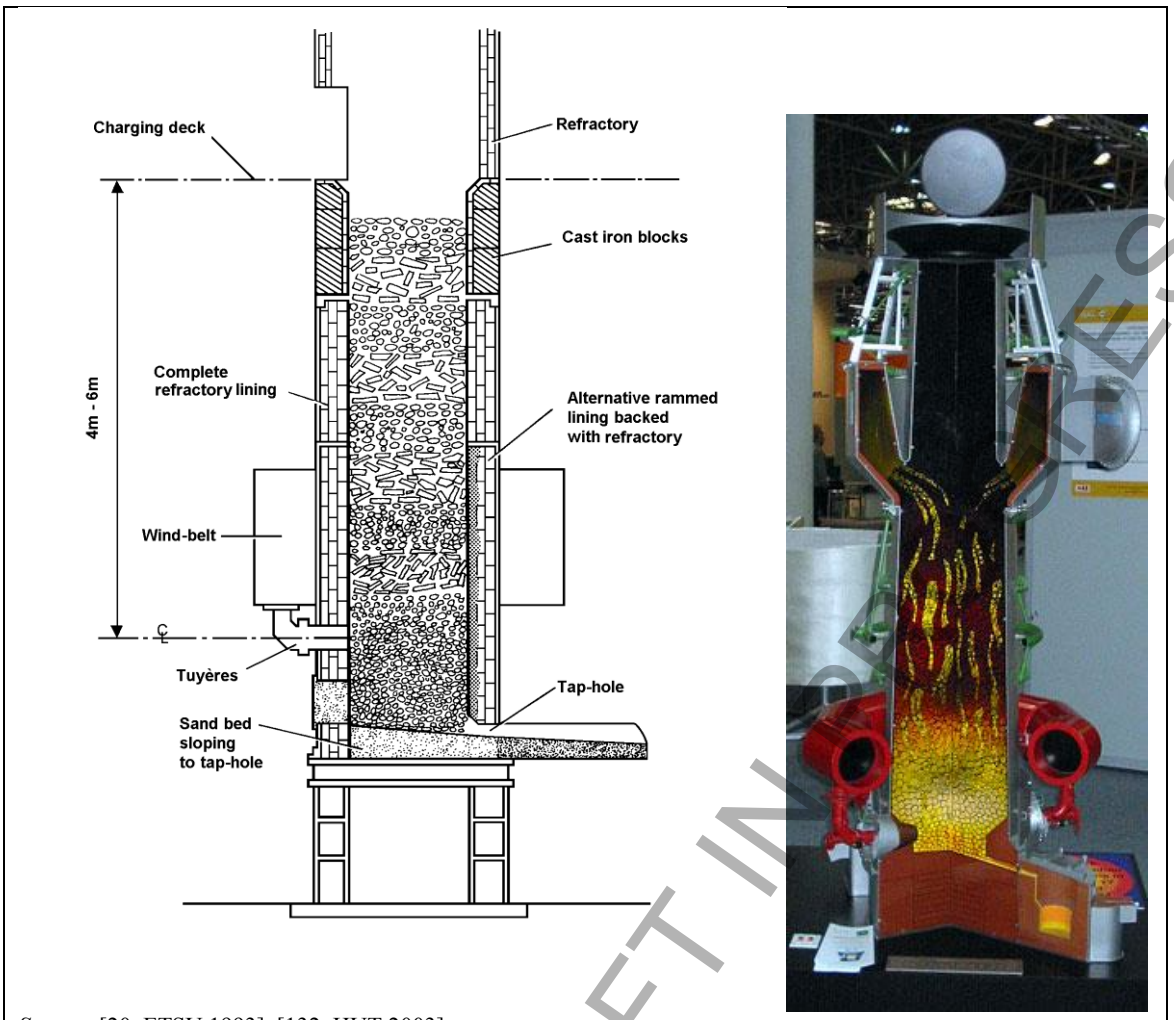
2.2.4.1.1.1 Description

The cupola is a refractory lined shaft furnace where the metal charge is heated by the combustion of coke, which takes place in the lower part of the shaft (the 'hearth'). Combustion air, supplied by fans, is injected in the hearth through a number of exhaust nozzles ('tuyères'). A ring and control valve allows a controlled and evenly distributed flow of combustion air through the tuyères. The metal (pig iron, steel scrap, scrap iron, foundry returns), coke, alloying elements (e.g. FeSi, SiC), slag forming (SiO_2) and fluxing agents (e.g. $CaCO_3$) are added to the shaft through a charging door at the upper part of the shaft. The combustion gases move upward from the hearth and exchange heat with the charge, before leaving the furnace through the cupola stack.

When the preheated charge reaches the combustion zone, the metallic parts melt due to the high temperatures, and the charged coke starts to burn in the presence of oxygen. The molten metal droplets run through the coke bed and gather in the zone called the well, which is below the combustion zone. All the impurities are trapped in the slag, which is mostly formed by SiO_2, CaO, Al_2O_3 and FeO. Fluxing agents lower the melting point and the viscosity of the slag. Due to its lower density, the slag floats on the molten metal in the well. Once the liquid metal in the well has reached a certain level, a tap-hole is opened. The metal flows discontinuously through the tap hole, via a refractory lined channel or launder into a separate collection vessel or ladle. Alternatively, the molten metal can be continuously directed to a holding furnace.

The slag is tapped separately by means of a dam and a slag spout placed at a higher level. It is collected discontinuously in pots, or continuously granulated in a water stream, or in a special installation for dry granulation.

In its basic configuration, the cupola is called a **cold blast cupola (CBC).** This is a cupola which uses the blast at atmospheric pressure and at normal environmental temperature.



Source: [20, ETSU 1993], [132, HUT 2003]

Figure 2.13: Schematic outline and miniature model of a (cold blast) cupola furnace

In order to reduce the CO emission and increase the energy efficiency, the conversion of cold blast furnaces to hot blast furnaces may be considered. However, for medium-sized foundries handling less than 2000 tonnes/month of good castings, the hot blast cupola will be difficult to consider because of the large investment it requires. The use of a hot blast cupola is also restricted to continuous melting, otherwise the running costs are too high. The cold blast cupola prevails for some types of production, e.g. enamelled iron castings, kitchenware, heating appliances, counterweights. ~~These types of castings allow a high level of old cast irons to be used in the melting bed; a charge material still plentiful in the countries of the old industrial Europe and one that is well suited to the cold blast cupola.~~
[20, ETSU 1993], [59, Godinot 2001], [100, TWG 2002], [134, CAEF 2020]

2.2.4.1.1.2 Maintenance

One specific feature of the cupola furnace is that the lining material (quartz-clay mixture) of the furnace at the melting and heating zone only lasts for one melting campaign. The intense heat and the presence of slag results in a chemical dissolution and mechanical wearing of the lining, which consequently converts it into slag. Cupola furnaces are therefore normally constructed in pairs. While one furnace is melting, the second one can be lined with new refractory material, with the operation is being switched around the next day of use.
[38, Vito 2001]

2.2.4.1.1.3 Advantages

- ~~the investment cost is EUR 125000 – 150000 per tonne installed per hour, inclusive of a dedusting installation~~
- Different kinds of (cheap) scrap can be used due to the cleaning and carburising operation.
- The thermal efficiency is acceptable if appropriate measures are utilised.

2.2.4.1.1.4 Disadvantages

- The production regime is not flexible.
- Difficult production management because of the slowness of the system.
- Expensive charge with pig iron, and little steel scrap.
- No quick alloy change possible.
- Sulphur pick-up/take-up in the cupola.
- An environmental burden is caused by the foundry, i.e. lots of dust, slag and refractory lining.
- Big dedusting installations are needed because of the high flue-gas rate.

[38, Vito, 2001]

2.2.4.1.2 Hot blast cupola furnace

2.2.4.1.2.1 Description

In order to optimise the efficiency of the cupola furnace, the combustion air may be preheated. This principle is used in the **hot blast cupola** (HBC), i.e. a cupola which uses a preheated blast.

~~The advantages of the hot-blast operation may be summarised as follows:~~
- ~~reduced coke consumption~~
- ~~increased metal temperature~~
- ~~increased melting rate~~
- ~~reduced sulphur pick-up~~
- ~~reduced melting losses~~
- ~~increased carbon pick-up and hence the ability to substitute steel scrap for pig iron in the furnace charge.~~

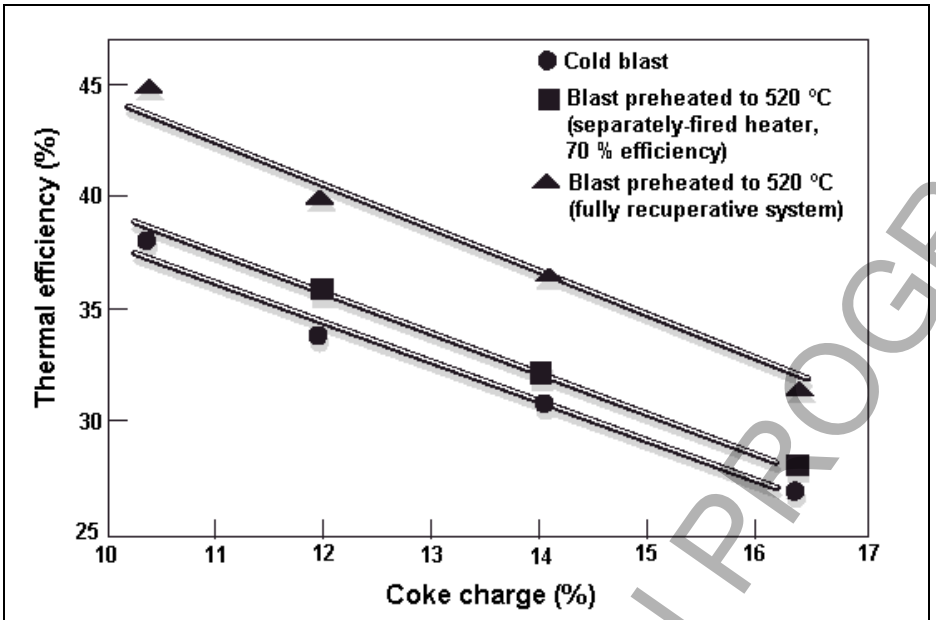
~~It should be noted that not all these advantages can be attained at the same time. For example, an increase in the proportion of steel scrap in the furnace charge may require an increase in the proportion of coke for recarburisation; this in turn will reduce the melting rate and increase the sulphur pick-up.~~

Two methods of heating are:

- *Recuperative heating*: This involves the transfer of the residual ('latent') heat of the flue-gases to the combustion air. The flue-gases are collected at the top of the furnace, mixed with sufficient air and then burned in a post combustion unit. This provokes the exothermic oxidation of CO. The burnt gases are led through a heat exchanger (recuperator) where the heat is transferred to the combustion air. Typically the blast air is heated at temperatures of 500 ºC to 600 ºC. Above these temperatures, problems arise with the sintering of furnace dust on the surface of the recuperator.
- *External heating*: Here the combustion air is heated by some external means, e.g. by a gas or fuel burner, by electrical resistance or by a plasma torch.

The combination of these two heating methods, permits the superheating of the blast air up to 1 000 ºC. These high temperatures, however, require the use of more expensive refractory materials and may cause too high a melt temperature.

Recuperative systems offer increased energy and thermal efficiencies. The effect of air preheating on thermal efficiency and coke use is depicted in Figure 2.14. It should be noted that the coke quality may affect the overall blast efficiency.



Source: [20, ETSU 1993]

Figure 2.14: Effect of air preheating on blast furnace efficiency

For medium-sized foundries producing up to 2 000 tonnes/month of good castings, the hot blast cupola is difficult to consider, in particular because of the large investment it requires. In these instances, the cold blast cupola prevails for some types of production. The hot blast cupola remains the most widely applied melting device for mass production foundries, e.g. for parts for the automobile industry, centrifugal casting, road accessories.

Hot blast cupolas are normally set up for long campaign operation, in order to minimise process switch overs and maintenance time and effort.
[14, CAEF 1997], [20, ETSU 1993], [59, Godinot 2001], [134, CAEF 2020]

2.2.4.1.2.2 Advantages

- Reduced coke consumption.
- High energy efficiency, heat recovery.
- High tap temperature.
- High melting capacity.
- Less sulphur pick-up in the cupola.
- Possibility to use different kinds of cheap lower grade ferrous scrap.
- More scrap steel can be used because of the higher pick-up of the carbon by pig iron.

It should be noted that not all these advantages can be attained at the same time. For example, an increase in the proportion of steel scrap in the furnace charge may require an increase in the proportion of coke for recarburisation; this in turn will reduce the melting rate and increase the sulphur pick-up.

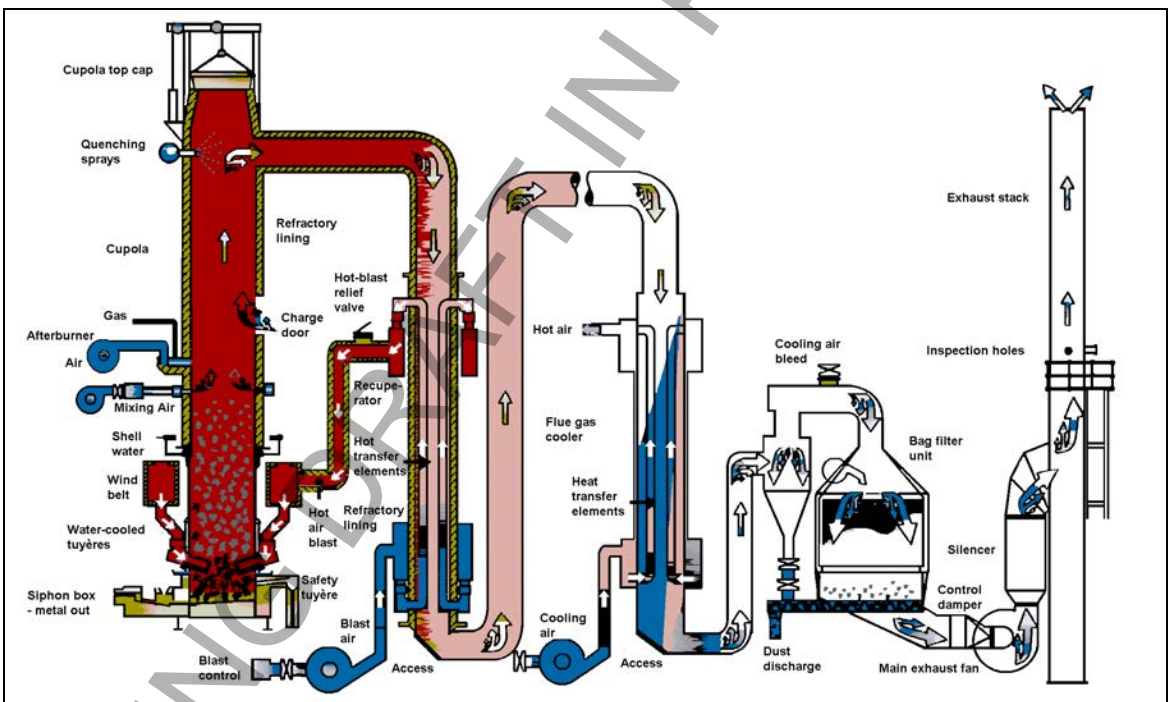
2.2.4.1.2.3 Disadvantages

- ~~very expensive investment, due to the additional environmental measures required~~
- Production regime is not flexible.
- Difficult production management because of the slowness of the system.
- Limited to iron alloys only, no quick alloy change possible.
- Environmental burden caused by the foundry, e.g. lots of dust, slag and refractory lining.
- Big dedusting installations are needed because of the high flue-gas rate.

[38, Vito 2001], [134, CAEF 2020]

2.2.4.1.3 Long campaign cupola

A **long campaign cupola** is usually a water-cooled refractory lined cupola that may be hot blast or cold blast. Such cupolas are operated daily for one, two or three shifts and are very often used only as a single unit. This form has a campaign life of several weeks or months. The liningless cupola allows a much longer campaign life but heat losses through the furnace shell can be significant. Further developments in refractories and operating practices are continually being made which improve the life and cost effectiveness of the long campaign cupola. A schematic representation of a long campaign cupola with an in-shaft afterburner is given in Figure 2.15.



Source: [54, ETSU 1998]

Figure 2.15: Schematic representation of a long campaign cupola

To allow for long campaign operation the following measures need to be taken:

- apply a more persistent refractory lining of the shaft, bottom and the hearth;
- apply water cooling of the furnace wall: this keeps the wall temperature low and thus prevents rapid wearing of the hearth lining;
- use water-cooled blasting pipes that penetrate deeper into the furnace shaft. Here, the combustion zone is not in direct contact with the furnace lining; water-cooling has also been used for reasons other than only reducing the consumption of refractories, such as:
- to extend the duration of the melt;
- to enable the internal diameter of the furnace to be increased, thus allowing a higher melting rate.

In the liningless operation, the charge is in direct contact with the water-cooled steel furnace shell. Liningless operation is only used on relatively large capacity cupolas, melting for long campaigns. This results in the following advantages:

- only one cupola is required;
- the cupola only requires internal repairs after one, or several, week's operation;
- daily bed-coke consumption is reduced;
- monitoring is easier throughout the campaign, because of the constant diameter and the more consistent melting conditions.

~~A specific type of long campaign cupola is the cokeless cupola. This is discussed in Section 3.2.2.1.8.~~

TWG please note that the cokeless cupola is now proposed for deletion as a BAT candidate technique, see Section 3.2.2.1.8

[14, CAEF 1997], [20, ETSU 1993], [38, Vito 2001], [54, ETSU 1998], [134, CAEF 2020]

2.2.4.1.4 Nature of atmospheric emissions

Cupolas can be charged with a wide range of materials, many of which may contain loose particles such as rust, sand and non-ferrous materials. The metallurgical coke can break and produce small pieces, as can the added fluxing materials. Breakage and mechanical abrasion during charge preparation, as well as during charging itself, generate particles, some of which are immediately emitted.

During melting, abrasion of the charge against the refractory lining will also generate dust.

A third source of particulate matter is coke ash, generated in the melting zone, which is not trapped by the slag phase.

Particulate matter of various sources, if light enough, can be entrained in the combustion gases of the cupola. Under certain conditions metallurgical fume may be generated from the melting zone, leading to a visible plume from the cupola stack. The smoke particles consist of submicron agglomerates of spherical soot particles and metallic oxides, such as ZnO, PbO, etc., if the metals are present in the charged steel or iron scrap, such as in galvanised or painted scrap. The smoke emission will increase with the proportion of coke and contaminants in the charge, the blast temperature, and the oxygen injection rate.

Carbonaceous smoke is airborne matter formed by the incomplete combustion of organic matter in the cupola. Scrap contaminants such as oil and grease, wood, textiles and, rubber will form oily vapours in the stack gases. Vapours and partially burnt organic matter may carry unpleasant ~~smells~~odour. Again, scrap cleanliness and its nature significantly effect the nature of the emissions. Clean scrap avoids generation and emission of organic substances.

The burning of coke creates ~~odorous~~ gas emissions containing CO_2, CO and SO_2 (odorous). Decreasing the proportion of the coke charge (by increasing the thermal efficiency) or (partial or complete) substitution of the coke by natural gas can help reduce the levels of these substances.

2.2.4.2 Electric arc furnace (EAF)

2.2.4.2.1 Description

The EAF is a batch-melting furnace consisting of a large bowl shaped refractory lined body with a dish shaped hearth. The wide furnace shape allows the handling of bulky charge material and leads to efficient reactions between the slag and metal. Typically the shell diameter is 2 m to 4 m. As shown in Figure 2.16, the furnace is covered by a refractory roof, which has ports for

three graphite electrodes. The electrodes are supported by arms, which allow movement up and down. Most furnaces use roof charging: by moving the roof and electrodes aside, the furnace can be charged using a drop bottom charging bucket or a magnet. The metal charge is heated by an electric arc, which is created by a three phase alternate electrical current between the three graphite electrodes. These are positioned above the charge, which itself acts as the neutral.

Source: [132, HUT 2003]

Figure 2.16: EAF furnace

The furnace is tapped by tilting it, forcing the metal to flow out through the spout. Opposite the spout, an operable door allows deslagging and sampling operations to be carried out prior to tapping.

The lining of the furnace may be acidic (SiO_2-based refractory) or basic (MgO-based refractory). A basic lining allows the use of virtually all kinds of steel scrap. The furnace can also be used for the production of high alloy and manganese steels. If scrap with high phosphor or sulphur conent is used, lime and limestone which are usually added for dephosphorisation and desulphurisation. An acidic lining would be attacked by these compounds. Therefore, the acidic type refractory is used for melting scrap with a low sulphur or phosphorus content only.

Electric arc furnaces are almost exclusively used for the melting of steel. Only in a few cases are they used for cast iron production, which requires an addition of coal dust to the melt. Electric arc furnaces designed for steel foundries' purposes usually range from 2 to 50 tonne capacities. They can be run intermittently and are suitable for a wide range of steel analyses. They can provide steel at high temperatures, with typical meltdown times of about one to two hours, while achieving high thermal efficiencies of up to 80 % (without taking into account the efficiency of electric power generation). Power consumption varies from 500 kWh/tonne to 800 kWh/tonne of molten steel, depending on the furnace capacity, the hot metal consumption, and the refining techniques, tapping temperature and pollution control equipment applied. The total melt time is typically 1 to 4 hours.

2.2.4.2.2 Melting and refining with the acidic-lined EAF

Due to the chemical nature of the acid lining (SiO_2), the refining abilities of this type of furnace are restricted to decarburisation. Consequently considerable care has to be exercised in selecting the charge for acceptable sulphur and phosphorus levels, as these cannot be removed in the acid melting practice. The charge consists of balanced quantities of pig iron, foundry returns and purchased scrap. The carbon in the charge is held at a high enough level so that after melting it is 0.2 % to 0.4 % above the final level.

The decarburisation starts by injecting oxygen into the metal bath. This creates a strong stirring action during which carbon in the melt is burned. At the same time the 'boiling' burns out Si, and flushes out H_2 and N_2 from the metal bath. All impurities (oxides) are trapped in the slag. During melting, sand (SiO_2) may be added to bring the slag to the proper consistency. When the carbon reaches the proper concentration, oxygen injection is stopped, and silicon and manganese are added to halt the boiling reaction.

After slag removal the metal composition is controlled and adjusted if necessary. Finally the metal is deoxidised by adding aluminium or other agents into the melt stream during tapping, to prevent the formation of CO bubbles during solidification. Additional desulphurisation and or dephosphorisation refining can be done in an AOD or VOD converter (see Sections 2.2.4.9 and 2.2.4.10).
[14, CAEF 1997], [63, UK Environment Agency 2002]

2.2.4.2.3 Melting and refining with the basic lined EAF

The alkaline MgO-based lining of this EAF makes it possible to refine the metal in the furnace itself. Therefore it is possible to charge the furnace with virtually any combination of scrap and foundry returns. The basic lining practice is used when the purchased scrap contains higher phosphorus and/or sulphur levels than desirable.

Dephosphorisation of the melt is performed by periodic additions of lime during meltdown. Upon the injection of oxygen in the bath, phosphorous oxide is formed and trapped in the slag, together with other metallic oxides and impurities. The lime keeps the slag very basic, which stabilises the phosphorous oxide. At the same time carbon is burnt out. After sufficient reaction time, the oxygen injection is stopped and the slag is fully removed.

Desulphurisation takes place in a second stage, in a similar way but at a higher temperature. Again, lime or limestone is added to the melt, reacting with sulphur to form insoluble CaS, that is trapped by the slag. Periodic additions of carbon, aluminium, or FeSi reduce the metallic oxides (e.g. manganese-, chromium oxides), and thereby minimise losses of these elements from the metal bath. All other impurities (oxides) are trapped in the slag and removed during the final deslagging operation.

After refining the metal composition is controlled and adjusted if necessary. Finally the metal is deoxidised by the addition of aluminium or other agents in the metal bath prior to tapping, to prevent the formation of CO bubbles during solidification. Further metal treatment, using an AOD or VOD converter (see Sections 2.2.4.9 and 2.2.4.10), may be applied if the final alloy composition requires it.
[14, CAEF 1997], [63, UK Environment Agency 2002]

2.2.4.2.4 Nature of atmospheric emissions

The emissions from EAFs originate from the charging, melting, and refining operations and during tapping of the furnace.

During charging, dust and particles~~dirt~~ will be emitted from the open furnace body. When charging a hot furnace (for instance when melting with a molten heel in particular), any combustibles such as grease, paint or oil ignite and give rise to smoke plumes of burnt and partially burnt organic material and dust particles. The mechanical abrasion of the furnace lining also generates additional dust.

During melting, heating of the scrap generates metal oxide fumes that significantly increase during the decarburisation treatment. The injection of oxygen gas into the molten metal develops significant quantities of iron oxide fumes, which leave the furnace as red clouds. The

addition of slag forming materials increases the furnace emission, but only in small quantities and only for a short time.

Minor emissions occur during the transfer of the molten metal into a ladle or holding furnace.

Emissions from the melting operation itself are referred to as primary emissions. Secondary emissions are the fumes and dust originating from the charging and tapping.

In considering the nature and quantities of the emissions, the different sources of dust and fume emissions, as described above, demonstrate that large differences exist between foundries, depending on the cleanliness of the charged material, the applied charging procedure, the composition of the charge, the refining treatments and on the additions to the melt. Since no coal or fuel is burned in the furnace the emissions solely depend on these parameters.

2.2.4.3 Induction furnace (IF)

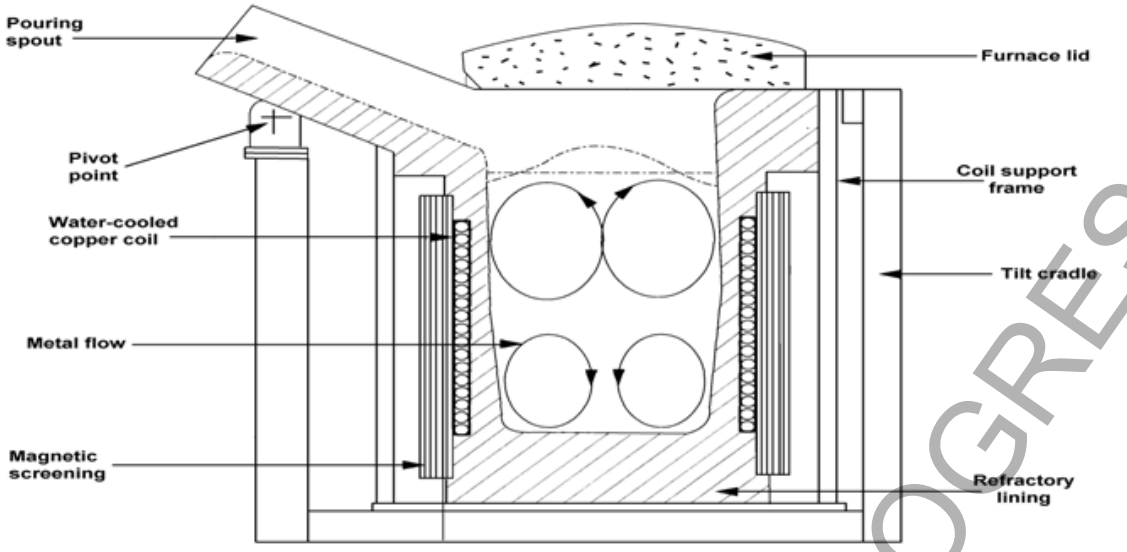
Induction furnaces are used to melt both ferrous and non-ferrous metals. There are several types of induction furnaces available, but all operate by utilising a strong magnetic field created by passing an electric current through a coil wrapped around the furnace. The magnetic field in turn creates a voltage across, and subsequently an electric current through, the metal to be melted. The electrical resistance of the metal produces heat, which in turn melts the metal. Induction furnaces are made in a wide range of sizes. Because there is no contact between the charge and the energy carrier, the induction furnace is suited for the melting of steel, cast iron and non-ferrous metals, so long as a suitable lining material can be found.

Proper functioning of the water cooling circuits is crucial to prevent the coil from overheating. The water cooling systems are therefore designed to provide the highest level of reliability, and thus incorporate various thermostats and flow-meters.
[18, US EPA 1998], [23, ETSU 1992], [38, Vito 2001]

2.2.4.3.1 Coreless induction furnace

2.2.4.3.1.1 Description

The coreless IF is a batch-melting furnace containing a water-cooled copper coil, the inside of which is internally refractory-lined. The outside is insulated and enclosed in a steel shell. The furnace body is mounted in a frame equipped with a tilting mechanism. A coreless induction furnace is normally a refractory-lined bucket-shape refractory, the top of which is open for charging and deslagging operations (see Figure 2.17).



Source: [23, ETSU 1992]

Figure 2.17: General arrangement of a coreless induction furnace

According to the capacity, the furnace is charged by a lifting magnet, bucket skips, a vibrating conveyor or manually. A large number of foundries use induction furnaces for producing relatively small lots in a large variety of compositions. Furnace capacities range from 10 kg up to 30 tonnes. The core is fed by mains, medium or high frequency alternating current (50 Hz, 250 Hz or 1 000 Hz, respectively).

Depending on the installed power density and the melting practice the thermal efficiency can exceed 80 %[1], but usually ranges from 60 % to 70 %. If the efficiency of the electric power generation is taken into account, an overall efficiency of 15-20 % results, which is rather low in comparison with other furnace types.

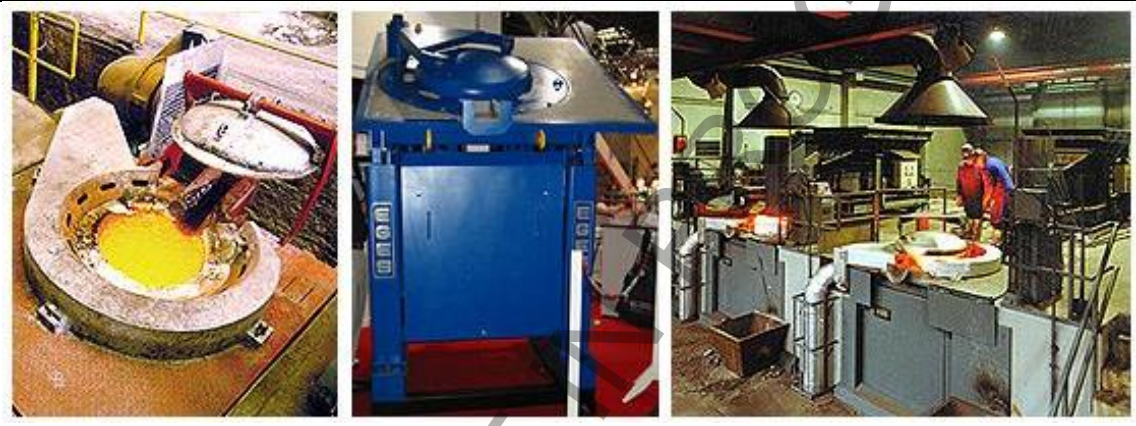
The coreless induction furnace can be designed to operate at any frequency from 50 Hz upwards. The induction heating of liquid metal causes a stirring effect. The lower the frequency of the primary current, the more intense is the stirring. Therefore, in a mains frequency furnace working at 50 Hz or 60 Hz, the turbulence is greater than in one operating at higher frequency. Because of the high turbulence, the power input to a mains frequency furnace is restricted to around 250 kW per tonne of capacity. With higher frequencies, the power density can be increased to three or four times this level.

The frequency of operation also affects the current penetration. The higher the frequency, the lesser the penetration depth. This affects the minimal charge piece size and the effective furnace size. 50 Hz furnaces are not practicable at capacities below 750 kg. At 10 kHz, charge pieces less than 10 mm in diameter can be heated, so furnaces as small as 5 kg capacity can be used. The availability of reliable frequency converters has allowed the development of application specific units, as given in Table 2.14. Frequencies are usually limited to 250 Hz to 350 Hz (in the case of variable frequencies), as at higher frequencies metal homogenisation becomes insufficient. Higher frequencies are used in special cases, such as with very small furnaces. Figure 2.18 shows coreless induction furnaces of various sizes.

[1] Without taking into account the efficiency for electric power generation.

Table 2.14: Field of application of available induction furnaces as related to their frequency

Frequency (Hz)	Application
70	Brass swarf
100	Aluminium scalpings
100 – 150	Cast iron borings
250	Aluminium extrusion scrap
250	Iron from foundry returns and steel scrap
500 and 1000	Steel melting and melting of wet cast iron borings
1000 and 3000	Wide variety of copper alloys
3000	Investment casting
10000	Jewellery trade
Source: [73, Brown, J. R. 2000]	



Source: [132, HUT 2003]

Figure 2.18: Coreless induction furnaces

Water-cooling systems are essential for operation of the coreless induction furnace. Cooling the coil protects both the coil and the insulation from thermal damage, not only during normal operation but also during the cool-down period when the power has been switched off and the furnace emptied. Several types of cooling are available, using closed circuits with heat-exchangers or open evaporative systems. The availability of a cooling system opens up the possibilities for internal energy recovery.
[14, CAEF 1997], [23, ETSU 1992], [38, VITO 2001], [73, Brown, J. R. 2000], [75, ETSU 1998], [100, TWG 2002]

2.2.4.3.1.2 Melting practice

The coreless induction furnace is used for melting but cannot be used for refining. Therefore, in steel foundries the induction furnace has to be charged with raw materials of the 'correct' chemical composition, i.e. that corresponding to the required composition of the melt; hence steel scrap is mainly used. If necessary, the metal can be refined after melting in an AOD converter or in special treatment ladles (see Section 2.2.4.12).

High powered furnaces allow melting following the 'tap and charge' method. Here the furnace is tapped completely empty and charged with cold material to start the next melting cycle. The 'molten heel' method is used on low powered (mains frequency) furnaces where approximately one third of the melt is tapped before the cold charge material is added. Because of the better electromagnetic coupling between the melt liquid and the coil compared to a less dense solid (cold) charge, the production rate increases significantly when using the latter method on low powered furnaces.

Steel grades containing more than 0.2 % of reactive elements such as Al, Ti and Zr cannot be melted in an oxidising environment such as air. They require an inert atmosphere or a vacuum melting and casting method. This is obtained by placing an induction furnace in a vacuum or airtight chamber. The application of a vacuum ensures very good degassing of the melt. Highly oxidisable elements are added in vacuum or after backfilling with an inert gas.

Induction furnaces are excellent melting units~~,~~ and can be used for combined melting and holding.~~but in general they are less efficient holders. When they are used for melting only, the molten metal is mostly moved to an efficient holding furnace as soon as it has reached the desired temperature.~~ Many types of coreless induction furnaces are available, with fixed or removable crucibles. For aluminium, both channel and coreless induction furnaces are available for melting and holding. However, the channel type is seldom used, due to difficulties in keeping the channel open and due to the need to maintain a molten heel at all times.
[14, CAEF 1997], [24, ETSU 1994], [134, CAEF 2020]

2.2.4.3.1.3 Advantages

Due to its multiple advantages, the induction furnace is increasingly being implemented. Its main advantages are*:*

- higher flexibility in alloys and melting regime; as such, it is an ideal melting technique for jobbing foundries and special alloys;
- short meltdown times;
- lower environmental burden caused by the foundry;
- little maintenance, depending on the lifetime of the refractory lining;
- good process control: computer support and fully automatic operation is possible, which allows optimal temperature control;
- maximum thermal efficiency is possible, if process parameters are locally calculated and set-up;
- heat recovery (cooling water) is possible;
- intense stirring in the bath makes the melt homogeneous;
- charging, sampling and deslagging of holding the liquid metal, though typically with low efficiencies, although high holding efficiencies have been reported for copper and aluminium.

2.2.4.3.1.4 Disadvantages

- Because of the monopoly of the local electricity supplier, the operator is fully dependent on the connection conditions of the local electricity grid, the energy costs and any possible extra costs (peak control, etc.)
- ~~the energy costs are more expensive than the costs of using fossil fuels~~
- The cleaning action of the induction furnace on the melt is limited because of the small amount of slag and the relatively small contact area between the slag and melt. This requires the use of a high quality, and thus, more expensive charge than cupola or EAF ~~furnaces~~.
- ~~the installation requires a high investment, although the operator can save on additional environmental investments. The net cost per tonne installed furnace content is around EUR 375000~~
- Other melting techniques are more suitable for capacities > 15 tonnes per hour. Depending on the intended alloy, the hot cupola or electric arc furnace may be considered.
- It has a low efficiency during holding because of the heat losses in the water-cooled induction coil.

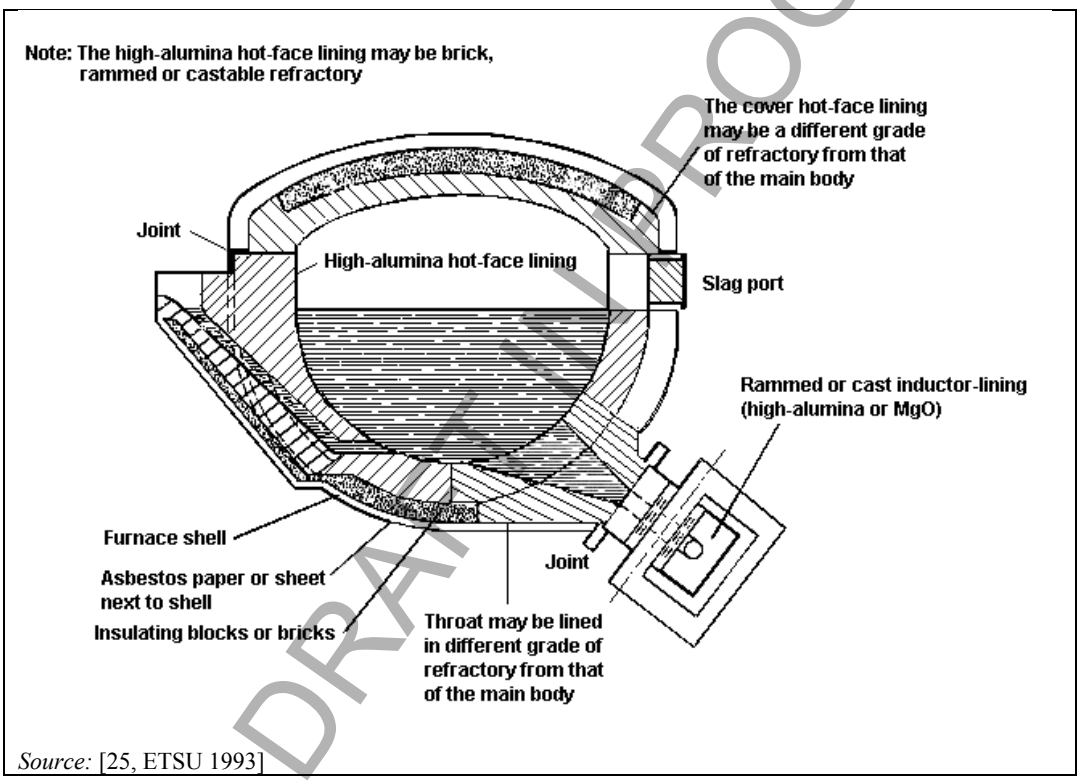
[38, VITO, 2001], [134, CAEF 2020]

2.2.4.3.2 Channel induction furnace

2.2.4.3.2.1 Description

This type of furnace is mainly used for holding purposes, though it may also be used as a combined melting- and holding aggregate.

The channel induction furnace consists of a big, thermally isolated bucket, equipped with an isolated top-lid for introduction of the charge (Figure 2.19). The bottom is equipped with one or more U-channels. Around these channels is a water-cooled induction coil, which heats and circulates the metal. The induction current has the frequency of the local electricity grid. The furnace is generally mounted in an hydraulically tiltable frame for tapping or maintenance operations. Pressurised and non-tilting furnaces are also in use.



Source: [25, ETSU 1993]

Figure 2.19: Typical construction of a bath channel furnace

In order to allow operation, a minimum amount of molten metal needs to stay inside the crucible and channel. The crucible needs to stay filled up to one third of its capacity. Two values are usually quoted when the capacity of a holding furnace is defined, these are total capacity and useful capacity; for example 60/35 tonnes. The difference between these two values represents the amount of metal that must be retained in the furnace.

Thermal losses through the cooling water and the furnace wall are low compared to those in the coreless induction furnace. Equipping the furnace with pouring channels according to the 'teapot principle' allows for a reduced oxidation of the melt and wearing of the refractory.

Due to the large content of the crucible, any changes in the melt composition are flattened out. This principle however counteracts the flexibility of the furnace, as changing to another melt composition requires a long transition period. In practice, the melt composition is therefore kept fairly constant.

Source: [132, HUT 2003]

Figure 2.20: Channel induction furnace

The channel induction furnace finds its main application as a holding furnace in iron foundries. An example picture is given in Figure 2.20. It is the furnace of choice for duplex operation with cupola furnaces. The capacity varies between 5 tonnes and more than 100 tonnes. The holding furnace serves as a buffer between the melting and casting shop. It is important to assess foundry and production requirements fully when considering whether to use a holding furnace. There may be more cost-effective and energy efficient methods of achieving the requirements, and it is advisable to investigate thoroughly all possible solutions before a decision is made. For aluminium, the channel type is seldom used, due to difficulties in keeping the channel open and due to the need to maintain a molten heel at all times.

Output requirements are an important consideration when deciding the size of a channel furnace. The choice of a smaller furnace may be advantageous. Although a smaller furnace is less efficient, the loss in efficiency will be offset by its reduced annual power consumption compared with larger furnaces.
[24, ETSU 1994], [25, ETSU 1993], [38, VITO 2001],

2.2.4.3.2.2 Advantages

- High thermal efficiency as a holding furnace.
- Minimal burn-out of the alloy elements.
- Little maintenance.

2.2.4.3.2.3 Disadvantages

- A minimum amount of molten iron, but which may be a substantial part of the furnace capacity, has to be maintained in the furnace body in order to guarantee proper electrical functioning.
- The furnace cannot perform a cold start because of the limited power density that can be achieved in the loop.
- Difficult to monitor the channel wear.
- Potential danger of accidental leaks, because of the induction coil on the bottom.
- Contact between the cooling water and metal is difficult to prevent.

[38, VITO 2001]

2.2.4.3.3 Nature of emissions

Since no coal or fuel is burned in the induction furnace and no refining procedures are executed, the emissions solely depend on the cleanliness and the composition of the charged material.

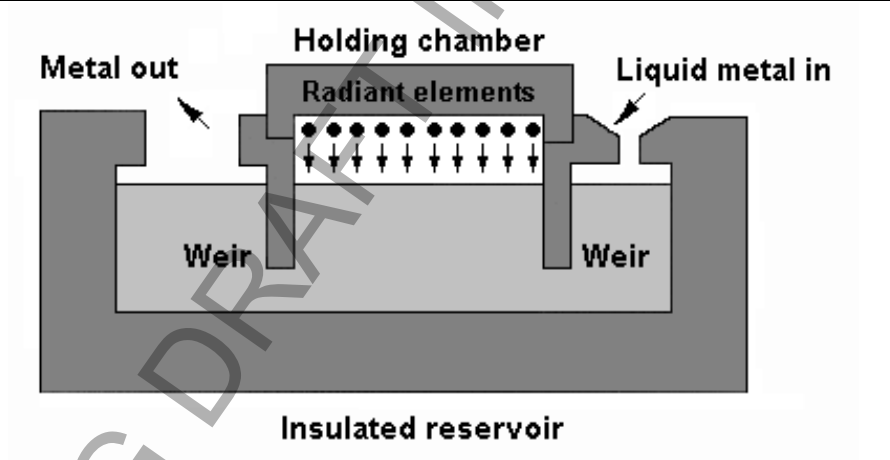
Two major categories of emissions can be distinguished. The first, and major, category relates to the charge cleanliness, e.g. rust, dirt, foundry sand, paint, oil, galvanised or soldered metal, all of which are elements which give rise to the emission of dust and fumes (organic or metallic). The second category relates to chemical reactions at high temperatures, (e.g. while holding or adjusting the metal composition), which can give rise to metallurgical fume due to oxidation.

Additionally the refractory lining (acid SiO_2-based, neutral Al_2O_3-based, or basic MgO-based) may add a small amount of dust particles to the emission.

It is difficult to obtain average emission data since the charge cleanliness, which is the dominant contributor to emissions, varies from foundry to foundry.

2.2.4.4 Radiant-roof furnace (resistance heated)

The radiant-roof furnace is a low-energy holding furnace with a heavily insulated box design with banks of resistance elements in a hinged, insulated roof. They are mainly used in non-ferrous (aluminium) pressure die-casting shops with centralised melting facilities. Typical units have a capacity of 250-1 000 kg with a 5 kW to 12 kW connected load. Bale-out and charge wells are separated from the main bath by refractory walls with connectors at the bottom to allow clean metal to pass from one area to another. Figure 2.21 gives a schematic view of the radiant-roof principle.



Source: [24, ETSU 1994]

Figure 2.21: Radiant-roof furnace

The advantages of radiant-roof furnaces are:

- No crucible required;
- ~~very low energy costs~~
- close temperature control;
- clean, cool, silent working conditions.

Although most low-energy holding furnaces serve individual casting machines, some larger ones are used as buffers between bulk melters and machine furnaces. This latter use allows better use of the melter, which is seldom an efficient holder.

Some foundries use large radiant-roof furnaces with higher power as melters, for example to generate molten metal for low-pressure die-casting. Several manufacturers build versions of radiant-roof furnaces that can be fully sealed and pressurised by gas, in order to function as

dosing furnaces. Dosing furnaces provide precise shots of metal for pressure or gravity die-casting and compete, to some extent, with mechanical ladle systems as automatic pouring systems. Provided that they are carefully maintained and used, radiant-roof furnaces can provide a valuable control of both temperature and shot weight and can improve yield.
[24, ETSU 1994]

2.2.4.5 Rotary furnace

2.2.4.5.1 Description

The rotary furnace consists of a horizontal cylindrical vessel, in which the metallic charge is heated by a burner located at one side of the furnace. The flue-gases leave the oven through the opposite side. To generate the required heat, fuel or natural gas is used combined with air or pure oxygen.

A tilting mechanism allows the furnace to be lifted to a certain angle or into a vertical position. This position is used for charging of the furnace with a drop bottom bucket or a vibrating chute, and for lining repair or renewal. During heating and melting the furnace is rotated slowly to allow the heat transfer and distribution. The furnace atmosphere is controlled by the air (oxygen)/fuel ratio.

Once the metal is melted, and after a composition check and adjustment, a tap-hole in front of the furnace is opened and the melt in the furnace is discharged into ladles. Because of its lower density, the slag floats on the metal bath in the furnace and is finally collected through the tap-hole into slag pots.

A melting cycle spans 1.5 to several hours. For continuous molten metal production, foundries install two to four rotary furnaces, which are operated consecutively. The thermal efficiency of the rotary furnace is very high, i.e. at 50 % to 65 %[2], depending on the capacity. This high yield is achieved by using pure oxygen instead of air as the combustion medium.
[14, CAEF 1997]

2.2.4.5.2 Melting practice

For cast iron melting, the furnace is charged with pig iron, foundry returns, steel scrap, slagging (e.g. sand, lime), and carburisation agents (e.g. graphite). The melting cycle starts with a slightly oxidising and short flame (air factor, $\lambda = 1.03$), which gives the highest energy input. The furnace is rotated stepwise through 90 º and the direction of the rotation is changed from time to time. This way, the furnace walls can exchange heat with the charge by convection. As soon as the charge is melted, the flame is reduced to prevent excessive oxidation of the alloying elements. During overheating and holding, a long and reducing flame is applied ($\lambda = 0.9$) and the furnace movement is changed to full and continuous rotation. The slag layer provides thermal insulation and prevents the burning-off of the alloying elements. After controlling and adjusting the melt composition and temperature, the tap-hole is opened and the metal is tapped into ladles. The slag floats on the metal bath and is collected separately after the metal is removed.

The lifespan of the refractory is largely dependent on the overheating temperature and the charge composition. In the charging operation, mechanical shocks and cold start-ups need to be prevented. The furnace atmosphere, the holding time, rotational speed and the burner position also affect the refractory life. In normal conditions the refractory life is 100 to 300 melting cycles.

[2] This thermal efficiency is calculated provided that the energy for oxygen production is not taken into account. With oxygen production, the efficiency will be 10-15 % less.

[14, CAEF 1997], [38, VITO 2001]

2.2.4.5.3 Metallurgy

The rotary furnace has been used in non-ferrous melting for many years. In this application traditional oil-air burners can provide the relatively low melting temperatures. The development of oxygen-air burners has enabled the introduction of cast iron production, using a higher relative amount of steel scrap and applying graphite for carburisation.

A significant disadvantage of the rotary furnace is that it also burns Fe, C, Si, Mn and S. These losses have to be compensated for by the addition of alloying elements before or after melting. The efficiency of uptake of these elements is usually rather low. Concentration gradients may occur between the front and the back of the metal bath due to the absence of axial motion and due to inhomogeneities in radiation and the atmosphere above the wide bath surface.
[38, VITO 2001]

2.2.4.5.4 Application

Due to its batch character, the rotary furnace provides a flexibility equal to that of the coreless induction furnace in the cast iron foundry. ~~The investment costs however are lower. A 5 tonne furnace costs EUR 500000 – 600000, of which 30 % are for the exhaust system and dedusting. The rotary furnace is also a good alternative for the small-scale cold blast cupola, due to its higher flexibility and lower environmental costs.~~ Rotary furnaces are used for melting volumes of 2-20 tonnes, with production capacities of 1-6 tonnes per hour.
[38, VITO 2001]

2.2.4.5.5 Advantages

- Quick change of alloy possible.
- Melting without contamination, e.g. without sulphur pick-up.
- ~~low investment costs~~
- Small dedusting system because of low flue-gas rate.
- Easy to maintain.

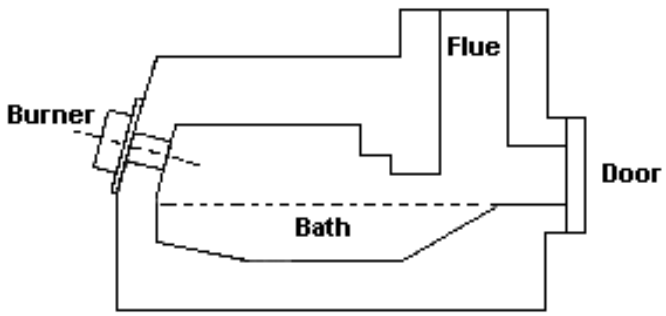
2.2.4.5.6 Disadvantages

- Easy burn-out of C, Si, Mn.
- Gas and oxygen use can be high if not operated continuously.
- The energy consumption increases if more steel is added to the charge.

[38, VITO 2001]

2.2.4.6 Hearth-type furnace

The hearth-type furnace is also known as a reverberatory or bale-out furnace. It is a static furnace with direct heating. Hot air and combustion gases from oil or gas burners are blown over the metal (melt) and exhausted out of the furnace. The hearth-type furnace finds its main application in non-ferrous metal melting. A typical furnace design is given in Figure 2.22.



Source: [74, Brown 1999]

Figure 2.22: Cross-section of a hearth-type furnace

This is a refractory-lined, rectangular or circular bath furnace that is fired by wall or roof-mounted burners. Varieties of fuels are used and additionally oxy-fuel burners can be used to increase the melting rate. Extraction and treatment of the combustion gases is typically carried out and for this the furnaces are partially sealed. Hoods and covered launders provide extraction during tapping and charging. The furnace can be constructed in a number of configurations depending on the particular metal and application, variations include the provision of sloping hearths and side wells for specific melting purposes, tuyères and lances for the addition of gases. The furnaces can sometimes be tilted to pour or blow metal.

The melting efficiency of a hearth-type furnace is usually not great because of the poor heat transfer from the burner. The efficiency has been improved in practice by the use of oxygen enrichment or by using combinations of gas and solid fuel to extend the flame length. These furnaces are used for batch melting, refining and for holding a variety of metals. Hearth-type furnaces are mainly used to melt large quantities of non-ferrous metals [1, COM 2017].

Large hearth-type furnaces give rapid melting and can handle bulky charge materials, but the direct contact between the flame and charge may lead to high metal losses, gas pick-up and to considerable oxide contamination. Temperature control can also be difficult. These difficulties can be overcome to some extent by good practice. For example, dross can be removed by applying suitable fluxing practice, and applying modern burners reduces problems with the temperature control. After tapping, filtering and degassing, further treatments can be applied as the metal is transferred to holding furnaces.
[18, US EPA 1998], [24, ETSU 1994], [1, COM 2017], [74, Brown 1999]

2.2.4.7 Shaft furnace

2.2.4.7.1 Description

This is a simple vertical furnace with a collecting hearth (inside or outside the furnace) and burner system at the lower end and a material charging system at the top. The burners are usually gas-fired. Metal is fed into the top of the furnace and is melted as it passes down the shaft. Independent control of the fuel/air ratio is usually provided for each burner. Continuous CO or hydrogen monitoring is also provided for each row of burners and monitor the combustion gases from each burner in turn. Combustion gases are usually extracted and cleaned. An afterburner is sometimes used to decompose any carbon monoxide, oil, VOCs or dioxins that are produced. The addition of oxygen above the melting zone has been used to provide afterburning in the upper levels of shaft or blast furnaces.

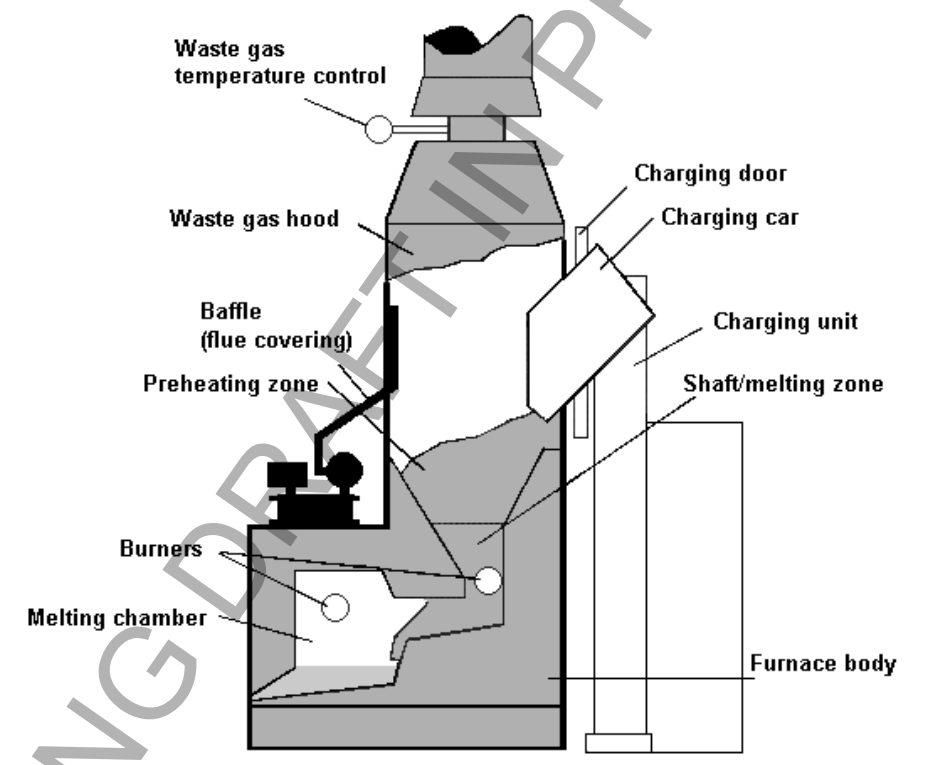
The furnace is used to melt pure metal, but occasionally metal that is contaminated with organic material may be used. If oily metal is fed into the furnace, it passes through a temperature

gradient existing between the charging area and the burners. The low temperature can produce a mist of partially burned organic material. The shaft furnace is also used to preheat the charge material before smelting. A typical representation of this furnace is given in Figure 2.23.

This furnace type is only used for non-ferrous metal melting, mainly for aluminium. Due to the complex construction and difficult renewal of the refractory, the furnace is only used for metals with low melting points. Therefore, the maintenance requirements of the furnace lining are rather limited. Typical refractory lifetimes are 4 to 8 years.

Modern furnace types with computer-controlled burner systems reach an energy use of 650 kWh/tonne of melted aluminium (at 720 ºC). The theoretical energy needed is 320 kWh/tonne. The thermal efficiency therefore is 50 %.

The shaft furnace is a continuous melting furnace with high capacity, ranging from 0.5 tonnes to 5 tonnes per hour and with a holding capacity of up to 50 tonnes. Due to its holding function, a change of alloy is difficult.
[24, ETSU 1994], [1, COM 2017]



Source: [24,ETSU 1994]

Figure 2.23: Shaft furnace

2.2.4.7.2 Advantages

- Due to the long preheating, the charge is very well dried before the melting starts. This makes the furnace well suited for al, due to the reduced risk of hydrogen uptake.
- ~~relatively low investment and operating costs. Operating costs are kept low by the effective preheating, automatic control and long refractory life~~
- Technical advantages are: low gas pick-up, excellent temperature control and low metal loss.

2.2.4.7.3 Disadvantages

- No flexibility regarding a possible change of alloy.

[38, VITO 2001]

2.2.4.8 Crucible furnace

2.2.4.8.1 Description

These are simple crucibles that are heated externally by the combustion gases from gas or oil combustion, by electricity or, for lower temperatures, by thermal fluid. Contact with a direct flame is avoided to prevent there being local hot spots at the base of the crucible and so that good temperature control can be maintained in the melt, to prevent oxidation and vaporisation of the metal.

This furnace type is only used for non-ferrous metal melting. Due to the indirect heating (through the crucible wall) no burn-off or gas take-up can take place. These furnaces are used for the production of small amounts of molten metal (less than 500 kg per batch) and for low production capacities. Example furnaces are displayed in Figure 2.24.

Source: [132, HUT 2003]

Figure 2.24: Crucible furnaces

The crucible is tilted manually, with a crane, or automatically to pour the molten metal into the mould. For copper based materials, only graphite or carborundum (silicon carbide) crucibles are used, whereas aluminium can also be melted in cast iron crucibles.

Crucibles used for holding, transport and metal treatment in ferrous foundries are called ladles. [38, VITO 2001], [41, Teknologisk 2000], [120, TWG 2003]

2.2.4.8.2 Melting practice

The cold load is brought into the crucible, and heating is started at full power in order to melt the load. At 50 ºC to 100 ºC below the melting temperature, the power is switched off, and the load is heated further by the thermal inertia of the crucible. Afterwards, the temperature is levelled off using a control system. After deslagging, metal treatment can be performed. This involves oxygen removal, degassing, grain refining and the adjustment of volatile metals such as zinc and magnesium. The slag is then removed once more before casting takes place.

Besides regular renewal of the crucible, no maintenance is needed. The renewal time is primarily dependent on the alloy to be melted. Multiple alloy changes cause a more rapid crucible wear. SiC-crucibles, used for low melting alloys, have a useful life of 130 to 150 charges. For high melting alloys, the useful life is 50 to 80 charges.

Thermal efficiencies are 750-3 000 kWh per tonne of aluminium, i.e. 15-30 % efficiency.
[15, Binninger 1994], [38, VITO 2001], [41, Teknologisk 2000]

2.2.4.8.3 Advantages

- Simple technology.
- Low maintenance.
- Flexibility regarding change of alloy.

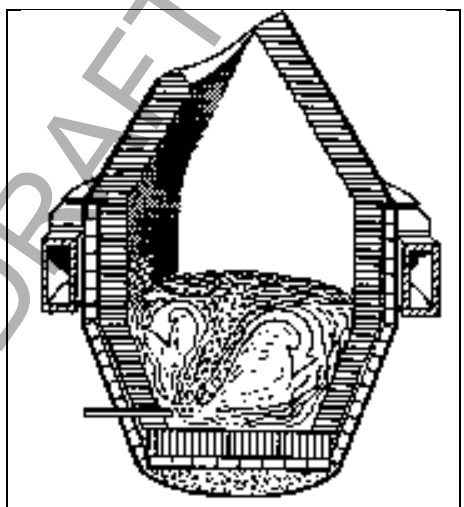
2.2.4.8.4 Disadvantages

- Low efficiency and production capacity.

[38, VITO 2001]

2.2.4.9 Argon Oxygen Decarburisation (AOD) converter for steel refining

The AOD converter is a special vessel for refining steel. The molten metal is transferred directly from the melting furnace (generally electric arc or induction) into the converter. As shown in Figure 2.25, oxygen (for the removal of carbon, silicon) and argon gas (for the stirring action) can be injected into the converter by means of tuyères positioned in its lower part, to refine the metal. The converter is equipped with a tilting mechanism in order to allow filling and emptying. Steel with a precise chemistry can be produced using AOD, but at a high cost. This system is not widely used in steel foundries outside the US.



Source: [132, HUT 2003]

Figure 2.25: AOD converter

The first phase of the refining process consists of a decarburisation, through the injection of oxygen into the converter. This is a refining operation that holds the carbon content of the charge material within a specific range, as required. Decarburisation is initiated by injecting oxygen into the metal bath. This creates a strong stirring action during which carbon in the melt is burned. At the same time the 'boiling' burns out silicon, and flushes out hydrogen and nitrogen from the metal bath. All impurities (oxides) are trapped in the slag. During melting, lime may be added to bring the slag to the proper basicity. When the carbon reaches the required concentration, oxygen injection is stopped and silicon and manganese are added to halt the boiling reaction, especially in the production of stainless steels. A dilution of the oxygen with argon or nitrogen assists the oxidation of carbon in preference to metallic elements such as iron,

chromium, etc., leading to very good metallic yields. Consequently Al or Si and limestone are added to the metal and argon is injected in order to remove sulphur. The continuous gas injection causes a violent stirring action and an intimate mixing of slag and metal which can lower sulphur values to below 0.005 %. The residual gas content of the treated metal (hydrogen and nitrogen) is very low. All impurities are trapped in the slag and removed with it. After temperature and alloy adjustment the metal is transferred to ladles for pouring.
[73, Brown, J. R. 2000], [14, CAEF 1997]

2.2.4.10 Vacuum Oxygen Decarburisation converter (VODC) for steel refining

The VODC (Vacuum Oxygen Decarburisation Converter) operates in such a way that molten steel is contained in the converter, which is attached to vacuum pumps, steam ejectors and an argon gas source. Two distinct processes are carried out in the vacuum treatment of stainless steel to obtain a higher quality level.

First, the steel is decarburised by introducing oxygen into the melt. At the same time, some argon is injected from the converter base. The converter uses vacuum pumps to lower the partial pressure of carbon monoxide, to such an extent that effective decarburisation can be carried out without oxidising too much of the chromium. This first process is similar to AOD decarburisation, but less argon is needed thanks to the lower total gas pressure and the process is much more efficient. The oxidised chromium is reduced back to liquid steel with aluminium.

The second process involves degassing. The converter is brought under deep vacuum (1-5 mbar) using a water ring pump and steam ejectors. Slight argon bubbling is continued in order to maintain an effective steel movement. At the very low pressure, gaseous impurities such as hydrogen and nitrogen are eliminated effectively. At the same time, the total oxygen content and the sulphur content are drastically decreased, which is beneficial for the mechanical properties of the end steel.

Low alloyed steels are normally only degassed.

The VODC process provides specific steel qualities, which cannot be obtained by other methods. The total oxygen content is also lower than what is typical for electric arc melted and AOD-treated steel, because a high level of oxide inclusions are removed form the melt during the VODC process, and most of the dissolved oxygen is further removed during the degassing phase.
[100, TWG 2002]

2.2.4.11 Metal treatment of steel

In order to guarantee a good casting quality, cast steel needs further treatment to remove impurities and the possible causes of defects, i.e.:

- *Deoxidation*: Oxygen dissolves in liquid steel, in the form of FeO. During solidification, the oxygen can then combine with C in the steel to form CO. This process can thus change the composition of the steel and generate porosity. Deoxidation is therefore always necessary. Deoxidation is performed with an element that preferentially binds the oxygen. Silicon, calcium silicide, titanium, zirconium and aluminium are possible deoxidants, with aluminium being the most powerful and the one that is most generally used. Aluminium is added in the form of a stick or wire (see Figure 2.26). The treatment is usually performed in the furnace and in the ladle. The produced aluminium oxide is insoluble in the melt and mixes with the slag.

Source: [132, HUT 2003]

Figure 2.26: Deoxidation, using an aluminium wire

- *Sulphide formation*: As the tensile strength of steel increases, the harmful effect of sulphur increases. Sulphur is soluble in liquid steel, but on solidification it precipitates as MnS. Precipitates can take various forms and have different effects. The form of the sulphides is related to the residual aluminium content after deoxidation. The residual amount of Al should allow the formation of type III sulphides.

[38, VITO 2001], [73, Brown, J. R. 2000]

2.2.4.12 Cast iron treatment

2.2.4.12.1 Alloying

During melting, some elements in the melt oxidise and are lost to the slag. At the end of the melting period a correction of the composition needs to be performed, in order to guarantee the appropriate final quality. For unalloyed cast iron, this is needed for: C, Si, Mn, S and P. If special properties are desired, specific alloying elements can be added, ranging from aluminium to zirconium, in concentrations of less than 1 % to more than 30 %. In general, these are added as ferrous alloy blocks or grains. The additions are made to the liquid iron, since this reduces the risk of oxidation losses.

The addition is performed in the furnace, in the molten metal flow during pouring, or by putting the additives in the transport ladle before pouring the molten metal into it.
[38, VITO 2001]

2.2.4.12.2 Homogenisation

The addition of alloying elements can introduce impurities such as oxides, sulphides or carbides into the iron. In order to reduce the negative effects from these compounds, the metal is overheated at 1 480 ºC to 1 500 ºC. Nevertheless overheating can affect graphite precipitation during solidification. Homogenisation has the following positive effects:

- Reduction of oxides (FeO, SiO_2, MnO) by C, generating CO bubbles. On their way through the melt these bubbles remove H_2 and N_2 from the melt.
- At high temperature and under intense bath movements, impurities coagulate and rise to the melt surface more quickly, where they are then taken up by the slag.

[38, VITO 2001]

2.2.4.12.3 Desulphurisation and recarburisation of cupola melted iron

Due to the intimate contact of the liquid metal with the coke, cupola melted iron shows a relatively high sulphur content. Sulphur pick-up in the cupola gives rise to a lower viscosity of the liquid metal, which is an advantage in some cases, e.g. for thin walled grey iron castings.

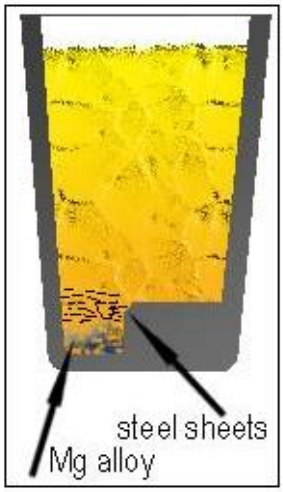
However, if the cast iron is to be treated with Mg (as described in the next section) to produce a nodular cast iron quality then the sulphur should be neutralised, to prevent excessive Mg consumption. This is performed by using one of a number of methods. In the porous plug method, nitrogen or argon gas is used to agitate the metal and CaC_2 powder is added to the metal. Upon contact with the liquid metal CaS is formed and removed as slag. The treated metal then flows to a holding ladle from which it is tapped for further treatment.

2.2.4.12.4 Nodularisation treatment of the melt

Nodular cast iron is obtained by the addition of Mg, either pure or as a FeSiMg or NiMg alloy, to the molten metal. Prior to this, a desulphurisation treatment may be necessary to guarantee successful nodularisation. The presence of Mg in the melt provokes a solidification of the graphite phase in the shape of microscopic spheres. This gives rise to higher mechanical properties, such as strength and ductility.

There are several techniques that can be applied to introduce Mg into the liquid metal:

- *The pour over technique*: This is the simplest method, whereby the liquid metal is poured over the Mg alloy in the bottom of the ladle.
- *The sandwich method*: Here Mg alloy is placed at the bottom of a specially designed ladle and covered with steel sheets or FeSi, as shown in Figure 2.27. The metal is poured into the ladle and after melting of the cover the Mg reaction takes place.
- *The Tundish Cover*: This is an improved sandwich technique, whereby the ladle is covered by a lid after the Mg alloy has been placed at the bottom of the ladle. The metal is poured in the concave lid and flows through a hole in the ladle, where the reaction takes place.
- *The plunging method*: Using a plunger bell, the Mg alloy is submerged in the liquid metal until the reaction is finished. During the treatment the ladle lid is closed, to prevent MgO fume emissions.
- *The G Fischer converter*: This process uses a special ladle that is closed tightly with a lid after the metal is poured into the converter in the horizontal position. The converter is then tilted into a vertical position, allowing the Mg alloy to react with the metal. Once the reaction is finished the converter is turned back into the horizontal position and is tapped after opening the lid.
- *The core wire injection*: Here very fine powdered Mg alloy is rolled in tin steel sheet, forming a filled wire. This wire is then injected, by a controlled mechanism, into a slender shaped ladle, where the Mg is released.
- *The flow through treatment*: Here the metal is poured into a special designed reaction chamber in which the Mg alloy was put earlier.
- *The ductilator*: In this method the metal is poured into a reaction chamber where the flow is forced to form a vortex. The Mg alloy is injected into the vortex with an inert carrier gas. The treatment can be performed on large quantities of metal or during mould filling.
- *The inmold process*: In this process the Mg alloy, shaped as a tablet, is put directly into the mould cavity (gating system). The reaction takes place during mould filling, ensuring a high yield.



Source: [132, HUT 2003]

Figure 2.27: The sandwich method for nodularisation

After treatment, the metal has to be poured into the mould within a specific time, as the Mg effect tends to fade quickly, necessitating a new treatment if a certain time limit (10-15 minutes) is exceeded.

The efficiency, the qualitative assessment of flue-gas production and the complexity of the various nodularisation methods are compared in Table 2.15.

Table 2.15: Comparison of various nodularisation procedures

	Sandwich	**Tundish cover**	**Plunging**	**Flow through**	**Wire injection**	**Inmold**	**Ductilator**
Mg- take-up efficiency (%)	35 – 50	45 – 60	40 – 60	40 – 50	20 – 50	70 – 90	60 – 75
Flue-gas production	High	Low	Low	Low	Low	No	High
Comment	Easy operation	Optimised sandwich but more maintenance	High maintenance	High maintenance	Expensive installation	Different design of pouring system	High maintenance
Source: [110, Vito, 2001], [225, TWG, 2003]							

2.2.4.12.5 Inoculation of the melt

The presence of coarse shaped graphite in a metal matrix leads to poor mechanical properties of the material. In order to get a fine crystalline metallurgical structure, inoculation of the melt is necessary prior to casting. This process introduces seeds for crystal growth into the metal melt. Usually FeSi alloys are used for this purpose. Ca, Al and rare earth materials are often included in the inoculant.

Again, several techniques can be used to inoculate the molten metal:

- *Injection during tapping*: Here the inoculant is injected directly into the metal flow during tapping.
- *Injection during pouring*: Here the inoculant is injected directly into the metal flow during pouring of the mould (see Figure 2.28).
- *Filled wire injection in the melt* (see Section 2.2.4.12.4).
- *Inmold process* (see Section 2.2.4.12.4).

Source: [132, HUT 2003]

Figure 2.28: Inoculation during pouring

2.2.4.13 Non-ferrous metal treatment

There are three main metal treatment (or refining) operations carried out in **aluminium** melting processes. These are as follows:

- *Degassing*: Molten aluminium dissolves hydrogen, which is then expelled upon cooling and can thus lead to porosity in the finished casting. Hydrogen therefore needs to be removed. This is done by bubbling an inert gas through the melt. Good degassing methods provide bubbles with high residence time and high surface area. The degassing of aluminium is mostly performed using an impeller station. This treatment uses a rapid-spinning mixer and nitrogen injection into the melt. Degassing is often combined with a cleaning of the melt. Cleaning is performed to remove alkali or alkaline earth metals, such as Ca. Cleaning can be done by Cl_2 gas. The use of HCE for this purpose has been banned in the EU *(Dir. 97/16/EC)*. A mixture of nitrogen with 3 % Cl_2 is generally used, for simultaneous degassing and cleaning. Alternative degassing methods use tablets, a lance with a porous head, or a porous stone in the holding furnace.
- *Modification and grain refining*: For aluminium alloys this usually involves the addition of small amounts of metal to the melt. These additions control the grain size and modify the microstructure of the solidifying metal and thus enhance the casting mechanical properties. Sodium or strontium are used for the modification, while grain refinement is achieved with titanium, titanium boride, zircon or carbon. This treatment is mostly performed in combination with degassing in a dedicated metal treatment station.
- *Fluxing*: This usually involves the addition of solid fluoride-based fluxes to the melt, to remove solid contaminants.

[65, UK Environment Agency 2002], [74, Brown 1999], [77, Wenk 1995]

There are four main metal treatment (or refining) operations carried out in **magnesium** melting processes. These are as follows:

- *Grain modification*: Grain modifiers for magnesium alloy processes are usually in the form of zirconium or formerly hexachloroethane (HCE). The use of HCE for this purpose has been banned in the EU *(Dir. 97/16/EC)*.
- *Fluxing*: This usually involves the addition of alkali, earth alkali, chloride and fluoride proprietary fluxes to the melt to remove solid contaminants.
- *Degassing*: For magnesium processes, nitrogen or argon gas sparging may take place for degassing and oxide removal. The degassing of magnesium alloys may also be effected by a mixture of argon and chlorine gases, when argon is used as a carrier gas.
- *Oxidation control*: The presence of beryllium within the melt grain modifies and stops oxidation. Finished magnesium alloys may contain up to 15 ppm beryllium by weight. A master alloy of aluminium/beryllium, containing up to a nominal 5 % beryllium, may be added to the molten magnesium alloy to give it this beryllium loading. Oxidation control

may also be achieved by blanketing the surface of the metal with an ~~carrier~~ inert gas, such as SO_2 or mixtures of nitrogen and R134a or of nitrogen and CO_2 and/or SO_2 or of sulphur and argon. ~~carbon dioxide or argon, containing up to 4 % sulphur hexafluoride. To date, the only flux-free alternative to SF_6 is SO_2. SO_2 is significantly cheaper then SF_6 but its main drawback is its toxicity, and as a result operations need to be enclosed better. Up to the present, only 1/3 of the foundries in Europe have been using SO_2.~~ Occasionally oxidation control may be achieved by sprinkling sulphur powder on the surface of the melt. ~~This issue is discussed in Section.~~

There are three main metal treatment (or refining) operations carried out in **copper** melting processes. Molten copper dissolves oxygen and hydrogen, which may recombine to form water vapour. This in turn will generate porosity in the casting. Degassing and deoxidation are thus applied to remove hydrogen and oxygen, respectively. The applicable metal treatment operations are as follows:

- *Deoxidation*: Deoxidation is performed by adding a reagent which binds the oxygen and forms a fluid slag. Care must be taken to prevent the deoxidation products from being entrained in the solidified casting and the residual deoxidant from adversely affecting the alloy properties. Phosphorus is the most commonly used deoxidation reagent. Alternatives are magnesium, manganese, calcium, silicon and boron.
- *Degassing*: Hydrogen is removed from the melt by bubbling an inert gas through it. Both argon and nitrogen may be used. The technique is comparable to aluminium degassing.
- *Fluxing*: Aluminium in alloys can oxidise and generate oxide skins. These can cause problems upon casting. In non-aluminium alloys, traces of aluminium can cause defects. Therefore they need to be removed, using fluxing agents. Fluxes are also used to cover the surface in order to prevent oxidation, zinc loss and hydrogen pick-up during melting. Specific fluxing agents exist for each type of treatment.

[66, UK Environment Agency 2002], [81, Closset 2002], [134, CAEF 2020]

2.2.5 Mould and core production

Moulding consists of making a mould in which the molten metal will be poured. ~~Some moulds may need to have special properties to produce high quality castings, which, for example:~~

~~- reproduce exactly and with a high dimensional precision the shape of the casting model~~
~~- give a smooth skin to the casting in order to avoid excessive fettling~~
~~- avoid any casting defects such as cracks, worming, pinholes, etc.~~

Just as the mould defines the outer shape of the casting, the core defines the inner one, or at least the parts not directly attainable by moulding.

Moulds may be classified in two large families:

- **Lost moulds** (single use moulds): These are specially made for each casting and are destroyed after pouring. The moulds are generally made of sand, and are chemically bonded, clay-bonded, or even unbonded. Investment casting can also be included in this family.
- **Permanent moulds** (multi use moulds): These are used for gravity and low-pressure casting, high-pressure die-casting, and centrifugal casting. Typically the moulds are metallic.

The cores used for ferrous castings are practically always made of sand. The choice of binder technology used depends on factors such as the size of the casting, the production rate, the metal poured, the shake-out properties, etc.

For sand moulding, the mould may be produced by manual or mechanical ramming actions, such as by jolt, squeeze, air impact, vibration, etc.. When the mould has sufficient strength it is released from the model, which can then be used to produce a new mould.

Generally, cores are produced by the same techniques as moulds, but small or medium sized cores are often blown or shot into wooden, plastic or metallic core boxes.

For non-ferrous casting, about 30 % of copper alloys are cast in sand moulds. Only about 10 % of light non-ferrous metals are cast in single use moulds. ***TWG, please update these figures***

The production of patterns and dies is generally carried out by specialised external suppliers. These activities are found in the metal and plastics treatment sectors.
[2, Hoffmeister et al. 1997], [14, CAEF 1997], [38, VITO 2001]

2.2.5.1 Selection of the mould type

TWG, please note that this section has been moved here from Section 4.3.1 in the previous BREF

The selection of the mould type is mainly based on technical criteria. The applicability of the various moulding types is summarised in Table 2.16. Additionally, Table 2.18 gives the general properties of various systems.

Table 2.16: Technical properties of the various moulding types

TWG, please note that industry (CAEF) proposes the deletion of this table as it is based on outdated US figures and it does not provide any necessary knowledge

	Green sand casting	Chemically bonded sand	Low-pressure and gravity die-casting	High-pressure die-casting
Relative cost in quantity	Low	Medium high	Low	Lowest
Relative cost for small number	Lowest	Medium high	High	Highest
Permissible weight of casting	Up to about 1 tonne	Up to a few hundred tonnes	50 kg	30 kg
Thinnest section castable, centimetres	0.25	0.25	0.3	0.08
Typical dimensional tolerance, centimetres (not including parting lines)	0.03	0.02	0.07	0.02
Relative surface finish	Fair to good	Fair to good	Good	Best
Relative mechanical properties	Good*	Good*	Good*	Best
Relative ease of casting complex design	Fair to good	Good	Fair	Good
Relative ease of changing design in production	Best	Fair	Low	Lowest
Range of alloys that can be cast	Unlimited	Unlimited	Copper base and lower melting point metals preferable	Aluminium base and lower melting preferable
(*) Mechanical properties may be enhanced by heat treatment *Source*: [42, US EPA, 1998][18, US EPA 1998]				

Table 2.17: Applicability of the various moulding types

	Lost moulds				Permanent moulds				
	Moulding methods				Casting technique				
	Green sand moulding	Shell sand	Phenol/Furan	Pep set/water glass	Low-pressure die-casting	Pressure die-casting (hot)	Pressure die-casting (cold)	Centrifugal casting	Continuous casting
Cast Iron									
Grey cast iron	X	X	X	X	O			X	X
Nodular cast iron	X	X	X	X				X	X
Malleable cast iron	X	O	X	O					
White cast iron	X	X	X						
Steel									
Unalloyed	X	X	X	X				X	
Low alloy steel	X	X	X	X				X	
Highly alloyed manganese steel	X	X	X	X				X	
Stainless and heat resistant	X	X	X	X			O	X	
Heavy Metals									
Brass	X	X	X	X	X				
Bronze	X	X	X	X					
Copper	X	X	X	X	X		X	X	X
Zinc alloys					O		X	X	
Light Alloys									
Aluminium alloys	X	X	X	X	X		X		X
Magnesium alloys	X	O	X	X	X	X	X		
Titanium	O	O	X	X	O				

X: The method can be used
O: The method is possible but not often employed
Source: [41, Teknologisk 2000]

Table 2.18: Technical properties of the various moulding types

	Green sand casting	Chemically bonded sand	Low-pressure and gravity die-casting	High-pressure die-casting
Relative cost in quantity	Low	Medium high	Low	Lowest
Relative cost for small number	Lowest	Medium high	High	Highest
Permissible weight of casting	Up to about 1 tonne	Up to a few hundred tonnes	50 kg	30 kg
Thinnest section castable, centimetres	0.25	0.25	0.3	0.08
Typical dimensional tolerance, centimetres (not including parting lines)	0.03	0.02	0.07	0.02
Relative surface finish	Fair to good	Fair to good	Good	Best
Relative mechanical properties	Good*	Good*	Good*	Best
Relative ease of casting complex design	Fair to good	Good	Fair	Good

Relative ease of changing design in production	Best	Fair	Low	Lowest
Range of alloys that can be cast	Unlimited	Unlimited	Copper base and lower melting point metals preferable	Aluminium base and lower melting preferable
(*) Mechanical properties may be enhanced by heat treatment *Source*: [42, US EPA, 1998][18, US EPA 1998]				

2.2.5.2 ~~Raw~~ Moulding materials

2.2.5.2.1 ~~Refractory materials~~ Moulding sands

~~Whatever~~ Independently of the type of binder applied, the physical and chemical properties of the moulding sands ~~refractory material~~ used to make the moulds or cores affects their characteristics and their behaviour during pouring. This is not surprising as these materials make up 95 % to 99 % of the produced~~ts~~ moulds and cores~~used~~.

The purchase price of each sand type has four main components – extraction, preparation, packaging and transportation. Transportation costs will vary for different regions. The main factor however in the price is the sand type. The average purchase price for the various types varies widely. ~~From a 1995 UK questionnaire, the tonnage price of chromite and zircon sand were respectively a factor 9 and 14 times higher than that of silica sand. In Portugal the cost of sand varies according to the amount purchased, but sand is generally cheaper in Portugal than in Spain, France or Italy. Portuguese prices (year 2003) range between EUR 20 - 25 per tonne of dry sand AFS 55, plus transport. Prices in the Czech Republic (year 2003) for silica sand range between EUR 10 and 20 for silica sand, with the price depending on the volume, packaging and treatment of the sand. The price for chromite sand is EUR 250 – 300/t, and for zircon sand EUR 250 – 400/t.~~
[29, ETSU 1995], [120, TWG 2003], [134, CAEF 2020]

The different types of refractory sands used for foundry purposes are described in the following sections.

2.2.5.2.1.1 Silica sand

This type of sand is the most commonly used, mostly because of its wide availability and its relatively low cost. Silica sand is composed of the mineral ‘quartz’ (SiO_2), which is more or less pure and clean, depending on its origin. Its dry piece specific weight fluctuates between 2.5 kg/dm^3 and 2.8 kg/dm^3. The dry bulk density (or loose volume weight) of silica sand is 1.4 kg/dm^3 to 1.6 kg/dm^3.

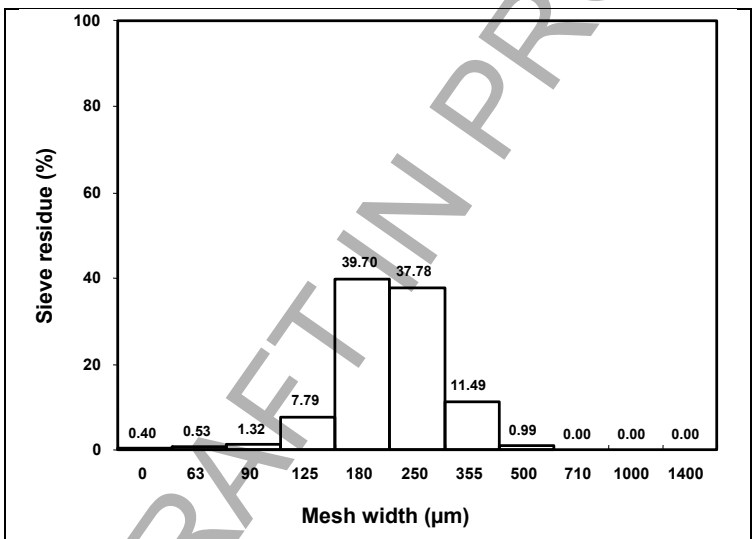
The thermal expansion of silica sand generates a mould movement upon pouring and cooling. Specific additives are therefore used, especially when producing cores, in order to prevent casting errors. These may be wood fluff, iron oxide~~ or cured foundry sand~~. Sand containing feldspar has a lower thermal expansion than pure quartz sand and a lower sintering point, but it is widely used in order to minimise expansion defects in castings.

Silica sand is neutral and is compatible with all binders and normal cast alloys. The respirable particulate matter (RPM) fraction of quartz is classified by IARC as carcinogenic [233, IARC, 1997]. Respirable crystalline silica (SiO_2) dust generated by a process is not subject to classification in accordance with Regulation (EC) No 1272/2008. On the other hand, work involving exposure to respirable crystalline silica dust generated by a work process is included in Annex I to Directive 2004/37/EC and a limit value for respirable crystalline silica dust (‘respirable fraction’) is established. This is mainly an occupational ~~This is a~~ health~~ and safety~~ issue. ~~Studies are ongoing to determine whether or not an air pollution issue also exists. The amount of quartz in dust is defined by the content of quartz in the input materials.~~ In the SF

data collection, SiO_2 emission data were reported by six plants (16 emission points) with concentrations ranging from 0.02 mg/Nm^3 to 3.1 mg/Nm^3; in total 15 out of the 16 emission points reported concentrations lower than 0.27 mg/Nm^3. [169, TWG 2021]

In green sand moulding technology, control of the grain size distribution is very important. Figure 2.29 shows a typical grain size distribution for silica sand. The grain size distribution is used to calculate the AFS number (AFS: American Foundry Society). This gives the overall fineness of the sand. The higher the AFS number, the finer the sand. An alternative classification system is the middle grain number or MK.

A finer sand grade will have more grains per gram, and thus a higher surface area. This requires more binder addition for an equal mould strength. Operators therefore try to use the coarsest sand, but one that still gives a good surface finishing aspect. Standard AFS numbers are 50-60. For very smooth surfaces a fine sand is needed, typically one with an AFS of 90-110 is used. Fine sands are also used in some instances to replace mould coatings.
[38, VITO 2001], [100, TWG 2002], [120, TWG 2003], [134, CAEF 2020]



Source: [38, VITO 2001]

Figure 2.29: Typical grain size distribution for silica foundry sand

2.2.5.2.1.2 Chromite sand

Chromite is a chrome ore, with the theoretical formula $FeO.Cr_2O_3$, which contains other components such as magnesium and aluminium oxides. For its use in foundries, its silica content must be lower than 2 % in order to prevent sintering at low temperatures. Its characteristics are as follows:

- density: 4.3 to 4.6, compared to 2.65 for silica sand;
- theoretical melting point: 2 180 ºC, but the presence of impurities can lower this to 1 800 ºC;
- thermal diffusivity: more than 25 % higher than that of silica sand;
- thermal expansion: regular, without a transition point, and lower than that of silica sand;
- pH: rather basic, from 7 to 10.

Chromite sand is more refractory than silica. It is more thermally stable and has a greater chilling power. Chromite sand provides a better surface finish on large castings. It is therefore used for the production of large castings and in areas of the mould where chilling is required.
[14, CAEF 1997]

2.2.5.2.1.3 Zircon sand

Zircon is a zirconium silicate, $ZrSiO_4$. Zircon is the most widespread zirconium ore. Its characteristics are as follows.

- density: 4.4 to 4.7, compared to 2.65 for silica sand;
- melting point: higher than 2 000 ºC;
- thermal diffusivity: more than 30 % higher than that of silica sand;
- thermal expansion: regular, without a transition point, and lower than that of silica sand.

The general characteristics of zircon sand are similar to that of chromite, but zircon sand produces a better finish as a finer grade is used. These physical and thermal properties account for its use for moulding or core-making in difficult cases, in spite of its very high price.
[14, CAEF 1997], [29, ETSU 1995]

2.2.5.2.1.4 Olivine sand

Olivine sands are a mineral group which includes forsterite, fayalite and others. The characteristics of olivine sands are as follows:

- melting point: forsterite: 1 890 ºC, fayalite: 1 205 ºC;
- density: 3.2 to 3.6;
- pH: around 9.

The basic pH makes this type of sand not suitable for use with acid catalysed binder systems.

Olivine sand is produced by crushing natural rocks, which explains its diverse characteristics. It is usually used for moulding and core-making in manganese steel casting. The presence of manganese prohibits the presence of silica as these two components react to give a very fusible compound. ~~The reported purchase price in Spain is EUR 130/tonne (2002).~~
[14, CAEF 1997], [108, Martínez de Morentin Ronda, J. 2002]

2.2.5.2.2 Binders and other chemicals

2.2.5.2.2.1 Bentonite

Bentonite is a smectite clay, which has a lamellar structure. By adding water, the clay structure swells due to the adsorption of water molecules. The clay then becomes workable and can be spread to coat the sand grains during mixing.

Natural calcium bentonites do not swell or gel when mixed with water. They are rarely used at present, being used only for very special castings. Alternatively, these materials may be ‘activated’ by treatment with soda ash to give ‘soda activated bentonites’. These are used extensively in ferrous foundries throughout Europe; their properties approach those of natural sodium bentonites.

Natural sodium bentonites greatly swell when mixed with water. The main features in green sand are their high dry strength, good tolerance to water content variation, high resistance to burn-out and their improved high temperature durability. As they are imported from the US, where they are in common use, their price generally limits their use to high value steel casting or in blends with activated calcium bentonites.

Pouring molten metal into a green sand mould subjects the moulding-sand to considerable heat. This heat removes moisture from the sand and destroys the clay-bonded structure (and additives). If during pouring and cooling bentonite stays below the deactivation temperature, the

lamellar structure is maintained as well its ability to swell and develop cohesion. The deactivition temperature varies with the bentonite type.

~~Prices for bentonite range between EUR 70 – 250/t, depending on the packaging and product type (Czech Republic, 2003).~~
[14, CAEF 1997], [30, ETSU 1995], [100, TWG 2002], [120, TWG 2003]

2.2.5.2.2.2 Resins

Over the past few decades a range of chemical binders have been developed. These are single- or multi-component systems which are mixed with the foundry sand until all the grains are coated with a thin film. After mixing, a hardening reaction starts, binding the sand grains together and developing mould strength. Resins can be classified according to the hardening method:

- cold-setting resins;
- gas-hardened resins;
- hot-curing resins.

The various resin types will be discussed under Section 2.2.5.7. In Table 2.19, Table 2.20 and Table 2.21 an overview ~~survey~~ of the applicability and the distribution of the various sand systems~~resins~~ are given.
TWG, please update the tables below with more recent data if available

Table 2.19: ~~Survey~~ Overview of various resin types and their applicability

~~Hardening~~ Curing	Resin type ~~("commercial name")~~	Mould production	Core production	Curing temperature	Hardening time (*)	Metal types	Size of series
Cold-setting	Furan resin, acid curing	Medium to large	Some	10 – 30 ºC	10 – 120 min	Ferrous + non-ferrous	Small to large
	Phenolic	Large	~~No~~Some	10 – 30 ºC	10 – 180 min	Ferrous	Small to large
	Polyurethane (phenolic isocyanate) ~~("Pepset/Pentex")~~	Small to medium	Some	10 – 30 ºC	5 – 60 min	Ferrous + non-ferrous	Small to large
	Resol-ester ~~("Alfaset")~~	Small to Large	Some	10 – 30 ºC	5 – 400 min	Ferrous + non-ferrous	Small to large
	Alkyd oil	Large	Some	10 – 30 ºC	50 min	steel	Small
	Silicate - ester ~~Water glass~~	Medium to large	No	10 – 30 ºC	1 – 60 min	Ferrous + non-ferrous	Small to medium
~~Gas-hardening~~	~~Phenolic/Furan[1] ("Hardox")~~	~~Small~~	~~Yes~~	~~10 – 30 ºC~~	~~<60 s~~	~~Ferrous + non-ferrous~~	~~All~~
Gas-hardening	Polyurethane Coldbox, Amine catalyst ("Cold-box")	Small	Yes	10 – 30 ºC	<60 s	Ferrous + non-ferrous	All
	Resol, Methyl formate curing ~~("Betaset")~~	Small	Yes	10 – 30 ºC	<60 s	Ferrous + non-ferrous	All
	~~Acryl/~~Epoxy/ acrylic SO_2 curing ~~("Isoset")~~	No	Yes	10 – 30 ºC	<60 s	Ferrous + non-ferrous	All
	Silicate, CO_2 curing	Small	Yes	10 – 30 ºC	<60 s	Ferrous + non-ferrous	All

	Resol, CO_2 curing	No	Yes	10-30 ° C	< 60 s	Ferrous	All
Thermosetting	Oil	Small	Yes	180 – 240 ºC	10 – 60 min	Ferrous	Small
	"Warm-box"	Seldom	Yes	150 – 220 ºC	~~20 –~~ < 60 s	Ferrous	Medium to large
	"Hot-box"	Seldom	Yes	220 – 250 ºC	~~20 –~~ < 60 s	Ferrous + non-ferrous	Medium to large
	Shell moulding, "Croning"	Yes	Yes	250 – 270 ºC	120 – 180 s	Ferrous + non-ferrous	Large
	Silicate; Inorganic binder	No	Yes	150-180 ° C	< 60 s	Al	Large

(*) i.e. the release time - the time in which the mould/core has gained sufficient strength to be released from the pattern.
[1] Not applied for capacities < 20 tonnes/day.
Source: [38, VITO 2001] amended by [134, CAEF 2020]

TWG, please update the tables below with more recent data if available

Table 2.20: Share of no bake sands in German ferrous and non-ferrous metal foundries in 2012

System	Share [%]
Furan resin	80
Phenolic resin	15
Polyurethane resin	< 3
Resol resin, ester cured	< 3
Silicate	< 3
Source: [133, DE UBA 2014]	

Table 2.21: Share of core sands for serial production in German ferrous and non-ferrous metal foundries in 2012

System	Share [%]
Polyurethane Coldbox, Amine	78
Warm-box, Hot-box	7
Water glass system	5
Epoxy/acrylic, SO_2 curing	4
Resol CO_2	3
Shell moulding/Croning	1
Methyl formate curing	1
Source: [133, DE UBA 2014]	

2.2.5.2.2.3 Coal dust

Coal dust is usually added to green sand for cast iron moulding. It is used to a limited extent in some non-ferrous foundries. Coal dust may be mixed with small amounts of resins and oil products. During casting, the thermal degradation produces 'lustrous carbon', which improves the casting surface finish and shake-out properties. Coal dust is added for three reasons:

- to create an inert atmosphere in the mould cavity during pouring, through the combustion of organic compounds, which in turn slows down the oxidation of metal (slag formation);
- to reduce the penetration of metal in-between the quartz grains, through deposition of a graphite film, which also creates a flat casting surface;
- to reduce the amount of sand remaining on the casting surface upon shake-out.

In addition to the black and sticky dust caused by handling, coal dust may contain or generate polycyclic aromatic hydrocarbons (PAH) during pouring.

For steel castings, coal dust is not used because of carbon pick-up. In this case, it is usually replaced by cereal binders such as starch or dextrin.

Various types of coal dust or coal dust replacements exist. These consist of ~~blends of high volatile, high~~ lustrous carbon generating materials blended with clays. ~~They are generally more environmentally acceptable than coal dust, i.e. producing less fume during casting, although some coal dust replacements will generate more PAH in the sand.~~
[73, Brown, J. R. 2000], [120, TWG 2003], [134, CAEF 2020]

2.2.5.2.2.4 Cereal binders

Cereal binders are used mainly in steel foundries to increase the strength and toughness of the green sand. There are two main types of cereal binder: starch and dextrin. Starch is the basic material and is produced from a number of plant materials, with maize starch being the most commonly used for foundry purposes. Dextrin is a repolymerised form of starch, produced through a subsequent acid and thermal treatment of starch.

Starches can help to reduce expansion defects, since as they burn out, they allow the sand grains to deform without deforming the mould. Cereals increase the green strength, dry strength and toughness but can reduce the flowability. Dextrines improve the flowability and moisture retention, preventing moulds from drying out and edges becoming friable.

Cereal additions do not improve the erosion resistance of the sand or its resistance to metal penetration.
[73, Brown, J. R. 2000], [120, TWG 2003]

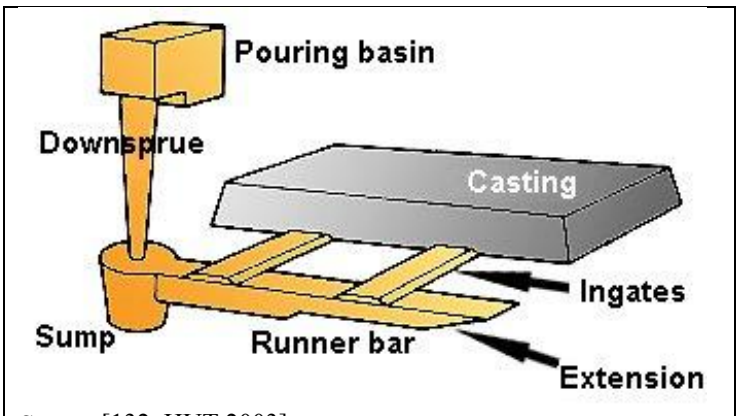
2.2.5.2.2.5 Iron oxide

Iron oxide reacts with quartz at high temperature and forms a low melting compound, fayalite. This glassy plastic product sinters the grains together. It is mainly used in the production of core sand, in order to reduce the formation of veins.
[38, VITO 2001]

2.2.5.2.3 Running, gating, feeding and filtration

The different parts of the running and gating system are shown in Figure 2.30. The system carries out the following functions:

- controls the flow of the metal into the mould cavity at the rate needed to avoid cold metal defects in the casting;
- avoids turbulence of metal entering the mould;
- prevents slag and dross present in the melt from entering into the mould;
- avoids high velocity impingement of the metal stream onto cores or mould surfaces;
- encourages thermal gradients within the casting, which help to produce sound castings;
- enables the casting to be separated from the running/gating system easily.



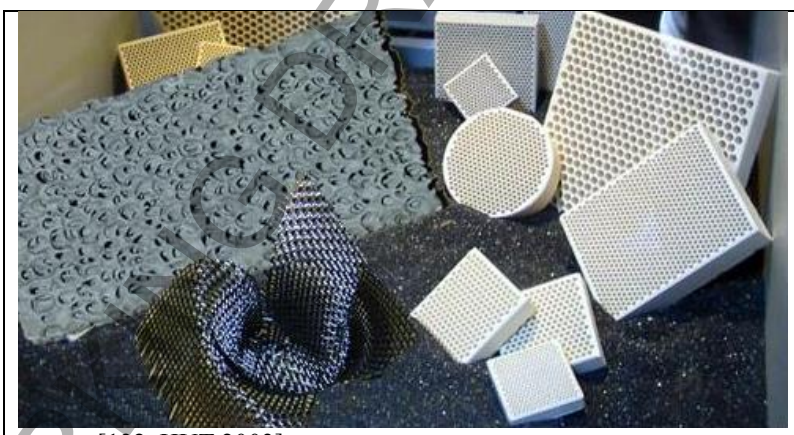
Source: [132, HUT 2003]

Figure 2.30: Components of the running and gating system

The design of the running system needs to take account of the varying slag and dross forming properties of the metal to be poured, e.g.:

- in lamellar iron, some furnace slag may be present but the melt is not subject to inclusions due to oxidation;
- nodular iron contains magnesium silicate and sulphide dross, arising from the nodularisation treatment;
- steel is susceptible to oxidation and slag formation;
- aluminium alloys (and aluminium bronzes) are all subject to dross formation, whereby a film of oxide forms immediately on any metal surface exposed to air.

Inclusions in steel can arise from slag entrapment, the erosion of furnace or ladle linings or refractories, or from deoxidation. Filtration is now widely used to reduce the presence of inclusions. The introduction of ceramic filters has even enabled simplifications to be made in the design of running and gating systems. Various types of filters are shown in Figure 2.31.



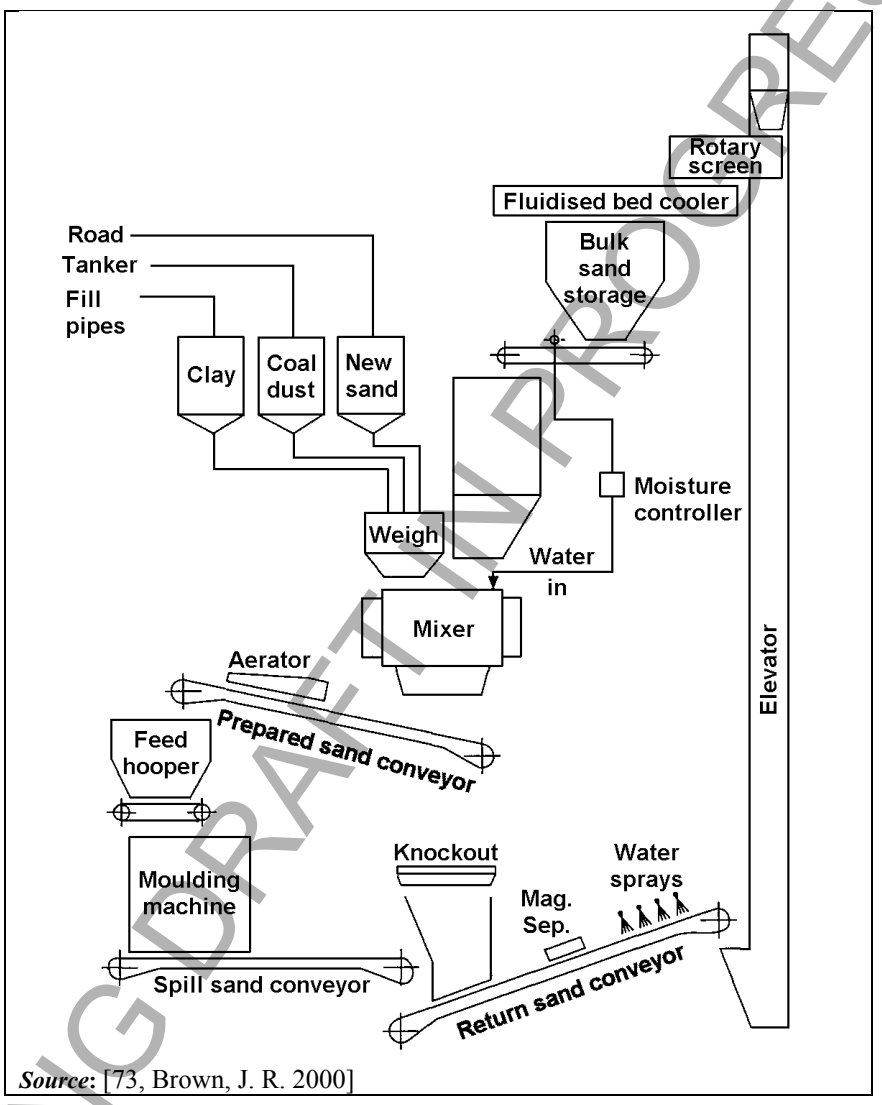
Source: [132, HUT 2003]

Figure 2.31: Various types of filters

2.2.5.3 Sand preparation (transport, sieving, cooling, mixing)

2.2.5.3.1 Sand conditioning (preparation) for green sand moulding

One of the major advantages in using green sand moulding is that the sand from the moulds can be reconditioned for multiple re-use. The layout of a typical green sand plant is depicted in Figure 2.32, and some examples of sand mixers are shown in Figure 2.33.



Source: [73, Brown, J. R. 2000]

Figure 2.32: Flow diagram for a typical green sand plant

Source: [132, HUT 2003]

Figure 2.33: Various types of sand mixers

As the sand usually contains metallic elements such as flashes, pouring drops, pieces of sprue or even small parts of casting, all these have to be removed, at first by means of magnetic iron separators. If separation of the magnetic iron castings is not achieved or not possible, separation may be carried out by Eddy current separators. The residual sand lumps are then broken up. It is important not to crush the sand, in order to prevent the demixing of the sand and bentonite.

Usually, the sand has to be cooled in order to keep the moisture level of the prepared sand as constant as possible and to avoid any loss by evaporation. Cooling is often performed in a fluidised bed, which also allows the sand to be dedusted by removing excessive amounts of fines.

The sand is then screened to remove the remaining lumps and stored before mixing with the required amounts of additives, say clay, water, etc. to prepare the green sand for reuse.
[14, CAEF 1997], [73, Brown, J. R. 2000]

2.2.5.4 Moulding with natural sand

Some foundries use naturally bonded sand. This is sand which contains a natural percentage of clay. Only water needs to be added in order to activate the binding capacity. If needed, some additives may be mixed as well. The approximate composition of natural sand is given in the following table.

Table 2.22: Composition of natural sand

Compounds	Approximate %
Quartz sand	80
Clay	15
Water	5
Source: [41, Teknologisk 2000]	

Natural sand, which is found ready-mixed in nature, does not have the same high demands for mixing equipment as synthetic sand. It is mainly used in small-sized non-ferrous (e.g. copper) foundries and is ~~not~~ seldom used in foundries casting iron and steel.

2.2.5.5 Moulding with clay-bonded sand (green sand moulding)

Green sand moulding is the most common moulding process. Green sand is generally not used to make cores. Cores are formed using a chemical binding system. Green sand is the only process that uses a moist sand mix. The mixture is made up of about 85 % to 95 % silica ~~(or olivine or zircon)~~ sand; 5 % % to 10 % bentonite clay; 3 to 9 % carbonaceous materials such as powdered ~~(sea)~~ coal, ~~petroleum products, corn starch or wood flour;~~ and 2 % to 5 % water. The clay and water act as the binder, holding the sand grains together. The carbonaceous materials burn off when the molten metal is poured into the mould, creating a reducing atmosphere which prevents the metal from oxidising as it solidifies. Table 2.23 gives a survey of the additives used for various types of metal castings.

Table 2.23: Composition of additive mix for green sand preparation (excluding water)

Metal	Additives for green sand preparation
Nodular cast iron casting Lamellar iron casting Malleable iron casting	Bentonite Cereal binder* Coal dust
Steel casting	Bentonite Cereal binder*
Light metal and aluminium casting	Bentonite Cereal binder*
Magnesium-alloyed-aluminium casting	Bentonite Boric acid
Magnesium casting	Bentonite Powdered sulphur Boric acid
Heavy metal casting (copper alloys)	Bentonite Cereal binder* coal dust
* Optional additive. *Source:* [16, Winterhalter et al. 1992]	

Green sand, as demonstrated by its widespread use, has a number of advantages over other casting methods. The process can be used for both ferrous and non-ferrous metal casting and it can handle a more diverse range of products than any other casting method. For example, green sand is used to produce the total range of castings, from small precision castings up to large castings of up to a tonne. If uniform sand compaction and accurate control of sand properties are maintained, very close tolerances can be obtained. The process also has the advantage of requiring only a relatively short time to produce a mould compared to many other processes. In addition, the relative simplicity of the process makes it ideally suited to a mechanised process.

Although manual moulding is still in use, machine moulding is currently the most widespread. Two sequential operations must be performed by a moulding machine: the first is ramming the sand, followed by separating the pattern from the compacted sand. The most commonly used processes proceed from the working principles described hereafter.

Squeeze moulding machines use pressure to pack the sand, which is applied through a squeeze head or by a multiple-piston squeeze head. Moulding by squeezing alone becomes less effective as the depth of the half mould increases. In these cases, jolting the work table greatly increases the compaction of the sand.

In impact moulding, sand is fed under gravity into the flask and compacted by the instantaneous release of compressed air through a rapid acting valve. This process gives a high and uniform densification, particularly in the sand surrounding the pattern.

Flaskless moulding, with both vertical and horizontal parting, achieves impressive production efficiencies. High mould accuracies can be achieved, but this process requires an effective set-up and high quality patterns to achieve the desired objective.
[14, CAEF 1997], [18, US EPA 1998]

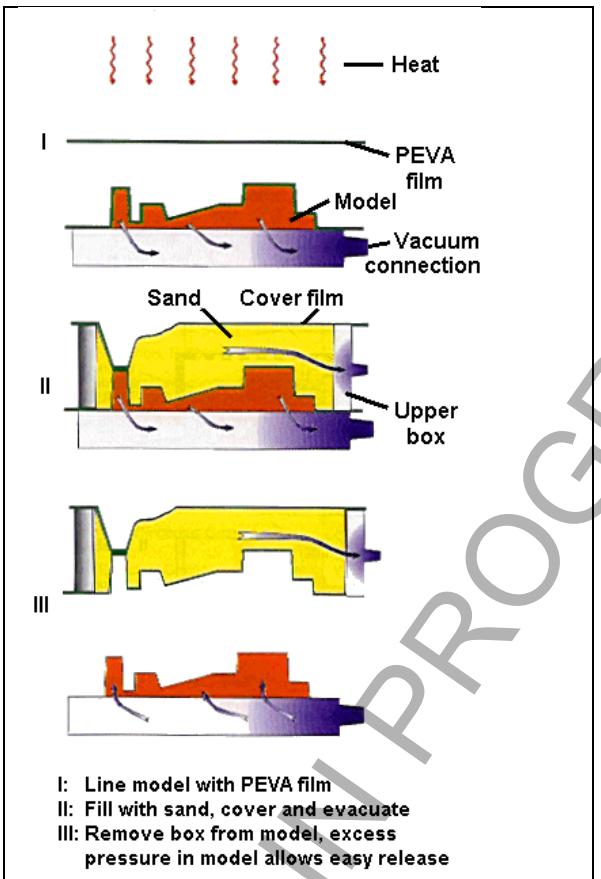
2.2.5.6 Moulding with unbonded sand (V-process)

This process uses dry sand, rammed by vibration without any binder addition, with the sand held between two polyethylene sheets by partial vacuum.

The production of a half mould is illustrated in Figure 2.34. The successive steps of the process are as follows:

- The pattern is fixed to an airtight chamber which is connected to a vacuum pump. The pattern is vented by small diameter holes connecting through the airtight chamber.
- A thin film of polyethylene vinyl acetate (PEVA), 75 to 100 microns thick, is heated up to 85 ºC.
- This film, which is expanded under heat, is applied on the pattern and fixed by vacuum applied through the airtight chamber.
- A moulding box, in which a vacuum can be created, is placed on the pattern, and filled with dry sand.
- This sand is compacted by vibration, made even, and then a second film of PEVA is applied to the sand.
- Air is extracted from the moulding box and at the same time, the vacuum is released in the airtight chamber; the vacuum stiffens the sand and the half mould can then be stripped off.
- The second half mould is made in the same way and both are assembled and closed, with the vacuum still being applied.
- The metal can now be poured, the two moulding boxes remaining under vacuum until the casting is cool enough to be shaken out.
- Shake-out occurs simply by shutting off the vacuum: the sand flows out from the box through the grid and may be recycled after dedusting and separation of the unburned plastic sheets.

[73, Brown, J. R. 2000]



Source: [78, Hoppenstedt 2002]

Figure 2.34: Vacuum moulding

2.2.5.7 Moulding and core-making with chemically bonded sand

For core-making, chemical binding systems are primarily used. Cores require different physical characteristics than moulds; therefore, the binding systems used to make cores may be different from those used for moulds. Cores must be able to withstand the strong forces which can occur when molten metal fills the mould, and often must be later removed from small passages in the solidified casting. This means that the binding system used must produce strong, hard cores that will collapse to allow removal after the casting has hardened. Therefore, cores are typically formed from silica sand (and occasionally olivine, zircon or chromite sand), and strong chemical binders. The sand and binder mix is placed in a core box where it hardens into the desired shape and is removed. Hardening, or curing, is accomplished with a chemical or catalytic reaction or by heat.

Table 2.21 (in Section 2.2.5.2.2.2) gives the relative share of the various core-making processes in German ~~automobile~~ foundries in 2012~~1991~~. This shows that the amine cold-box and warm-box/hot-box systems dominate the market. ~~Over 90 % of the automobile foundries use the amine cold-box system.~~ Since the 2010s, the share of inorganic silica systems in aluminium foundries producing automotive parts has been increasing. The other processes ~~(croning, CO_2-silicate)~~ are mainly used for supplementary use, i.e. making cores with specific requirements (size, thickness, etc.)
[18, US EPA 1998], [73, Brown, J. R. 2000], [134, CAEF 2020]

~~System~~	~~Number~~
~~Amine cold-box~~	~~44~~
~~Hot-box~~	~~10~~
~~Shell/croning~~	~~9~~

~~CO_2 – silicate~~	~~3~~

~~Core-making processes used in 48 automobile foundries in Germany, 1991~~
~~**[174, Brown, 2000][73, Brown, J. R. 2000]**~~

2.2.5.7.1 Cold-setting processes

The curing of cold-setting sands is effective at ambient temperature. The process begins when the last component of the formulation has been introduced into the mix. It then continues for a few minutes to several hours, depending on the process, the amount of binder and the hardening agent strength.

These processes are more often used to make moulds ~~than~~and cores, especially for medium or large sized castings.

2.2.5.7.1.1 Phenolic acid ~~catalysed~~ curing

This process has been in use since 1958. As the components are relatively cheap, it is mainly used for the production of large parts. It is applicable for all alloy types. ~~The hardening of these resins is more difficult and less regular compared to the furan resins.~~

The resins are either phenol-formaldehyde (PF), or urea-formaldehyde/phenol-formaldehyde copolymers (UF/PF), both being 'resols', with a formaldehyde/phenol ratio higher than one.

The catalysts are strong sulphonic acids, such as paratoluene, xylene or benzene-sulphonic, with sometimes an addition of sulphuric acid, usually used in a diluted form.

2.2.5.7.1.2 Furan acid curing~~catalysed~~

These binders, firstly introduced in foundries in 1958, are commonly used for the moulding and core-making of medium and large sized parts, for small and medium batch production and for all alloy types. Only certain types are used for steel casting, as cracks, fins or pinholes may occur. The process allows good flexibility in application and properties. Furfuryl alcohol (FA) has the disadvantage of being a (strategic) basic product, which leaves it subject to market price variations. Furan binders are comparable to phenolic binders in that their setting mechanism and the acid catalysts used are the same for both processes. Some examples of furan cores are shown in Figure 2.35.

Source: [132, HUT 2003]

Figure 2.35: Furan cores

The addition of an acid ~~catalyst~~ to a furan resin causes an exothermic polycondensation, which cures ~~hardens~~ the binder. Furan resins are available with different formulations, all of which are based on furfuryl alcohol:

- furan resin FA;
- urea - formaldehyde - furfuryl alcohol UF - FA;
- phenol - formaldehyde - furfuryl alcohol PF - FA;
- urea - formaldehyde - phenol - furfuryl alcohol UF - PF - FA;
- resorcinol - furfuryl alcohol R - FA.

A silane is nearly always added to enhance the resin-sand bond. The acids for curing~~catalysts~~ are strong sulphonic acids, such as paratoluene, xylene or benzene-sulphonic, sometimes with an addition of sulphuric or phosphoric acid, usually used in a diluted form.
[38, VITO 2001]

2.2.5.7.1.3 Polyurethane (phenolic isocyanate)

This process is used to a minor extent for moulding and core-making, with restrictions for steel casting, as cracks or pinholes may occur. These can be prevented however, by the addition of iron oxide. ~~and by drying the moulds and cores. In some countries (e.g. Sweden) this type of binder has not been used for 25 years, mainly because of its effect on the working environment.~~

This process is based on a polyaddition reaction between a phenolic resin and an isocyanate (mostly MDI), catalysed by a pyridine derivative; with the result being a polyurethane structure. All the components are in solution in aromatic and/or polar solvent (i.e. aliphatic solvent) with a high boiling point. Contamination by water must be strictly avoided since water reacts strongly with the isocyanate.

2.2.5.7.1.4 Resol-ester (alkaline phenolic ester curing~~hardened~~)

This process is used for small or medium batch production. It may be used for all alloy types but is of special interest for lighter alloys, because of the ease of shake-out. The absence of nitrogen in the compounding reagents is a benefit for steel casting.

The resin is an alkaline phenolic resol solution, which reacts with a liquid ester. The resin and the ester produce an unstable complex, causing gelification. The complex disintegrates and causes cross-polymerisation of the resin, producing a salt and an alcohol.

In this process, the curing speed is not adjusted by the addition rate of the hardener, but by using different grades. The curing ~~hardening~~ time may vary from a few minutes to more than one hour. Mechanical properties immediately after curing~~hardening~~ are rather poor, but improve upon storage.

2.2.5.7.1.5 Alkyd oil, unbaked

This process is mostly used for single castings or for small batch production in steel foundries. It provides the benefit of a good surface finish and good stripping properties. However, it is expensive.

An oil modified polyester resin is mixed with isocyanate, producing a polyurethane resin, which hardens slowly. The curing of the mould is accelerated by a catalyst and completed by heating to 150 ºC.

2.2.5.7.1.6 Ester silicate

This process is used mostly in steel foundries, for medium and large sized castings in medium and small series. It is similar to the unbaked alkyd oil process. However, it has poor shake-out properties and lower mechanical resistance than organic resin-bonded systems.

The curing ~~hardening~~ of a silicate - ester sand proceeds through an intermediate step, which consists of the hydrolysis of the ester by the alkaline silicate solution. This hydrolysis produces glycerol and acetic acid, which precipitates a silicate gel to form the initial bond. Further strength develops as the residual silicate dries.

2.2.5.7.1.7 Cement

This process is only used for very large sized castings. Its application is relevant for public works applications. It does not generate any emission problems during moulding or core-making.

2.2.5.7.2 Gas curing ~~hardened~~processes

In these processes, curing takes place by injecting a catalyst or a hardener in a gaseous form. The curing speed can be very high, which allows high production rates to be achieved. They are suitable for moulds and cores of limited size, in medium batch or mass production. Their use has been constantly expanding over the last decades~~few years~~.

The chemistry behind many of these gas curing~~hardened~~ processes is similar to the cold-setting processes. Because of the gaseous form of the catalysts, it is sometimes necessary to collect and treat their emissions.

2.2.5.7.2.1 Cold-box (amine-catalysed~~hardened~~ phenolic urethane binder)

This process is commonly used to make cores of up to 100 kg and more, and small moulds. It provides a very smooth surface finish, and the dimensional accuracy is very high. The core removal properties are excellent and the sand can easily be reclaimed. This process is the most commonly used in core-making. An example cold-box core is shown in Figure 2.36.

Source: [132, HUT 2003]

Figure 2.36: Cold-box core

The chemistry of this polyurethane based process is very similar to the polyurethane cold-setting one, e.g. it involves a phenolic resin and an isocyanate (MDI). Only the catalyst is different; here a tertiary amine is used, such as triethylamine (TEA), dimethylethylamine (DMEA), dimethylisopropylamine (DMIPA) or dimethylpropylamine (DMPA). The amine is

applied as a vapour, using compressed air, nitrogen or CO_2 as a carrier gas. Both resin and isocyanate are in solution in aromatic and/or polar solvents that have high boiling points. Contamination by water must be strictly avoided as it reacts strongly with isocyanate and weakens the binder.

The amine is delivered either by a generator, in which a supporting gas, preferably inert, is saturated with amine vapours, or by an injector, which measures out just the right amount of amine required for the operation, this latter being carried to the sand by compressed air or gaseous nitrogen. The addition rate for the binder varies from 1.0 % to 2.0 % based on the sand weight, with resin and isocyanate in a 50:50 ratio.

The amine is just a catalyst and is not consumed in the reaction. After curing, it remains in the sand of the mould or core and has to be purged. The purging period currently lasts 10 to 15 times longer than the injection of the amine. The amount of amine required for curing is about 0.05 % based on the sand weight, but typically 0.10 % to 0.15 % is used.

~~In a variant of the process called the 'Cold-box Plus' process the core box is heated to 40 - 80 ºC using circulating hot water. This yields cores with even better mechanical properties, but results in higher interval times.~~
[38, VITO, 2001]

2.2.5.7.2.2 Resol-methyl formate~~ester~~ (alkaline phenolic methyl formate curing~~hardened~~)

~~This process is relatively new. Its advantages and disadvantages are similar to those of the cold-setting process from which it is derived. As its price is relatively high,~~ This process is mostly used for core-making. Even though difficulties in recycling used sand have been reported, this process is ~~widely~~ used, mainly because of its shake-out properties; the ability to prevent cracking, veining and pinholes; and because of its low odour emissions. The process can be used for all types of series and alloys. ~~but is mainly used for light and super light alloys (easy shake-out) and steel (low crack risk).~~

The resin is an alkaline phenolic resol, which reacts with methyl formate to produce methanol and an alkaline formate. The phenolic resin is precipitated as a gel that binds all compounds together. Further cross-linking leads to even higher strength on storage.

Methyl formate is liquid at ambient temperature, the boiling point being 32 ºC, but it is gasified by air typically heated up to 80 ºC; which also acts as the carrier in the process. The gassing period is always followed by an air purge, the purpose of which is to evenly distribute the methyl formate throughout the mass of sand.

2.2.5.7.2.3 SO_2-hardened furan resins

TWG, please note that industry (CAEF) proposes the deletion of this process because according to their knowledge the process is no longer in use

~~This process is no longer in widespread use, although it is suitable for a large range of applications in the manufacturing of small to medium sized moulds and cores in any alloy. The sulphur catalyst may cause some metallurgical problems on the surface of ductile iron castings. The major advantages it provides are long lifetime of the prepared sand, good mechanical properties and shake-out performance, and the prevention of cracks. Nevertheless its effective implementation is limited due to the adhesive character of the resin and due to concerns in using sulphur dioxide as a hardener.~~

~~This process uses furan resins, which contain about 80 % furfuryl alcohol. Both resins polymerise under acid conditions. These resins need to be mixed with the sand and with oxidising agents, such as organic peroxides or hydrogen peroxide. The reaction between these peroxides and the injected sulphur dioxide then generates sulphuric acid, which causes a rapid~~

~~polymerisation. The gassing period is always followed by a purging period, the purpose of which is to remove the excess unreacted sulphur dioxide from the mass of sand.~~
~~[14, CAEF 1997], [73, Brown, J. R. 2000]~~

2.2.5.7.2.4 ~~SO_2 hardened~~ Epoxy/acrylic resin, SO_2 curing (free radical curing)

This process offers many advantages: good compaction ability; long bench lifetime of the prepared sand (the mixers or shooting heads do not need to be cleaned); good mechanical properties; no nitrogen, phenol or formaldehyde; good shake-out performance; and no crack formation. However, the higher cost of binder constituents is one major disadvantage though.

This process is characterised not by the type of resin, but by the principle of its cross-linking, which occurs through free radicals. The resin must contain carbon double bonds: polyester - acrylic, polyester - urethane or polyester - epoxy resins may be used. These resins generally have a low molecular weight and are diluted with organic solvents at nearly 50 % by weight, though solvent free types are also available. They are mixed with an organic peroxide, which acts as a reaction initiator. For curing, sulphur dioxide is carried by an inert gas, such as carbon dioxide or nitrogen, through the sand.

The gassing period is always followed by purging with the same inert gas that was used for curing, the purpose of which is to remove the unreacted excess sulphuric dioxide from the sand mass.

2.2.5.7.2.5 CO_2-hardened sodium silicate (water glass)

This process presents ~~real~~ advantages: it is cheap, easy to handle and environmentally clean as well as ~~. Also~~ for workers health and for reliability of operation. These are ~~this technique has~~ advantages over organic binders. Its use however, has declined in popularity due to technical reasons, such as poor compaction ability and problems with collapsibility, poor mechanical strength, sensitivity to crumbling, moisture pick-up and poor reclaimability. Furthermore, the use of water glass can lead to increased cleaning costs. The cores reach their full strength only after a drying period. This reduces their applicability in automated processes. The technique therefore finds its main application in small scale foundries.

The silicate generally used is sodium silicate, defined by its concentration (dry solid content) and modulus (silica soda ratio SiO_2/Na_2O). This modulus ranges from 2.0 to 2.8, the most common being 2.0 to 2.3. This silicate is mixed with the sand at a concentration of between 2 % and 4 %. Shake-out and de-coring additives are commonly used and are usually pre-mixed with the silicate.

Curing occurs by gassing with carbon dioxide, due to its slightly acidic character. The CO_2 ratio should not exceed 1 to 2 % of the mass of sand, with a gassing time in the range of 10 to 60 seconds. The cured moulds and cores do not require purging.
[41, Teknologisk 2000], [56, Notzon and Heil 1998]

2.2.5.7.2.6 Resole, CO_2 curing ~~hardened alkaline phenolic~~

This process was introduced for the first time in 1989 and has been undergoing improvements ever since. It is ~~now~~ commercially available ~~and is in use in a few locations,~~ but its use is not ~~yet~~ widespread.

The resin is an alkaline phenolic one, containing a linking substance stabilised at a high pH, approximately 14. Curing occurs by gassing with carbon dioxide, which dissolves in the water solvent of the resin, so lowering its pH and activating the linking substance.

2.2.5.8 Hot curing processes

In these processes, curing takes place by heating the sand-resin mix or, more often, by allowing it to come into contact with the heated pattern or core-box equipment. They all provide a high dimensional accuracy, which can only be achieved by means of using high quality (metal) patterns, which can be very expensive. For this reason, hot curing processes are used for the production of cores of limited size, mostly in mass production processes. Their use, very widespread for years, is now on the decline, as they are being replaced by gas cured processes or in aluminum foundries producing automotive parts by processes using inorganic binders rather than the warm-box or hot-box systems.

Hot curing processes are characterised by major emission problems: when heated, the resins and catalysts emit noxious chemicals including ammonia and formaldehyde that can be the source of odour nuisance. ~~A number of abatement techniques have been tried to solve these problems, such as scrubbing, combustion or biological abatement, but none of these has proven to be effective.~~ More information on the associated emission levels is given in Section 2.3.

2.2.5.8.1.1 Hot-box, phenolic- and/or furan-based

This process can produce cores of a high dimensional accuracy and good mechanical strength.~~, but to achieve these, the operators need a very good knowledge and control of the production process. The limits of the process are set by its cost, principally for the resin, energy and pattern equipment, and by the poor internal working conditions caused.~~ It is currently used in the manufacturing of small or medium-sized cores in mass production.

A resin binder and a heat activated catalyst are pre-mixed with sand and the mixture is blown into a heated core box or pattern, where it is cured for approximately 5 to 60 seconds.

A wide range of resins may be employed, such as:

- urea - formaldehyde UF;
- urea - formaldehyde - furfuryl alcohol UF - FA;
- phenol - formaldehyde PF;
- phenol - formaldehyde - furfuryl alcohol PF - FA;
- urea - formaldehyde - phenol - formaldehyde UF - PF;
- urea - formaldehyde - phenol - formaldehyde - furfuryl alcohol UF - PF - FA.

The catalysts are ammonium salts of mineral acids, sometimes with urea additions to reduce free formaldehyde. Additionally, other additives are used, such as silanes, iron oxides, preservatives and silicon oil.

The addition ratio for the resin varies from 1.2 % to 3.0 % based on sand weight, with an average of about 1.8 %. The addition ratio for the hardener ~~catalyst~~ varies from 10 % to 25 % based on resin weight, with most formulations being optimised at 20 %. The temperature mostly used for the pattern ranges from 230 ºC to 290 ºC, with the optimum range being 220 ºC to 250 ºC. If excessive heat is used in an attempt to accelerate the curing time, the core surface can be burnt, producing brittleness during pouring.

2.2.5.8.1.2 Warm-box

This process is very similar to the hot-box process and uses the same production techniques. Only the type of resin differs, allowing curing at a lower temperature. ~~However, this kind of resin is significantly more expensive than those in use in the hot-box process. Therefore~~ Although the warm-box process~~, in spite of~~ presents some ~~real~~ advantages over the hot-box process, its use is not ~~is not generally find~~ widespread ~~use~~.

The binder is furfuryl alcohol-based, with a typical composition containing around 70 % furfuryl alcohol or a low polymer of furfuryl alcohol. The catalysts are copper salts derived from aromatic sulphonic acids, in water or an alcohol solution. The distinctive feature of these catalysts is their excellent stability at ambient temperature and their relatively low dissociation temperature, which is 150-170 ºC. Accordingly, the tool temperature can be held at around 180 ºC, which leads to major energy savings of about 15 % to 25 % compared to the hot-box.

2.2.5.8.1.3 Shell moulding (Croning)

This process is the only one among all moulding and core-making processes using ~~that can use~~ pre-coated sand, directly available from suppliers and ready for use, although pre-coating of the sand may also be performed at the foundry.

The sand is cured by heating it in a metallic pattern, producing a hardened surface layer. The unheated or uncured sand may be discarded by turning the pattern upside down and then re-used. The cured sand forms a "shell", which has given its name to the process.

This process gives high dimensional accuracy and a good surface finish to the castings, good shake-out and de-coring properties and allows a nearly unlimited storage time for the pre-coated sand. The process limits are the high investment and high operating costs (energy costs). ~~price of the pre-coated sand and the pattern equipment costs.~~ Its use is restricted to the production of small or medium sized moulds and cores in mass production. Example cores and moulds are shown in Figure 2.37.

Source: [132, HUT 2003]

Figure 2.37: Croning cores (top) and moulds (bottom)

The resin used for pre-coating is a phenolic 'novolac', with a formaldehyde/phenol ratio lower than 1. Hexamethylenetetramine is added to the resin as a hardener~~. 'Hexa'~~ and decomposes at 160 ºC into its two basic components: formaldehyde and ammonia. When pre-coated sand contacts the heated pattern, the hexamethylenetetramine decomposes and the formaldehyde cross-links the resin binder to form the characteristic strong bond.

2.2.5.8.1.4 Linseed oil

This ancient process is probably the oldest one processing chemically bonded sands. It is very easy to use, does not need sophisticated patterns and has a good resistance to veining and cracking. It is still in widespread use for specialised small cores.

These sands are bonded with a mixture of drying oils, these usually being to a great extent linseed oil, often with an addition of dextrin and a few per cent water. The addition rate of oil varies from 0.8 % to 4 %, based on sand weight. Drying agents may also be added. Curing occurs by cross-linking of the unsaturated fatty acids contained in the drying oils, induced by atmospheric oxygen and accelerated by heating in a drying-oven at a temperature between 190 ºC and 260 ºC for 1 to 2 hours.

2.2.5.8.1.5 Alkyd oil, baked

This process is similar to the previously described unbaked alkyd oil process, the only difference being in this case heat treatment of the parts in order to accelerate the curing.

2.2.5.8.2 Coating of chemically bonded sand moulds and cores

The skill of the founder is to produce high quality castings, without defects, and requiring only minimal finishing and repair. To achieve this, the ideal is to minimise all the interactions that may occur between mould, core and metal during pouring. These effects may be generated by different causes, such as sand expansion, ramming defects, abrasion of sand, metal penetration, chemical decomposition or by interaction between the binders, etc.

For these reasons, it is often beneficial to coat the mould or the core with a refractory lining, in order to give a smooth surface finish to the casting and to reduce fettling cost.

2.2.5.8.2.1 Composition of coatings

Coatings are available as ready-to-use products or as a mass to dilute with water or alcohol. They usually contain the following components:

- one or more refractory fillings, such as talc, pyrophyllite, mica, zircon, magnesite, quartz, etc., or blacking;
- a make-up liquid, which may be an alcohol (e.g. isopropanol, ethanol) or water;
- high temperature bonding agents, such as bentonites, resins, boric acid;
- rheological agents, such as bentonites or synthetic polymers;
- additives, such as surfactants, foam breakers, fungicides, etc.

2.2.5.8.2.2 Coating process

The coating may be applied on the mould or on the core by different means:

- by brushing, for small cores or for localised application;
- by dipping, for complex shaped cores; this process often being automated;
- by spraying, usually airless;
- by flow-coating, for large or medium sized moulds or cores.

If alcohol-based coatings are applied, the working area needs to be ventilated in order to prevent the danger of fire or explosion. The coated moulds and cores are mostly burnt out, which limits the emissions. If they are not burnt out then drying is carried out under exhaust with the VOC

emissions maintained under control. Flow coating with alcohol-based coatings and subsequent firing or drying is presented in Figure 2.38.

Source: [132, HUT 2003]

Figure 2.38: Flow coating with alcohol-based coating, followed by firing or drying

The drying of water-based coatings occurs by heating in a drying furnace using hot air, infrared or microwaves. The dip-coating of cores and subsequent hot air drying is presented in Figure 2.39. Water-based coatings do not generate emission problems, neither during coating nor during drying. For these reasons, water coatings are now increasingly replacing alcohol-based ones. However, their application faces technical constraints in terms of the coating quality continuity and drying constraints. A full discussion of water-based versus alcohol-based coatings is provided in Section 3.2.1.5.5. [49, Inasmet and CTIF 2002]

Source: [132, HUT 2003]

Figure 2.39: Dip-coating with water-based coatings, followed by drying in a hot-air furnace

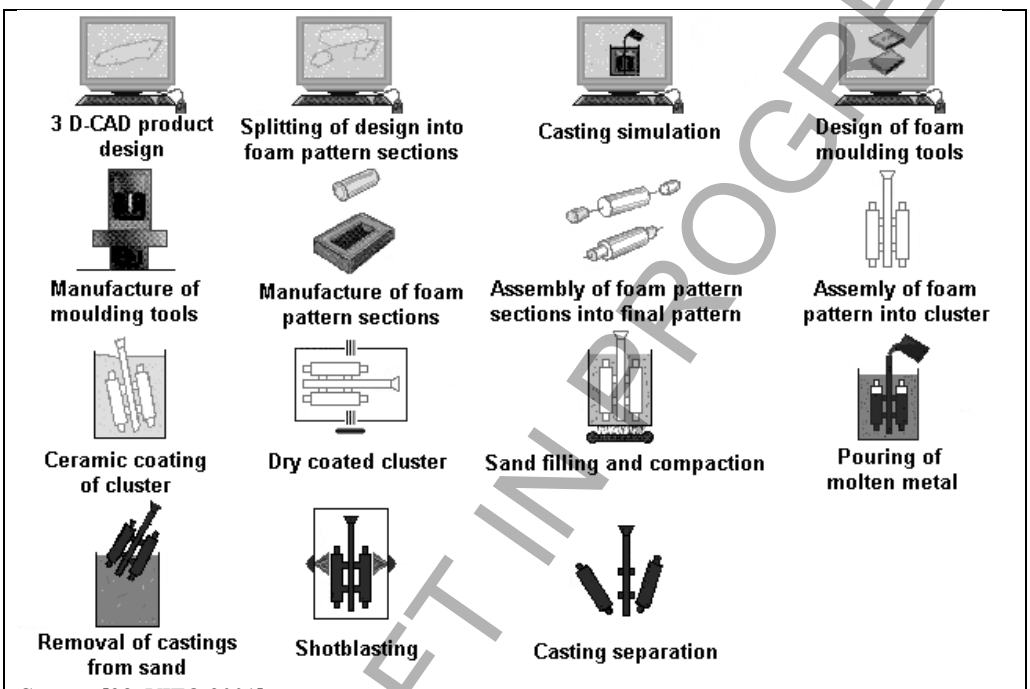
2.2.5.9 Expendable pattern casting

In expendable pattern casting, the pattern is not removed from the mould before pouring. The pattern, which is made of expanded material, is a single-use one, which is destroyed when poured. These expendable patterns may be embedded either in chemically bonded sands or in binderless sand, ~~hardened~~ condensed by vibration.

This process with binderless sand, commonly called 'Lost Foam casting', was developed some decades ago and its application is limited. ~~30 years ago and its commercial growth was initially rather slow.~~ However, during the last 10 to 15 years, it ~~is~~ has become more commonly used, primarily for the mass production of automotive parts or similar products, in spite of significant set-up difficulties.

2.2.5.9.1 Unbonded sand – Lost Foam process

The Lost Foam process (Figure 2.40) starts with the 3D-CAD design and production of a precision moulded foam pattern, made from expanded polystyrene (EPS) or PMMA, produced by automated injection moulding machines. These patterns can be made from one piece or by assembling a number of parts by adhesives. Here usually, a number of patterns, dependent on size, are fixed to a runner-down gating system, made from the same material as the pattern, thereby generating a cluster.



Source: [38, VITO 2001]

Figure 2.40: The Lost Foam process

The clusters are dipped in a water-based refractory-type coating, which creates a barrier between the molten metal and the sand during pouring. After drying, the cluster is positioned in a moulding flask, which is filled with unbonded sand. A low-viscosity resin may be added to the sand, in order to prevent deformation during compaction. The sand is compacted by triaxial vibration around the patterns, penetrating the holes and reproducing exactly all the details, thus making the core and core-making equipment unnecessary. Upon pouring, the molten metal causes a pyrolysis of the polystyrene and fills the emptied space.

The sand, mostly quartz, needs to be very permeable, in order to ensure the evacuation of the pyrolysis gases. Sand with an AFS-number of 35-50 is used. Interruption of the pouring may cause a collapse of the sand mould. Therefore an automatic casting system is often used.

The cast pieces are characterised by a very good dimensional precision, as shown in Figure 2.41. The technique can be used for any type of alloy and is used for medium to large sized series production. The process is environmentally friendly during the moulding but produces gaseous emissions during pouring and shake-out, due to the vaporisation of the expendable patterns. Lost Foam casting enables metal casters to produce complex parts which would often not be possible using other methods. The process allows designers to develop more complex shapes, to reduce machining need and to minimise assembly operations. Proper controls must be exercised in each step of the process to ensure consistent high quality castings. A lack of in-depth industry-wide knowledge on how to set up proper control measures has slowed adoption of the Lost Foam casting process.
[14, CAEF 1997], [38, VITO 2001], [50, US Dept. of Energy 1998]

***Source*:** [132, HUT 2003]

Figure 2.41: Expendable polystyrene pattern (R) for the Lost Foam process and an example of a casting produced by the Lost Foam method (L)

2.2.5.9.2 Chemically bonded sand – Full mould process

~~The Lost Foam process~~ Expendable patterns can also be used to produce single-piece prototypes, thereby permitting a shortening of the delivery time. Furthermore the technique can be applied for the production of very big pieces, such as bases for metal processing machines, or presses, etc. in cast iron, steel or non-ferrous alloys. The wall thickness may range from 5 mm up to 1000 mm. Pieces of up to 50 tonnes have been cast using this technique. For the production of these bigger pieces, the application of a (furan) binder is needed in order to attain the necessary mould strength.

This ~~Lost Foam~~ process with chemically bonded sand~~, in this case also~~ called the 'full mould process', is mostly used for producing medium or large sized castings, in single production or in small batch series.

The patterns are made from low-density expanded materials, such as:

- white, foamed polystyrene, with a density of 16-20 g/dm^3;
- blue, foamed polystyrene, also called 'poresta-blue', with a density of 18-22 g/dm^3;
- foamed polymethylmetacrylate, also called PMMA, with a density of 25 g/dm^3.

These materials are cut out as various parts, which are then assembled and stuck together with hot melt glue, thus creating the final shape of the casting, also taking into consideration any possible shrinkage of the metal.

The assembled pattern, with its gating and feeding system, has to be coated, mostly with a water-based coating system, and thoroughly dried before being embedded in the sand. The binding process of the sand has to be specially selected in order to avoid any moisture pick-up by the pattern before pouring.

This process, as far as moulding is concerned, is very environmentally friendly, but produces gaseous emissions during pouring and shake-out, due to the vaporisation of the expendable patterns and destruction of the sand binder.

~~As with the unbounded process, uninterrupted casting is very important in order to prevent the mould form collapsing. For the casting of big pieces, pouring is performed using two (or more) pouring ladles and two (or more) entry holes simultaneously.~~

The full mould process has the following advantages:

- high size precision;
- production of complex geometries, especially internal cavities;

- integration of several parts into one casted piece;
- reduction or exclusion of release edges;
- possibility of ~~thermal~~ sand regeneration.

Despite the fact that the Lost Foam and full mould techniques have been known for a long time, they are not widely applied in Europe. This is primarily because their optimisation requires a lot of research and development. The main difficulties are:

- definition of the product range: determining which pieces can be made more easily as compared to traditional methods;
- selection of the compaction technique: application of the sand in order to perfectly fill all cavities;
- choice of coating and sand type: these should have a sufficient gas permeability to allow the combustion gases to escape.

[38, VITO 2001]

2.2.5.10 Permanent (metal) moulds preparation

Permanent moulds are made from metallic elements adapted to the shape of the casting, whose assembly allows the moulding, pouring and stripping of the casting. These metal moulds are used for gravitational casting, high pressure die-casting, centrifugal casting, continuous casting and for low-pressure casting. Unlike sand moulds, they can be reused many times and for this reason, they are called permanent moulds.

If the shape of the casting cannot be easily made by the use of metallic core pins, sand cores may be used. For instance, sand cores are used to form the widening-out of centrifugal cast pipes.

Permanent moulds are generally coated with a 'white or black wash'; these water-based release agents are refractory based in the case of the white one and graphite based for the black one. Their function is to provide protection of the die, to regulate die cooling by water evaporation, and to provide lubrication. They also act as parting compounds.

In a few cases, blackening is provided by burning acetylene in the absence of air, producing acetylene black that partially sticks to the die. The non-adhesive black then has to be collected and filtered before emission.

Permanent moulds (or dies) are generally not made in the foundry, although die-casting foundries do have a workshop for die assembly, maintenance and repair. This type of operation, however, does not generate any environmental effects.

2.2.5.11 Investment casting and ceramic shell

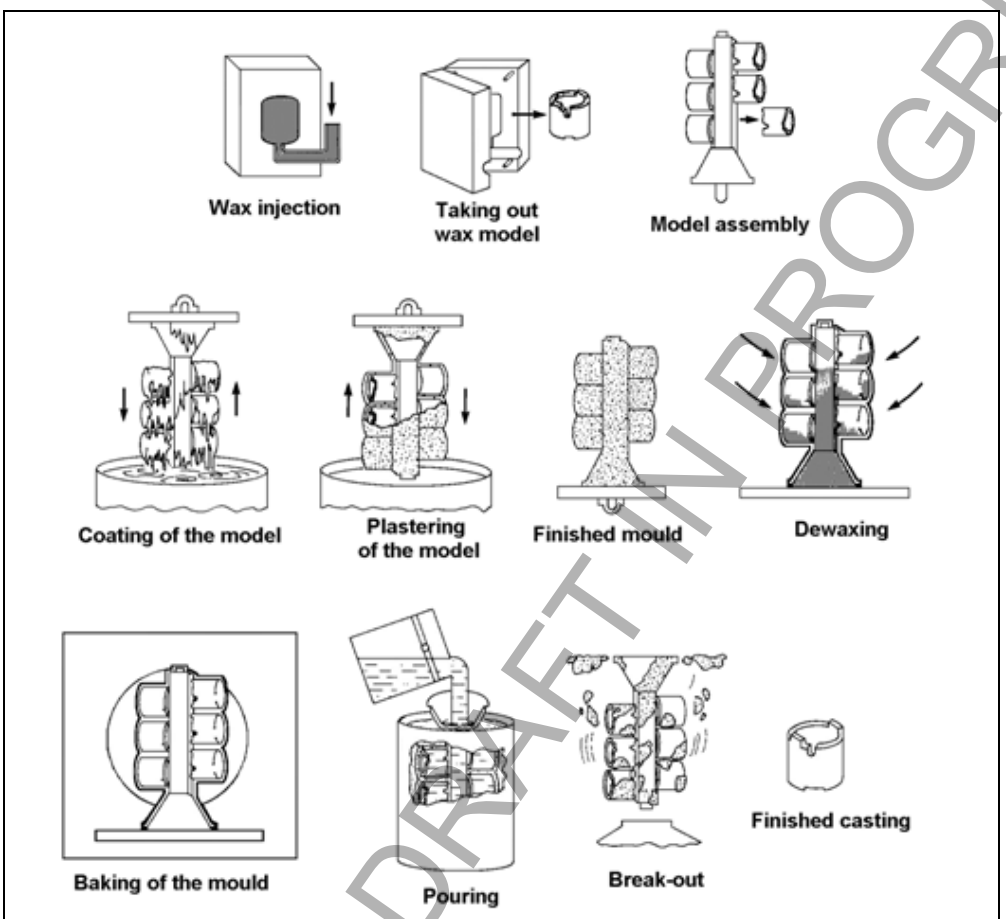
This process is used to produce intricate, thin section parts with high dimensional accuracy, fine details, and very smooth surfaces.

The process steps are depicted in Figure 2.42. They begin with the manufacture of expendable wax patterns, by injecting molten wax into an aluminium or epoxy die to form a pattern that is virtually an exact replica of the desired casting. The wax may contain fillers. For smaller castings, several wax patterns are attached to a wax gating system. Water soluble die release agents are used to facilitate the wax model take-out.

The wax patterns are cleaned with water or organic solvent and coated with a wetting agent, which helps the ceramic slurry to adhere to the wax. The cluster is then dipped in a liquid ceramic slurry, stuccoed with granular silica, zircon or alumina/silica refractories and then dried

before the application of the next coat. The coating process is continued until a sufficiently thick shell is established.

The dried mould is then de-waxed by inserting it into a steam autoclave in which the wax patterns are melted out, or into a 'flash furnace', in which the wax may be partially burnt out. After this, the shell is fired in a furnace at a high temperature. This burns out the residual wax and hardens the ceramic, leaving a one piece ceramic shell mould, into which the molten metal is poured to form the casting.



Source: [38, VITO 2001]

Figure 2.42: Investment casting process

In this process, air pollution may occur during two operations: investing and de-waxing.

Investing
The liquid ceramic slurry consists of a binder and a very fine refractory powder, reduced to slime by permanent mixing. The binder may be colloidal silica, hydrolysed ethyl silicate or hydrolysed sodium silicate, the choice of the technology applied being determined by technical reasons. When using ethyl silicate, drying is faster, which allows a higher cycle rate, but ethyl alcohol vapours are emitted. These vapours, if present in too large an amount, have to be collected and treated before emission.

De-waxing and firing
De-waxing by means of a steam autoclave does not produce any significant impact on air. However, this is not the case if the de-waxing is conducted in a firing oven, and during the firing of the shell, where wax residues are burned.

This burning occurs often in a lack of air, which results in the formation of carbon black particles. These particles have to be collected and either destroyed by afterburning or removed. Ceramic filters have been successfully used for this purpose, as they suit the high temperature of the exhaust gases, but this very recent technology has not yet become widespread.

This technique is used e.g. for precision casting and art casting. It is generally not applied in large-scale foundries (> 20 tonnes/day capacity), and therefore is mentioned here only for informative reasons.

The ceramic shell process (patented as Replicast®) extends the quality and precision of investment casting to larger components, using a combination of Lost Foam and investment casting principles. The technique uses an inert, fired ceramic mould. To create the mould, an expanded polystyrene replica of the required component is produced, which is dimensionally precise and of a high surface finish. No parting lines or cores are required, nor draft angles, and polystyrene replicas can be glued together to create complex geometries. The polystyrene is burnt out before casting, allowing a wide range of alloys to be cast in the mould - from ultra low carbon stainless steel to nickel based alloys. This is in contrast to the Lost Foam process where liquid metal consumes and replaces the polystyrene pattern, making it unsuitable for the vast majority of steel components (polystyrene is comprised of 92 % by weight carbon).
[117, Castings Technology International 2003]

2.2.6 Casting

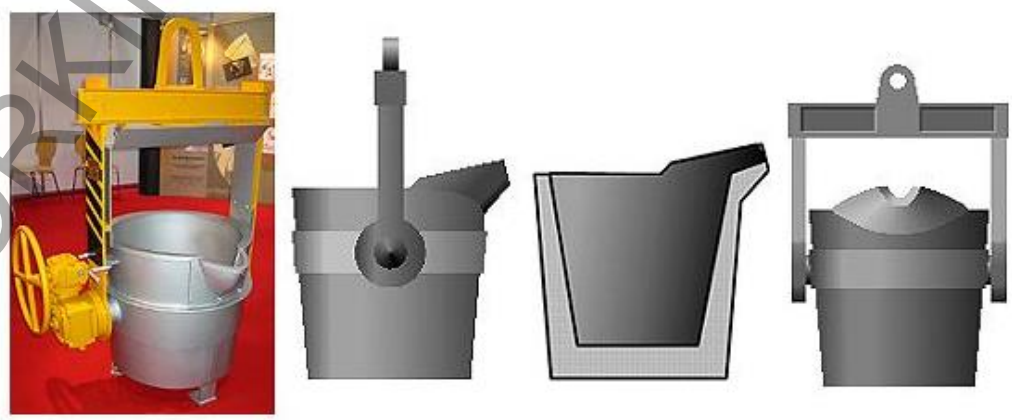
Pouring is the central activity in casting production. The finished mould is filled with the liquid metal under the effects of gravitational or centrifugal forces or pressure. After pouring the casting is cooled to allow solidification and is then removed from the mould for further cooling and treatment.
[14, CAEF 1997]

2.2.6.1 Casting in lost moulds

2.2.6.1.1 Pouring

There are two types of ladle generally used in pouring liquid metal: lip and teapot ladles. A third type (i.e. the bottom ladle) is more specific to steel.

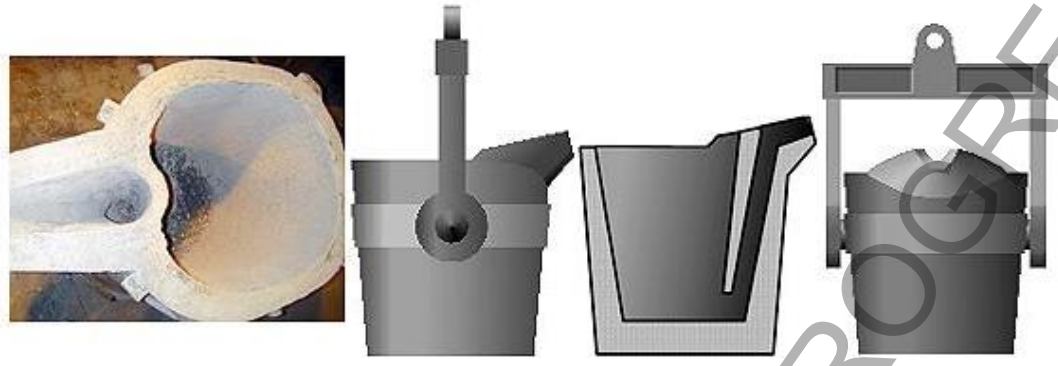
- *Lip pour*: In this type of ladle (Figure 2.43) the metal is charged over the lip, with the flow controlled by tilting the ladle using a geared handwheel. Since the metal flows from the top of the ladle, the metal surface must be slag-free or a skimmer must be used to prevent slag entering the mould. Lip pour ladles are used for pouring small steel castings.



Source: [132, HUT 2003]

Figure 2.43: Lip pour ladle for molten metal pouring

- *Teapot ladles*: As depicted in Figure 2.44, a refractory dam before the ladle lip ensures that the metal is drawn from the bottom of the ladle, so that the stream is slag free. The molten metal is generally cleaner than from a lip pour ladle. One disadvantage is that the narrow spout may occasionally permit the liquid steel to freeze if the heat is tapped cold or if pouring is prolonged.



Source: [132, HUT 2003]

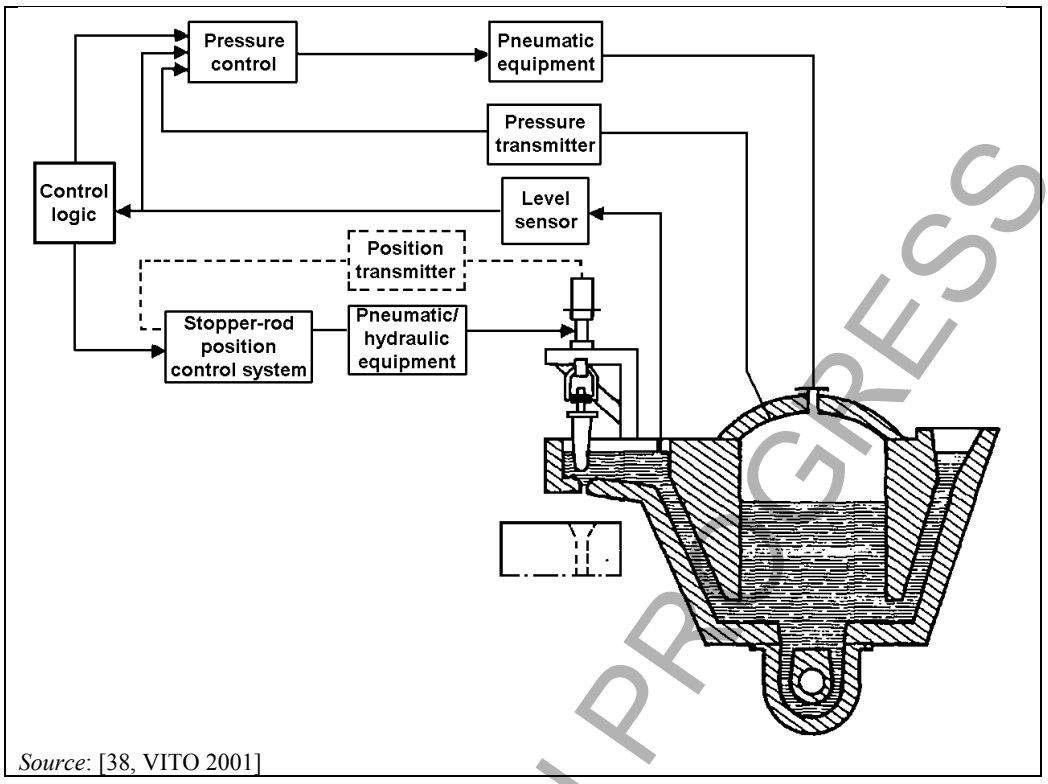
Figure 2.44: Teapot ladle for molten metal pouring

- *Bottom pour ladles*: The ladle is fitted with a pouring nozzle in its base, closed by a refractory stopper rod. The metal is drawn from the bottom and is therefore slag-free and non-metallics, such as deoxidation products, are able to float out of the melt. The metal stream flows downwards, so that there is no movement of the stream during pouring. The disadvantage is that the velocity and the rate of flow change during pouring as the ferrostatic head changes.

Source: [132, HUT 2003]

Figure 2.45: Bottom pour ladle for molten metal pouring

Automatic casting lines are often equipped with a pouring furnace. The working principle behind one example furnace is depicted in Figure 2.46. The casting line halts when a mould is in the correct position, i.e. under the pouring exit. Metal is poured during a fixed period by elevating a stopper. Because the metal level in the casting recipient is held constant, a fixed volume of molten metal is poured into the mould. The metal level in the furnace is controlled by a floating device, which controls the gas pressure inside the furnace. The casting furnace is refilled with metal from the melting furnace at fixed time intervals.
[38, VITO 2001], [73, Brown, J. R. 2000]



Source: [38, VITO 2001]

Figure 2.46: Pouring furnace

2.2.6.1.2 Solidification (first cooling)

The poured moulds are transported along the moulding line onto the cooling lines. The length of the cooling line determines the final temperature of the casting at the point of shake-out. This temperature must be low enough to provide the casting with sufficient strength during shake-out and further manipulation.

Big moulds are not moved during cooling. The cooling time can be up to several days.
[38, VITO 2001]

2.2.6.1.3 Shake-out

In the case of individual moulding, clay or chemically bonded moulds can usually be destroyed by vibration. In most cases this is accomplished by placing the moulding box on a vibrating grate, using a crane to do this. As a result of the vibration, the sand is separated from the casting and the moulding box. The casting and moulding box remain on the grate rods, whereas the sand falls through and is subsequently reprocessed. The casting is usually transported to a cooling area for further cooling in ambient air (second cooling).

A similar shake-out procedure is often carried out in mechanised systems and older low-capacity automated systems (Figure 2.47). Here the moulding boxes are removed from conveyor belts, by means of hoists or other transfer equipment, and placed on vibrators. Finally, the castings are left to cool down or placed in a casting cooling device. In many systems, the sand casting is pressed out of the moulding box and a subsequent controlled cooling of the castings and sand is achieved in combined or separate cooling devices, such as in cooling drums, swing pipes, chain conveyors, fluidised bed coolers, etc.

Source: [132, HUT 2003]

Figure 2.47: Shake-out at the end of an automated moulding line

Vacuum bonded sand moulds are destroyed by releasing the vacuum. The casting bucket or moulding box, containing the loose sand and the casting, is emptied and then the casting is cooled by one of the described methods.
[14, CAEF 1997]

2.2.6.1.4 Casting cooling (second cooling)

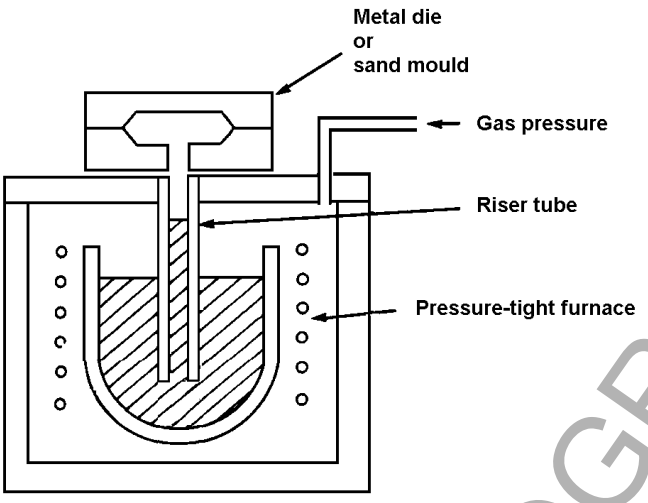
The controlled cooling of castings and sand is carried out in rotary drums, swing drums or on oscillating conveyor troughs. The casting is cooled in oscillating conveyors or in cable-car baskets. In many cases an airflow, which is often directed in the opposite direction to that of the casting, is used for cooling. In some cases, fine water jets are used in order to increase the cooling effect.

2.2.6.2 Casting in permanent moulds

2.2.6.2.1 Gravity and low-pressure die-casting

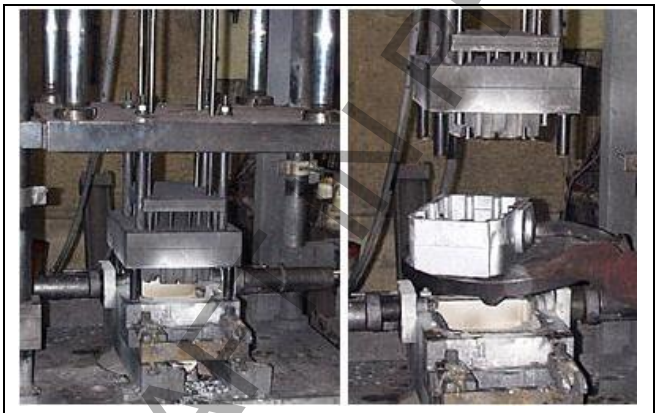
Gravity and low-pressure die-casting make use of a permanent steel die into which the melt is poured under the influence of gravity or a low-pressure gas. Sand cores can be used to form undercuts and complex interior shapes in the casting. Due to the rapid solidification process, permanent mould castings have a dense fine-grained structure with good strength characteristics.

The principle of low-pressure die-casting is shown in Figure 2.48. A metal die is mounted above a sealed furnace containing molten metal. A refractory-lined riser tube extends from the bottom of the die into the molten metal. When air is introduced into the furnace under low pressure (15-100 kPa) the molten metal rises up the tube to flow into a die cavity with low turbulence, the air in the die escaping through vents and the parting lines of the die. When the metal has solidified, the air pressure is released, allowing the still-molten metal in the riser tube to fall back into the furnace. After a further cooling time, the die is opened and the casting extracted. Due to the absence of feeders and risers, the casting yield is exceptionally high, generally over 90 %. A good dimensional accuracy and surface finish are possible and complex castings can be made using sand cores. This technique is typically used for aluminium castings, e.g. automotive parts such as wheels, cylinder heads, and electric motor housings, and for domestic kitchenware. The die must be coated to optimise the casting release and cooling. In general, a die coating is applied once per shift. The die life is normally around 30 000-50 000 shots. An example of a low-presure die-casting machine is given in Figure 2.49.



Source: [74, Brown 1999]

Figure 2.48: The principle of a low-pressure die-casting machine



Source: [132, HUT 2003]

Figure 2.49: Low-pressure die-casting machine

In gravity die-casting, the molten metal is poured under gravity into a permanent mould or die. Gravity die-casting machines range from simple, hand operated rack and pinion die sets, manually poured, to carousel machines, which usually have a tilting mechanism for filling the die and which are often operated using a pouring robot. The dies are coated with a refractory-based coating, controll the cooling rate. The time before the casting can be extracted from the die varies from 4 to 10 minutes depending on the type of casting. The process is therefore relatively slow, compared to pressure die-casting. To achieve reasonable output rates, a manual operator will operate two to four die sets in sequence, allowing an output of 30-60 castings an hour. Automatic carousel machines may have four to six stations with multiple die sets, allowing production rates of around one casting per minute to be achieved. The process is most widely used in aluminium casting for series' of 1 000 to more than 100 000 pieces per year for example for manifolds, cylinder heads, water pumps.

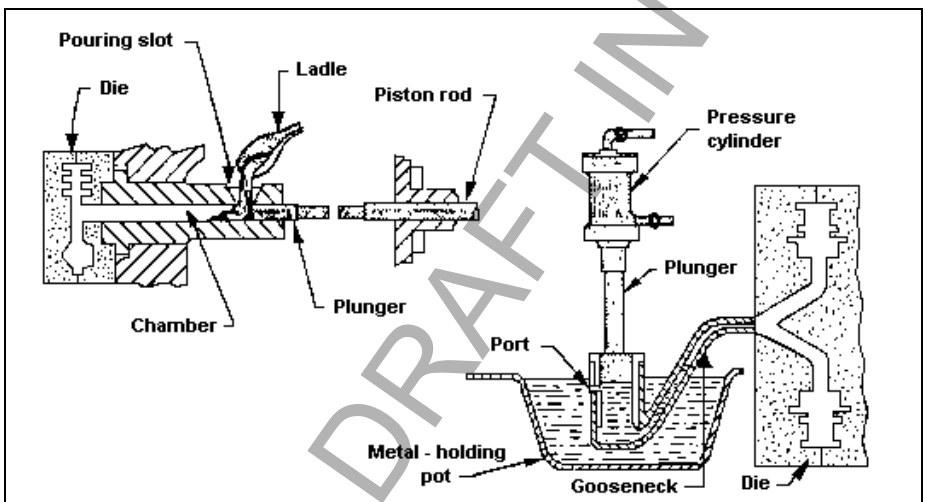
Permanent mould coatings are typically formulated using water as a carrier, a high temperature binder (normally sodium silicate) and a refractory filler or blend of fillers. There are two categories of coatings:

- insulating: containing blends of insulating minerals such as talc, mica, kieselguhr, titanium dioxide, alumina, etc.;
- lubricating: based on colloidal graphite or boron nitride to aid release of the casting.

Coatings are generally sprayed onto the die. Careful attention to die preparation, coating preparation and application and the type of coating equipment utilised can yield significant quality and productivity benefits.
[74, Brown 1999]

2.2.6.2.2 High-pressure die-casting

The term 'die-casting' often implies 'high-pressure die-casting'. The process utilises a permanent die (metal mould) into which molten metal is forced under high pressure. The application of high pressure causes a high and turbulent metal flow, which allows the production of castings with high surface areas and low wall thicknesses. Dies are usually made from two blocks of steel, each containing part of the cavity, which are locked together while the casting is made. Due to the high metal pressure, the maximum size of the casting is limited by the maximum locking force of the casting halves. Retractable and removable cores are used to form internal surfaces. Due to the high metal pressures, only metal cores can be used. This limits the complexity of the casted piece. The metal is held under pressure until it cools and solidifies. The die halves are then opened and the casting is removed, usually by means of an automatic ejection system. Dies are preheated and lubricated before being used, and are either air- or water-cooled to maintain the desired operating temperature. Two basic types of high-pressure die-casting (HPDC) machines are used: hot-chamber or cold-chamber (see Figure 2.50).



Source: [18, US EPA 1998]

Figure 2.50: Cold-chamber and hot-chamber high-pressure die-casting devices

Hot-chamber HPDC machines comprise a molten metal reservoir, the die, and a metal-transferring device, which automatically withdraws molten metal from the reservoir and forces it under pressure into the die. A steel piston and a cylinder system with a gooseneck is used to create the necessary pressure within the die. A gooseneck machine utilises a cast iron channel to transfer the molten metal from the reservoir to the die. Pressures can range from a few bar to over 350 bar. Hot-chamber techniques are mainly used for zinc alloys and magnesium alloys.

Cold-chamber HPDC machines have molten metal reservoirs separate from the casting machine. Just enough metal for one casting is ladled by hand, or mechanically, into a small chamber, from which it is forced into the die under high pressure. Pressure is produced through a hydraulic system connected to a piston, and is typically in the range of a few hundred bar to 700 bar. In cold chamber machines, the metal is just above the melting point and is in a slush-like state. Since the metal is in contact with the piston and cylinder for only a short period of time, the process is mainly applicable to aluminium alloys, and to a lesser extent magnesium alloys, zinc alloys, and even high melting point alloys such as brasses and bronzes.

Proper lubrication of the dies and plungers is essential for successful high-pressure die-casting. The die lubrication affects the casting quality, density, and surface finish, the ease of cavity fill, and the ease of casting ejection. Proper lubrication can also speed up the casting rate, reduce maintenance requirements, and reduce the build up of material on the die face. Although specific formulations are proprietary, in general, lubricants (also called release agents) are a mixture of a lubricant and a carrier material. Formulations may also include additives to inhibit corrosion, to increase stability during storage, and to resist bacterial degradation. Lubricating materials are typically mineral oils and waxes in water emulsions. Silicone oils and synthetic waxes are finding increased use. Both water-based lubricants and solvent-based lubricants are in use today. Water-based lubricants however dominate the market (95 %). The lubricant is applied to the open die by spraying, between each shot. Dilute solutions of lubricant are used (1:20-1:200 release agent:water ratio). Micro-spraying is used where possible. With appropriate casting geometry, it may be possible to use water-free systems as they provide good demoulding and lubrication. Often all types of release agents are applied depending on the casting and subsequent processes.

Electrostatic dry powder coatings are also currently available. Using this technique, a minimum amount of dry lubricant (e.g. 0.3-0.5 g/kg of injected aluminium) is applied to the mould at a temperature of 250 °C using electrostatic deposition. When it comes into contact with the hot mould, the powder coating distributed electrostatically melts and creates a highly efficient release film, without creating residual thickness and carbon formation. This constitutes a significant advantage over water-based lubrication systems. [193, Neto et al. 2009] Furthermore, by eliminating the use of water-based release agents, oil mist and waste water emissions are avoided.

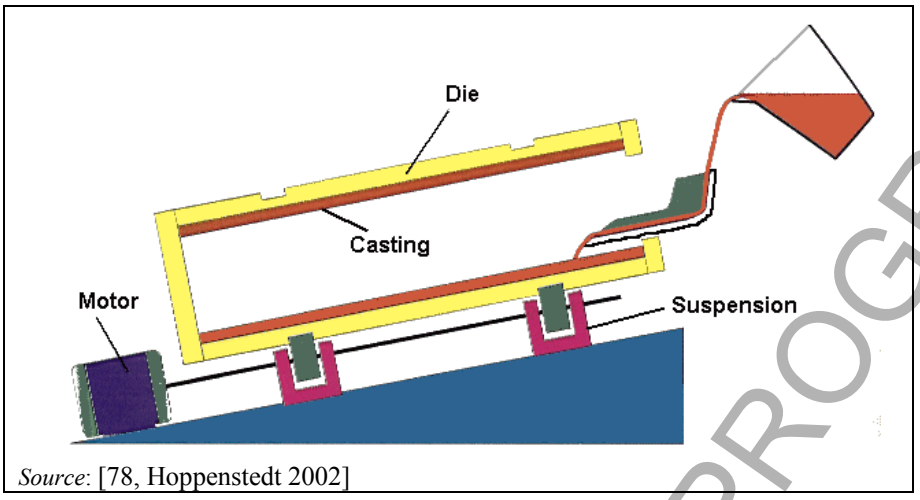
High-pressure die-casting is not applicable to iron and steel and other high-melting-point alloys. The technique finds widespread application for aluminium, magnesium and zinc castings. Dies are expensive but can have a life of 150 000 shots or more. The process is therefore most suitable for long runs of castings. ~~One major advantage of HPDC over other casting methods is that the castings produced can have very complex shapes. The ability to cast complex shapes often makes it possible to manufacture a product from a single casting instead of from an assembly of cast components. This can greatly reduce casting costs, as well as the costs associated with fabrication and machining.~~ Furthermore, HPDC produces castings which have a high degree of dimensional accuracy and surface definition ~~compared to other casting methods,~~ which may help to reduce or eliminate costly machining steps. Finally, castings with relatively thin wall sections can be produced using the HPDC method. This can result in substantial savings in material costs and reductions in component weight.

Relatively little waste is generated in the actual HPDC process ~~compared to other metal casting processes~~. However, some gaseous and fume emissions occur during metal injection. Metal oxide fumes are generated as some of the metal vaporises and condenses. Gaseous emissions can originate from: the molten metal itself; the evolution of chemicals from the lubricant as it is sprayed onto the hot metal die and as it contacts the molten metal. Emissions to water may occur from any leakage or spillage of hydraulic oil or heating oil and from cooling water.
[18, US EPA 1998], [42, IHOBE 1998], [74, Brown 1999], [120, TWG 2003], [134, CAEF 2020], [193, Neto et al. 2009]

2.2.6.2.3 Centrifugal casting

In centrifugal casting, a permanent mould rotates at high speed around its axis as the metal is poured. The speed of rotation and the metal pouring rate vary with the alloy and the size and shape being cast. The rotating axis is generally horizontal or under a small angle (Figure 2.51). Some specific devices apply rotation around a vertical axis. The resulting material has a very dense structure and properties that cannot be obtained with sand casting.

This technique is used to produce cylindrical products in cast iron, steel, and in alloys of aluminium, copper and nickel. Typical parts made by this process are pipes, boilers, pressure vessels, flywheels, cylinder liners and other parts that are axisymmetric.
[78, Hoppenstedt 2002]

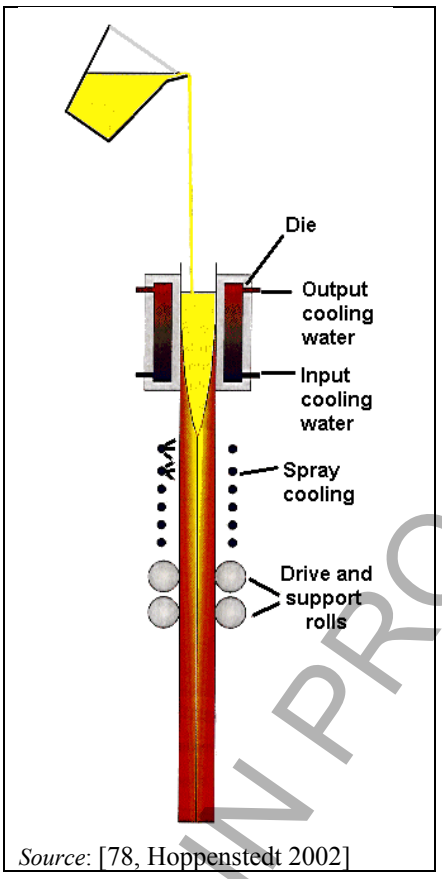


Source: [78, Hoppenstedt 2002]

Figure 2.51: Schematic representation of a centrifugal casting machine

2.2.6.2.4 Continuous casting

Continuous casting is a high-productivity device for the production of bars, tubes and profiles, where through rapid cooling, a fine-grained material with good mechanical properties is obtained. In continuous casting, the molten metal is cast into a water-cooled die, which is open at the bottom or at the side (Figure 2.52). The die gives the desired form to the product. Through intensive cooling, the outside of the metal product solidifies, while it is slowly pulled out of the mould. Through continuous pouring and extraction as the product is pulled out of the mould, the product gets longer. A burner cuts the product whenever the desired product length is reached. This technique is used for both ferrous and non-ferrous casting. The technique is used for the casting of bars, slabs and sheets as a final step in iron, steel and non-ferrous metals production. Its use in this context is described in the NFM BREF ~~for non-ferrous metal industries~~ [1, COM 2017] and the IS BREF ~~on iron and steel production~~ [109, COM 2013].



Source: [78, Hoppenstedt 2002]

Figure 2.52: Schematic representation of a thread casting machine used for continuous casting

2.2.7 Finishing and post-casting operations

Finishing of the raw castings encompasses all necessary treatments to yield a finished product. According to the process, various steps may be required, such as:

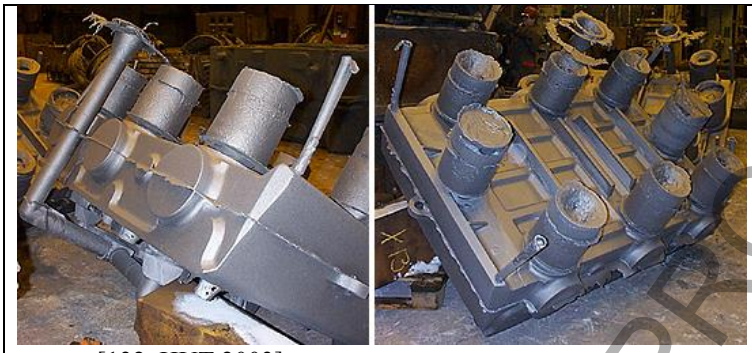
- removal of the running system;
- removal of residual moulding-sand from the surface and core remains in the casting cavities;
- removal of pouring burrs;
- repair of casting errors;
- preparation of the casting for mechanical post-treatment, assembly, thermal treatment, coating, etc.

In some cases, foundries also perform assembly, surface finishing and coating of the castings. However, these activities are not discussed in this document. Surface finishing and coating techniques are discussed in the STM BREF [171, COM 2006] and the STS BREF [208, COM 2020] ~~BREFs on Surface Treatment of Metals (STM BREF) and on Surface Treatment Using Solvents (STS BREF)~~.
[38, VITO 2001], [120, TWG 2003]

2.2.7.1 Removal of the running system

In the finishing of the raw castings and to remove the running system (see Figure 2.53), the following operations take place:

- *Beating, pressing*: In the case of brittle materials such as grey cast iron castings and white malleable cast iron, chamfers and feeders can generally be knocked off. Hydraulic equipment is increasingly being used for this task.
- *Grinding with grinding wheels:* These can be handheld, semi-automatic or automatic.
- *Cutting*: For the removal of massive pieces in carbon steel or low alloy steel, an oxygen-acetylene cutter is used. For cast iron or high alloy steel, oxygen-acetylene-powder or oxygen-LPG-powder cutters are used.
- *Sawing*: Materials which are sensitive to heat, such as aluminium alloys, are usually sawed.



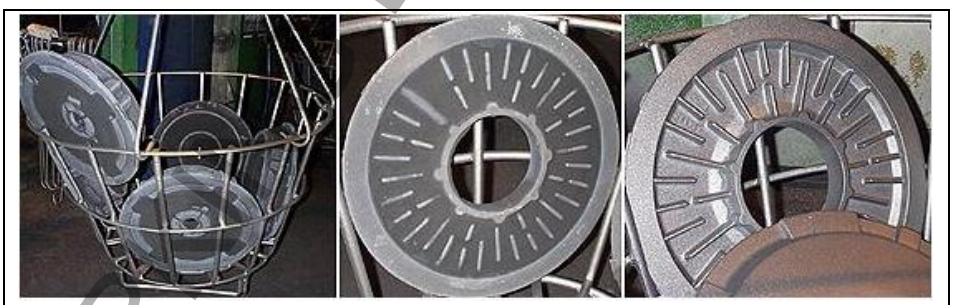
Source: [132, HUT 2003]

Figure 2.53: Casting with running and gating system

Through good design of the connection points, the feeding system may even get broken off during shake-out. This is mainly possible for grey iron.
[14, CAEF 1997], [100, TWG 2002]

2.2.7.2 Sand removal

Removal of the sand is performed in blasting cabins. The blasting medium is adapted to the material to be treated and varies from blasting grit to glass beads. The cleaning of model plates and permanent moulds is done with glass beads, aluminium beads or CO_2 ice grains. An example of castings before and after blasting is shown in Figure 2.54.



Source: [132, HUT 2003]

Figure 2.54: Castings before (L, C) and after (R) sand removal by blasting

Various blasting techniques exist. The acceleration of the grit is done with compressed air or turbine blades. The treatment is carried out in a closed room, with rubber-sealed doors.

The castings are suspended on a monorail and move batch wise through the blasting cabin. For smaller pieces, a specific moving belt is used. Big pieces are blasted manually, using a lance in an enclosed cabin. In this case, personal safety measures are very important. A helmet with a dust mask and respiratory equipment are required.

The coarse dust (sand and metal flakes) that is generated by blasting of the workpiece, is collected together with the grit. It is dedusted, magnetically separated and sieved. The fine fraction is removed from the exhaust air together with the coarse fraction, using a bag filter. Cleaning of the grit before internal re-use is of major importance as the presence of sand could cause a quick wearing of the throwing shovels.

2.2.7.3 Removal of burrs

Burrs, which occur at the point where mould and core pieces join, at veins and at other surface irregularities, are removed using grinding wheels and grinding stones. Grinding wheels are handheld or part of the grinding machines, whilst with grinding stones the casting is pressed against a rotating stone.

Other applied techniques include:

- *Slide grinding*: Grinding burrs and small amounts of other excess material on the casting surface can be removed without hand grinding. The parts are revolved in drums or vibrating containers together with abrasive shapes, causing them to be rubbed against each other and against the abrasive wheels. In a typical unit the castings are ground using a bed of pyramidal grinding stones, together with the addition of a water-soap emulsion. The roughness and the size of the grinding stones vary depending on the size of the castings
- *Tumbling*: This technique, also called blast removal, is used to remove thin burrs or small amounts of casting residue. During this process the burrs remove themselves in an airless blast cleaning process as a result of the parts being impacted together in a rotating drum. At the same time the edges are rounded-off. Sometimes the process is assisted by a liquid.

Source: [132, HUT 2003]

Figure 2.55: Burrs (l.) and their removal using a grinding stone (C) and slide grinding (R)

Automation of these operations is difficult due to the variability in shape of the burrs and the need to fix the casting easily and quickly. Nevertheless, automatic grinding machines are increasingly being used in serial production. Raw casting parts are inserted into such machines to produce suitably worked parts which do not need any retooling or further manual grinding work.

Furthermore the following techniques are applied in automated lines:

- *Punching*: Due to the use of cutting and forming techniques, serial casting parts are often designed in such a way that the unavoidable burr occurs in predetermined amounts which are easily accessible as far as processing is concerned. If the series is large enough, dedicated punching tools can be designed to quickly remove the burr and to provide the casting with a uniform contour.

- *Milling*: With the development of electronic controls for processing machines it has become increasingly easier to compile programs with which to process individual workpieces. Thus it is possible to use milling machines for smaller series instead of the punching machines with their single purpose tools. During such a process, the workpieces are taken up by the device and passed across a number of different milling machines.

Finally, welding may be carried out in order to join castings, as well as to manufacture and repair casting flaws. In most of these cases, arc welding is used. Depending on the requirements and equipment, the work is carried out either with hand operated stick electrodes or with welding wire and with or without inert gas. Scarfing is used on steel castings, which consists in applying grooves for stress relieve. This uses a cutting torch with a copper-coated carbon electrode.
[14, CAEF 1997], [38, VITO 2001], [100, TWG 2002]

2.2.8 Heat treatment

2.2.8.1 Introduction

For ferrous castings, there are basically two types of thermal treatments which can be applied: annealing and hardening. In the case of annealing, the tension caused in the workpiece as a result of pouring, and the subsequent cooling down of the casting, is reduced and the structure is evened out. In the case of hardening, the level of heat is raised above the transformation temperature and the workpiece is subsequently rapidly cooled, in a process known as quenching. This causes the material properties to change. Different results may be obtained by the use of water, oil or air quenching. 'Quench and temper' is the name of the procedure in which the workpiece is reheated to the tempering temperature following quenching, and the quenching procedure is repeated.

The malleablising of iron is a thermal treatment which differs from annealing and hardening. Here, the malleable unfinished casting is either transformed to a white or black temperature casting depending on the procedure.

Many non-ferrous castings are used in an 'as-cast' condition, but certain applications require higher mechanical properties than 'as-cast' material. Possible treatments are annealing, controlled cooling, solution heat treatment, artificial ageing and precipitation treatment.
[14, CAEF 1997], [74, Brown 1999]

2.2.8.2 Heat treatment furnaces

2.2.8.2.1 Chamber furnaces

Chamber furnaces are the most common furnace construction. Their actual design has been adapted in many sub-forms in order to meet the needs of the differing thermal treatments of various types of casting and production. Some examples of chamber furnaces are bogie hearth furnaces, top hat furnaces, hub open-hearth furnaces, etc. Chamber furnaces with continually running conveyance means are called tunnel furnaces. Heating is provided either electrically, or with gas or fuel oil.

For non-ferrous materials, some heat treatments are carried out close to the melting point of the casting, so accurate temperature control is needed. Forced air circulation is used to ensure that the temperature at all parts of the furnace is constant and equal.
[14, CAEF 1997], [74, Brown 1999]

2.2.8.2.2 Shaft furnaces

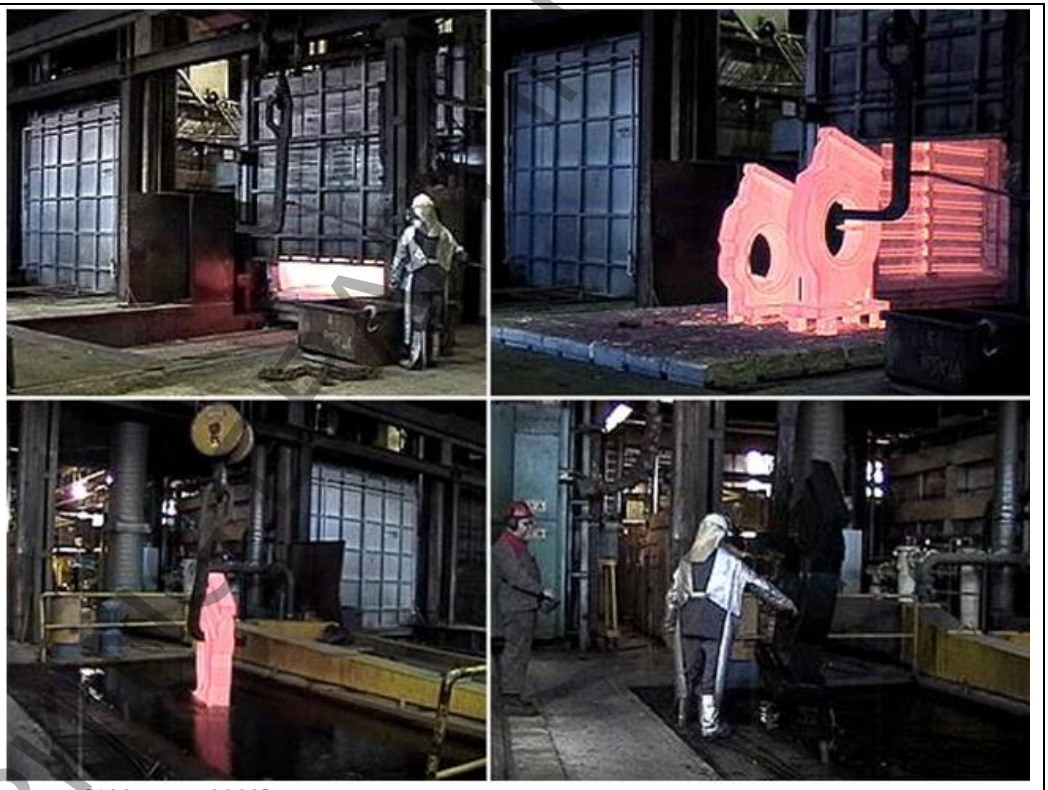
Pipes, long waves and similar parts are often treated while suspended in a vertical position in shaft furnaces. In shaft furnaces, the heating is provided by electricity, gas or fuel oil.

2.2.8.2.3 Annealing furnaces

Chamber, top hat or tunnel furnaces are used to temper unfinished castings. The heating of such furnaces is carried out via electricity, gas or fuel oil.

2.2.8.3 Quenching

In thermal treatment processes, chilling is the cooling down of a workpiece at a greater speed than in calm air. This can be achieved by means of a rapid submersion in water or oil (see Figure 2.56), as well as by forced air-cooling. Care should be taken that the workpieces are cooled at a uniform rate. When submersing in fluids, either the parts must be moved or the fluid must be continually circulated to ensure a full and even cooling of all parts of the workpiece. In a similar principle, in air quenching the blowing procedure must be arranged so that the air covers the entire surface.



Source: [132, HUT 2003]

Figure 2.56: Quenching of a hot casting shortly after heat treatment

2.2.8.4 Heat treatment of ductile iron (SG iron)

It is obviously desirable to achieve the required metal properties in the 'as-cast' form to save further treatments being necessary, but this is not always possible because of variations in section thickness, etc. The heat treatment of the castings can eliminate carbides in thin sections, produce more consistent matrix structures and for a given structure, often improve its

mechanical properties, especially by normalising the grain structure. Where tempered martensite structures are needed, heat treatment is essential.
[14, CAEF 1997], [73, Brown, J. R. 2000]

2.2.8.4.1 Stress relief

Stress relief consists of heating the castings at a rate of 50-100 ºC/h to 600 ºC (taking care not to exceed 610 ºC), followed by soaking them for a minimum of one hour, plus an extra hour for every 25 mm of section thickness in the thickest section, and then cooling them at a rate of 50-100 ºC/h or less. The castings must be adequately supported in the furnace so that they are not subjected to stress.

2.2.8.4.2 Breakdown of carbides

Thin section castings may contain carbides in the 'as-cast' structure. These can be eliminated by soaking the castings at 900-925 ºC for 3 to 5 hours.

2.2.8.4.3 Annealing to produce a ferritic matrix

Annealing involves soaking the castings at 900-925 ºC for 3 to 5 hours, followed by a slow cooling at around 20-35 ºC/h through the critical temperature range (about 800-710 ºC), and finally furnace cooling at, say, 50-100 ºC/h to 200 ºC.

2.2.8.4.4 Normalising to produce a pearlitic matrix

For normalising, a soaking of the castings above the critical temperature followed by air cooling is necessary. Again a soaking temperature of 900-925 ºC is usually used, to ensure that the carbides are broken down. Forced air cooling is used to form pearlite. The type of heat treatment furnace available and the size of the load determines the process cycle that is possible. It may be necessary to adjust the metal composition with tin or copper to help the formation of fully pearlitic structures.

2.2.8.4.5 Producing hardened and tempered structures

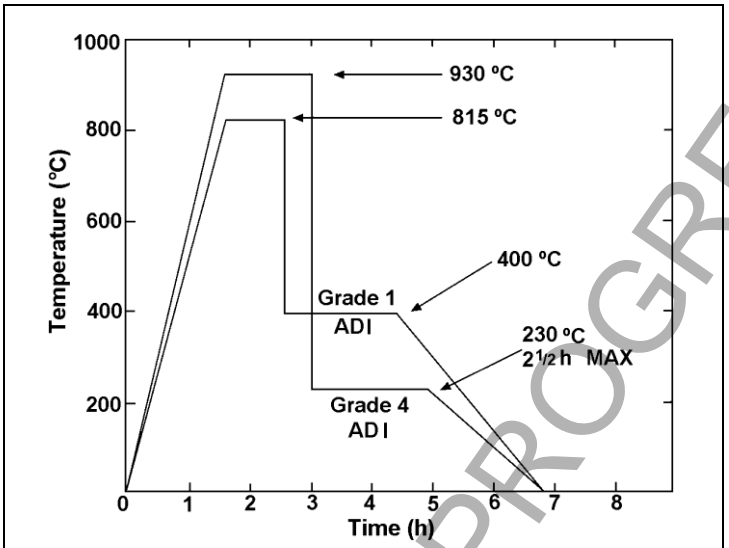
Hardened structures are produced by austenitising the casting at 900-920 ºC, followed by oil quenching. Tempering is usually carried out at 600-650 ºC.

2.2.8.4.6 Austempered ductile iron (ADI)

Austempering is an isothermal heat treatment for producing ausferrite structures. It can double the strength of ductile iron whilst allowing it to retain good ductility and toughness. Wear resistance and fatigue properties are excellent, even to such a degree that ADI is comparable with wrought and hardened-tempered steel.

The ADI heat treatment is a two-stage process, as shown in Figure 2.57. Austenitising is carried out at 815-930 °C to fully transform the matrix to austenite. This is done either in a non-oxidising atmosphere furnace or in a high temperature salt bath. Temperatures and times are determined by the chemical composition, the section size and the grade of ADI required; 1 to 1.5 hours is usually adequate. Slow initial heating of the casting is desirable to avoid the risk of cracking the complex shapes. The castings are then quenched to the required isothermal heat treatment temperature, usually between 210 ºC and 400 ºC. This is usually done in a salt bath. The castings are held at this temperature for 1 to 2 hours to complete the transformation of

austenite to ausferrite. Lower temperatures give high hardness, strength and wear resistance, while higher heat temperatures result in higher ductility and toughness. After the isothermal treatment, the castings are cooled to ambient temperature.



Source: [73, Brown, J. R. 2000]

Figure 2.57: Typical austempering heat treatment stages

Unalloyed ductile irons may be austempered in sections of up to about 8 mm thickness. Thicker section castings require the addition of Mo or Ni to increase the hardenability.

Austempered ductile iron is used as a replacement for forged steel components in the agricultural, railway, automotive and general engineering industries; for example, for plough tips, digger teeth, spring brackets, rear axle brackets, gears, etc. ADI production is growing but its use is limited to some extent by the lack of suitable heat-treatment facilities.
[14, CAEF 1997], [73, Brown, J. R. 2000]

2.2.8.5 Heat treatment of steel

Steel castings are normally subject to a heat treatment before delivery, e.g. normalising, with this heat treatment leading to a structural change. Additionally, potential casting stresses have to be reduced (stress relief annealing). Many steel casting qualities have to be additionally tempered after stress relief anneal (hardening and tempering).

Most steel castings are subjected to a heat treatment to attain the desired mechanical properties and to a stress relief, to obtain the right corrosion resistance and to avoid the difficulties during the finishing operations. The heat treatment is defined according to the steel grade. To remove the chemical and structural segregations, annealing at high temperature is generaly performed. Carbon and low alloy steels undergo:

- normalising and air cooling; or
- austenitising, quenching and tempering.

Austenitic or duplex stanless steels undergo a solution annealing and water quenching heat-treatment. Additionnal heat treatments such as for stress relief or post-weld treatment are also used to eliminate the internal stresses of the material.
[14, CAEF 1997], [100, TWG 2002], [120, TWG 2003]

2.2.8.6 Heat treatment of aluminium

Aluminium castings are heat treated for: homogenisation, stress relief, improved dimensional stability and machinability, optimised strength, ductility, toughness and corrosion resistance. Most often the heat treatment is a compromise between varying effects, maximising the important properties of one often at the expense of others. The heat treatment of aluminium may involve: annealing, solution heat treatment, quenching, artificial ageing and precipitation treatment. The type of treatment applied is indicated by a suffix to the alloy designation. This is called the temper designation. For sand, gravity and low-pressure die-castings all treatments are possible, though not all are standardised. Pressure die-castings are not solution treated and quenched in the same way as sand, gravity and low-pressure die-castings. Entrapped gas bubbles can expand and cause casting defects. Heat treatment is not a common step for high-pressure die-castings; only about 1 % of this type of castings are subjected to heat treatment. All die-castings may be quenched from the die, precipitation treated and stress relieved without suffering any harmful effects. In the low pressure die casting production of aluminium wheels 90 % of the castings are subjected to heat treatment
[120, TWG 2003].

2.2.8.6.1 Stress relieving and annealing

Castings with changes of section, or of a complex shape are likely to develop internal stresses. These can then cause dimensional changes upon machining. To stabilise the casting and to remove internal stresses, castings are heated to a temperature of 200 ºC for 5 hours, followed by slow cooling in the furnace.

2.2.8.6.2 Solution treatment and quenching

Castings are heated at temperatures just below the melting temperature and held there for a long time to take the alloying constituents into a homogeneous solid solution. The castings are then rapidly cooled by quenching to room temperature to retain the elements in solution. Water or special quenchants are used. The quench tanks are placed close to the furnace to ensure that rapid cooling is possible. Although sensitivity to the quench interval differs between alloys, good practice should limit the interval to 5-10 s.

2.2.8.6.3 Precipitation treatment

The controlled precipitation of alloying constituents is promoted by heating the casting to a temperature of between 150 ºC and 200 ºC. The casting strength and hardness are increased. The process is therefore also referred to as structural hardening. Each alloy has an optimal heat treatment cycle.

2.2.8.6.4 Artificial ageing

Some casting alloys increase in strength and hardness while left standing at room temperature. The process can take several weeks but can be speeded up by heating above room temperature and then sustaining this heat over time.
[74, Brown 1999], [100, TWG 2002], [111, CTIF at al. 2002], [110, Zalensas, D. L. 1993]

2.2.9 Quality control

During quality control the finished casting is checked for compliance with the product requirements concerning e.g. dimensions, metal structure defects, surface structure. Depending

on the type of casting and the size of the series, quality control can be achieved by visual inspection, with the use of measurement tools, or automatically.

In the production of aluminium wheels the castings are controlled via X-ray analysis. A standard image of a good casting is used for verification by a computer program. If there are any differences, the image is studied and assessed by a human operator. Random tests of the alloy are analysed with spectral analysis.

The quality control procedure informs the final decision to reject a casting or to allow its further shipment to the market. Rejected castings are brought back to the raw material input to be remelted.
[120, TWG, 2003]

2.2.10 Sand reclamation and regeneration

Since foundries make intensive use of sand as an inert primary material, the regeneration of this sand is a major point of consideration as part of its environmental performance. A clear distinction must be made between green sand and chemically bonded sand. Green sand can be easily reconditioned after use. Indeed, recirculated green sand shows a better technical quality than new sand. ~~Most~~All green sand foundries perform ~~primary regeneration~~ preparation of used sands (reconditioning).

~~Primary regeneration~~ Typical sand preparation, also known as attrition or particulation, involves breaking down the sand from moulds or cores back to its original grain size. This includes screening the sand, removing tramp metal, and separating and removing fines and over-sized agglomerates. The sand is then cooled before being sent for storage, returned to the sand system or blended with new sand. At this stage, the sand grains are likely to retain a partial coating of spent binder. ~~This affects the amount of reclaimed sand that can be used to make moulds and, more particularly, cores. New sand therefore has to be added to ensure that the sand mix produces adequate mould and core strength and subsequenty aids good casting quality.~~ Green sand is used principally for moulds - for core making only in very specific cases.~~Primary reclaimed sand is not generally of sufficient quality to be used for core-making, without further processing to remove residual binder materials, and is therefore used principally for moulds~~. The main ~~primary regeneration~~ green sand preparation techniques are vibration, rotating drum or shot blasting.

~~Secondary regeneration~~ Regeneration (reclamation) involves the further processing of the previously particulated sand to remove residual binder. The sand is returned to a quality similar to, or better than, that of new sand. ~~Foundries using secondary regeneration have, in some cases, virtually eliminated the need for new sand.~~ To remove residual binder, more aggressive techniques are needed than for~~primary regeneration~~ preparation. The main ~~secondary~~ regeneration techniques are:

- cold mechanical treatment:
- low energy attrition: friction, impact (for cold-setting resins);
- high energy attrition: pneumatic chafing, grinding, centrifugal friction;
- thermal treatment (usually in a fluidised bed) ;
- wet scrubbing.

Sands bonded with cold-setting resins may be regenerated using simple treatment techniques, due to the fragility of the binder layer. Mechanical regeneration systems ~~(e.g. fluidised bed systems)~~ are based on interparticle friction or impact.

Sands bonded with gas-hardened and thermosetting resins need more intensive treatment to remove the binder layer. These include grinding, pneumatical chafing and centrifugal friction. ~~Silicate sands can only be regenerated mechanically using pneumatical treatment.~~

Thermal treatment involves the burning of the organic binder. Bentonite is inactivated by the high treatment temperature. For sand flows containing green sand, any thermal treatment should therefore be combined with a mechanical treatment.

Wet regeneration involves binder removal through interparticle grinding. This technique applies only for green sand and silicate or CO_2-bonded sands and is not widely applied.

~~Secondary~~ ~~r~~Regeneration of green sand as a monosand flow finds limited implementation. For chemically bonded sands, mechanical regeneration is most widely applied (> 200 units in Germany in 1999) [33, ERM Lahmeyer International GmbH 1999]. The applicability of the various regeneration techniques and of the regenerated sand are summarised in Table 2.24 (monosands) and Table 2.25 (mixed sand). Each of the presented techniques will be discussed in more detail in the sections below.

The most important **monosand** flows for secondary regeneration are the core sands in non-ferrous foundries. ~~Due to the low thermal load they are easily separated from the green sand~~. Furthermore monosands are produced from mould and core-making with purely organic systems such as croning, furan resin and urethane cold-box. A smaller monosand stream is non-cured core sand, arising from broken or rejected cores in the core-making shop and the residual sand of core-making machines.

Mixed sands generally contain bentonite-bonded sand as well as chemically bonded sand. They are mainly generated in iron foundries and represent some 75 % of the total waste sand production.

Table 2.24: Fields of application of different regeneration systems for monosands

Type of sand	Regeneration technique	Regeneration equipment	Utilisation	Borderline conditions	Minimal quantity (tonne/h)
Organic monosystems					
Cold-setting resins	Mechanical or thermal	Mechanical: friction, impact, pneumatic chafing Thermal: turbulent bed, fluidised bed or rotary furnace	- for mould-making using cold-setting resins - 20 – 25 % substitution of new sand for cold-setting core-making	- mechanical: only if binder shells have become fragile enough upon pouring - the target values for regenerate quality must be met	1.5
Cold-Box, SO_2, Hot-Box and Croning sand	Mechanical or thermal	Mechanical: pneumatic chafing, centrifugal friction, fluidised bed chafing Thermal: turbulent bed, fluidised bed or rotary furnace	In core-making, as new sand substitute	- mechanical: only if binder shells have become fragile enough upon pouring - the orientative values for regenerate quality must be met - re-use of fines	0.75
Resol- ester methyl formate hardened sand	Mechanical	Mechanical: friction, impact, pneumatic chafing	With limitations, in mould-making with methyl formate sands	- regeneration as resol-ester cold setting but with lower yield - embrittlement of binder components	
Inorganic monosystems					
Green sand	Mechanical	pneumatic chafing, grinding	Renewal sand for green sand circuit	- requires predrying - re-use of fines	0.75
Sodium silicate sand	Mechanical		Only for making moulds and cores using sodium silicate sand	Embrittlement of binder components at 200 ºC	0.5
Source: [42, IHOBE 1998], [120, TWG 2003]					

Table 2.25: Fields of application of different regeneration systems for mixed sands

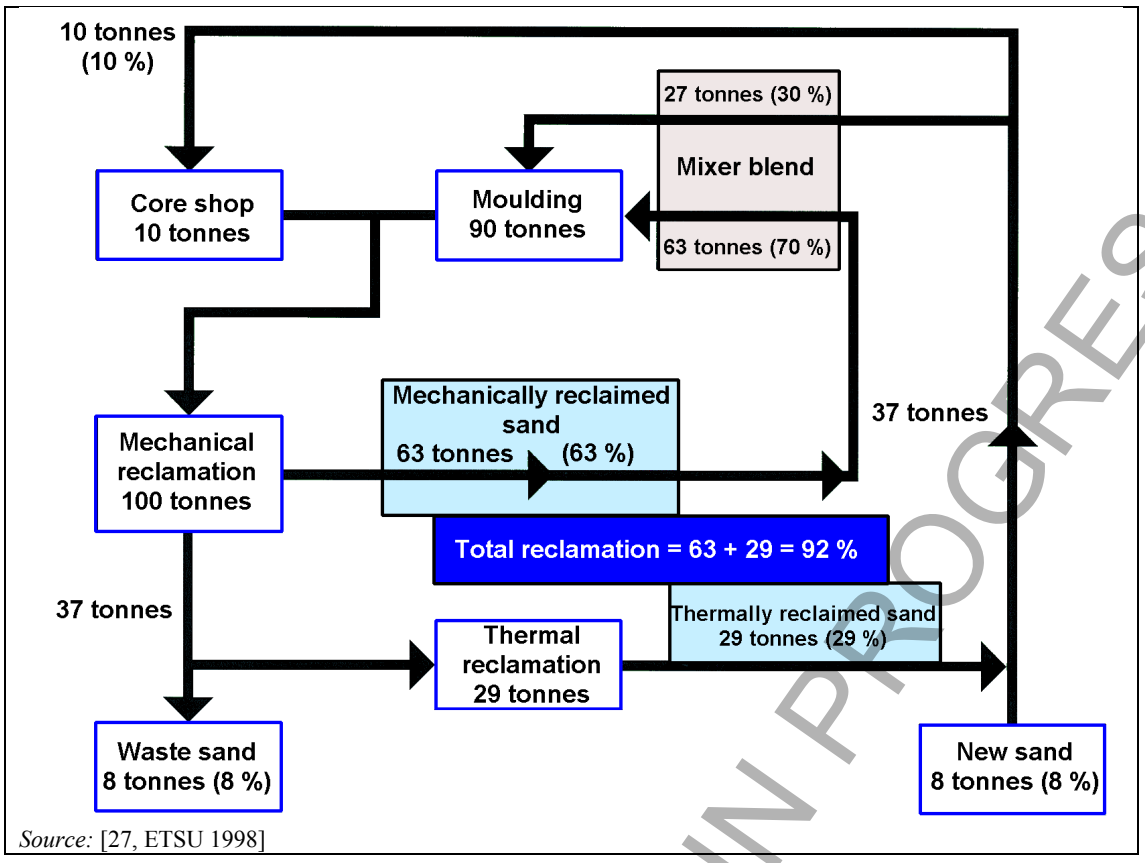
Type of sand	Regeneration technique	Regeneration equipment	Utilisation	Borderline conditions	Minimal quantity (tonne/h)
Mixed organic systems	Mechanical or thermal	Mechanical: pneumatic chafing, centrifugal friction, fluidised bed chafing Thermal: turbulent bed, fluidised bed or rotary furnace	- core-making substituting new sand	- mechanical: only if binder shells have become fragile enough upon pouring - the orientative values for regenerate quality must be met - re-use of fines	0.75
Mixed sands containing bentonite	Mechanical or mechanical-thermal-mechanical	Mechanical: grinding, pneumatic chafing, fluidised bed chafing Thermal: turbulent bed, fluidised bed or rotary furnace	- core-making substituting new sand - renewal sand for the green sand circuit	- require pre-drying - combined thermal regeneration requires efficient mechanical regeneration to remove active bentonite - re-use of fines	0.75
Source: [42, IHOBE 1998]					

The applicability of the various treatment systems is summarised in the following table and will be discussed further in the specific applicability sections.

Table 2.26: Applicability of various sand regeneration techniques to various sand types

	Simple mechanical systems	Cold mechanical			Wet regeneration	Thermal	Mechanical – thermal – mechanical
		Grinding	Impact drum	Pneumatic chafing			
Monosands							
Cold setting	x	x	x	x	x	x	0
Cold-box, SO_2, Hot-box, Croning	0	x	x	x	0	x	0
Silicate (CO_2 or ester)	0	0	0	x	x	0	0
Green sand preparation~~(primary)~~	x	0	0	0	0	0	0
Green sand regeneration ~~(secondary)~~	0	x	0	x	x	0	0
Mixed sands							
Mixed organic	0	x	x	x	0	x	0
Mixed green + organic	0	x	0	x	x	0	x
x: Applicable; 0: Not applicable							

The application of both primary and secondary regeneration in a mixed sand foundry in order to achieve a total regeneration of 92 % is shown in Figure 2.58. This simplified scheme does not take into account the various losses in the processing steps. The addition of new sand can be reduced to a minimum by integrating (the coarse fraction of) the filter dust sands (from the exhaust of hand forming lines, de-coring lines, storage silos, etc.)



Source: [27, ETSU 1998]

Figure 2.58: Sand balance diagram for a thermal/mechanical regeneration system

An overall reclamation ratio of 92 %, as given above, is a normal value for mixed green sand – chemically bonded sand systems. Regeneration ratios of up to 98 % have been reported. The actual ratio depends on the volume and chemical composition of the used cores. For furan cold setting monosands, values ~~around 78 %~~ of more than 90 % are reported.

Generally, the mixing of different types of sands has a negative effect on the strength of the cores and subsequently the moulds made with the regenerated sand, although there are a few exceptions to this general principle. In order to produce a good quality regenerated sand it is therefore of great importance to keep non-compatible sand types separate. Optimisation of the regeneration potential may therefore imply changing to compatible binder systems, if mixed sands are used, or the application of (shake-out) techniques that allow the separation of various sand types. Table 2.27 provides a cross-compatibility table.

Table 2.27: Compatibility of regenerated sources sands with various binders

Source system \ Goal system		Bentonite	Silicate	Cold-setting	Hot-box	Croning	Cold-box		
							Methyl-formate	Amine	SO_2
Bentonite		+	0	0	-	0	0	0	0
Silicate		0	+	-	-	-	-	-	-
Cold-setting		+	-	+	-	0	-	0	+
Hot-box		0	-	+	+	+	-	0	+
Croning		+	+	+	+	+	+	+	+
Cold-box	Methyl-formate	0	+	0/-	-	-	0	0	-
	Amine	+	+	+	+	+	0	+	+
	SO_2	+	-	+	-	0	0	+	+

+: Compatible, 0: Limited compatibility, -: Incompatible
Source: [17, Winterhalter et al. 1992], [120, TWG 2003]

Reference literature

[17, Winterhalter et al. 1992], [27, ETSU 1998], [42, IHOBE 1998], [46, Metaalgieterij Giesen B.V. 1996], [57, Umweltbundesamt 2002], [100, TWG 2002], [120, TWG 2003]

2.3 Current consumption and emissions levels in Foundries

[Most of the information contained in this section of the old BREF has been removed and replaced with up-to-date information obtained from the data collection. Some relevant elements of the old information have been kept when considered relevant for this BREF (following the fonts colouring code). Information from the old BREF could still be integrated back into this Section provided that TWG members kindly update with new information – where necessary - the content from the old BREF.]

The following sections present the consumption and emission data reported by the foundries (ferrous and non-ferrous) across the EU that took part in the 2020 SF data collection (in total 157 plants). The relevant plants are listed in Section 9.3.1 in which a list of installations/plants that participated in the 2020 data collection for the SF BREF review may be found.

The emission and consumption levels are presented and structured according to the environmental topics as follows:

For emissions to air, the reported levels are presented at a process level for:

- metal melting and ladle preheating;
- core-making and moulding using lost moulds;
- casting, cooling and shake-out using lost moulds;
- casting using alternative casting processes (i.e. lost foam, ceramic shell);
- casting using permanent moulds;
- finishing;
- sand reconditioning and regeneration.

For emissions to water, consumption of energy and water, operational material efficiency, sand regeneration and quantity of residues sent for disposal, the reported levels are presented at a plant level.

Handling of Confidential Business Information (CBI)
Energy consumption data were considered CBI by the plant operators. In order to maintain data confidentiality, plant names are not directly mentioned in the graphs describing energy consumption but are replaced with anonymised and randomly attributed CBI codes. In addition, no contextual information (e.g. process parameters or techniques applied) is included as this could reveal the identity of the plants. All the consumption figures are presented in ascending order of the maximum specific energy consumption values.

2.3.1 Mass stream overview

The general mass stream overview for the foundry process is given in Figure 2.59. This scheme generally applies ~~for~~ to both ferrous and non-ferrous foundries. Specific aspects of the various process steps and types ~~will be worked out~~ are detailed below.

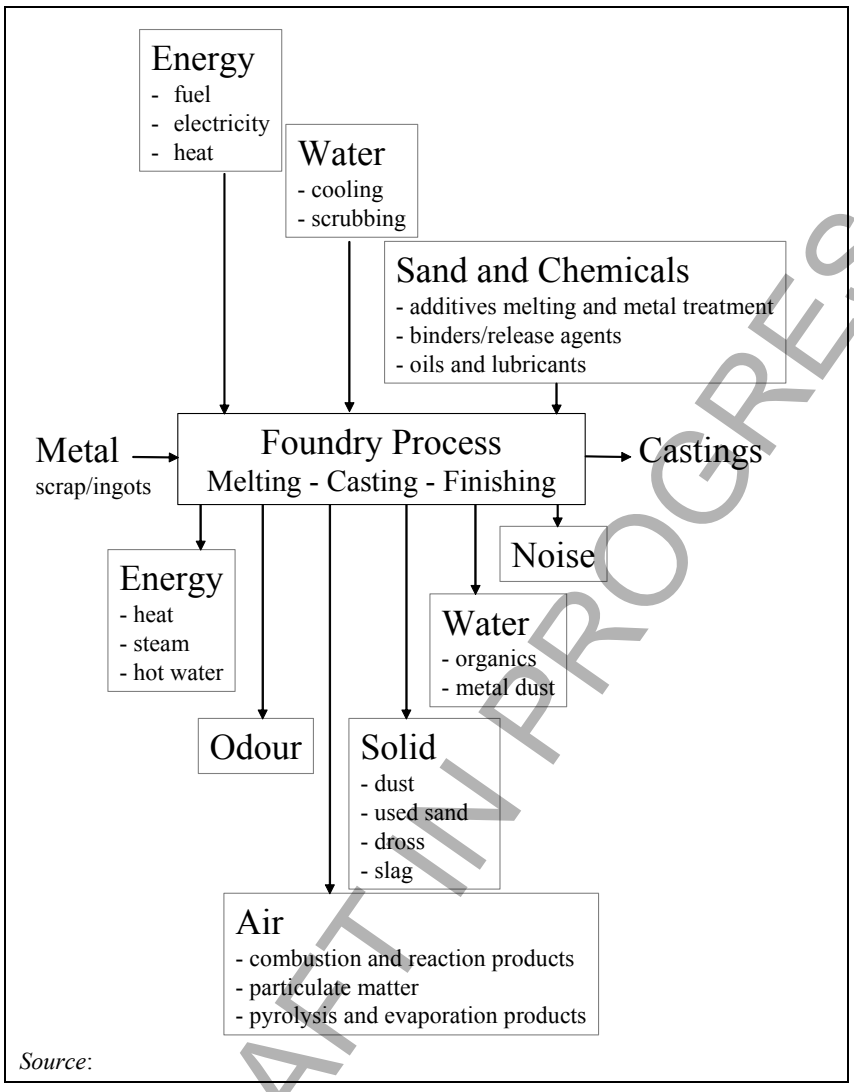


Figure 2.59: Mass stream overview for the foundry process

The inputs/outputs for the main furnace types used are also discussed in this section.

Table 2.28: Typical properties of melting furnaces used in ferrous foundries ~~properties and emission data~~

Process	Steel			Cast iron					
Type	ELECTRIC ARC FURNACE		INDUCTION F.	INDUCTION F.	CUPOLA FURNACE				ROTARY F.
Subtype	Acid lined	Basic lined	Coreless	Coreless	Cold blast	Hot blast	Hot blast – long campaign	~~Cokeless - duplex~~	
Energy source	Electricity	Electricity	Electricity	Electricity	Coke	Coke	Coke	~~Gas/fuel~~	Gas/fuel
Thermal efficiency[1] (%)	60 – 70	60 – 70	50 – 60	50 – 60	30 – 40	40 – 45	35 – 45	~~50 – 60~~	50 – 60
Primary thermal efficiency[2] (%)	21 – 25	21 – 25	15 – 20	15 – 20	30 – 40	40 – 45	35 – 45	~~45 – 50~~	35 – 45[3]
kWh/tonne metal charge	500 – 700	500 – 700	520 – 800	520 – 800	950 – 1200	800 – 900	810 – 1100	~~700 – 800~~	600 – 800
Batch/continuous	Batch	Batch	Batch	Batch	Continuous	Continuous	Continuous	~~Continuous~~	Batch
Production rate[4] (tonnes/h)					2 - 10	8 - 70	8 - 70	~~>5~~	
Furnace capacity[5] (tonnes)	2 – 50	2 – 50	0.01 – 30	0.01 – 30					1 – 20
Meltdown time (h)	1 – 4	1 – 4	1 – 2	1 – 2					2 – 4
Refining ability	Possible	Possible	No	No	Yes	Yes	Yes	~~No~~	No
Capital cost	High	High	High	High	Medium	High	High	~~Medium~~	Low
Slag production (kg/tonne metal charge)	10 – 40	20 – 80	10 – 20		40 – 80	40 – 80		~~40 – 80~~	20 – 60
Dust production[6] (kg/tonne metal charge)	5 – 8		0.06 – 1		5 – 13	4 – 12		~~0.8~~	0.3 – 2.9
~~**Waste gas[7] emission (kg/tonne metal charge)**~~									
~~**CO_2[8]**~~	~~Depending on power generation~~		~~Depending on power generation~~		~~400 – 500~~	~~350 – 480~~		~~100 – 120~~	~~120~~
~~**CO**~~	~~7.5 – 25 (decarburisation)~~		~~n.a.~~		~~Possible[9]~~	~~0.5 – 2.5~~		~~<10~~	~~1.0 – 1.5~~
~~**SO_2**~~	~~<1~~		~~Minor~~		~~1 – 2~~	~~<1~~		~~Fuel dependent~~	~~2.5 – 3.0~~
~~**NO_x**~~	~~n.a.~~		~~n.a.~~		~~<1~~	~~<1~~		~~0.5~~	~~0.3 – 0.4~~

1 Indicated values give an order of magnitude but largely depend on exploitation conditions, such as metal temperature, furnace capacity and production rate.
2 Efficiency of electrical power generation assumed to be 35 %.
3 Taking into account energy consumption for oxygen production and the raw materials, such as graphite and FeSi, to substitute the oxidised elements during melting.
4 For continuous processes only.
5 For batch processes only.
6 ~~Indicated values are general values found in literature~~
~~7 Indicated values are general values found in literature~~
~~8 Assuming complete combustion~~
~~9 Depending on local exploitation conditions and construction~~.

Source: [14, CAEF 1997], [38, VITO 2001], [100, TWG 2002], [120, TWG 2003] and comments from CTIF

Table 2.29: Typical properties of melting furnaces ~~properties for~~ in aluminium melting

	Units	Rotary furnace	Hearth type furnace	Shaft furnace	Crucible furnace		
Subtype			One chamber		Fuel heated	Resistance heated	Induction
Energy sources		Fuels (liquid, gaseous)	Fuels (liquid, gaseous)	Fuels (liquid, gaseous)	Fuels (liquid, gaseous)	Electricity	Electricity
Thermal efficiency[1]	%	15 – 40	<30 – 57	35 – 60	15 – 40	65	65 – 70
Primary thermal efficiency[2]	%	15 – 40	<30 – 57	35 – 60	15 – 40	22	22 – 25
Spec. energy demand[3]	kWh/t Al[4]	600 – 1250	975 – 1150	580 – 900 *610 – 720*	900 – 1200 *610 – 680*	750 *470 – 590*	475 – 640 *440 – 470*
Batch/continuous		Batch	Batch	Continuous	Batch	Batch	Batch
Melting capacity	t	3 – 10	0.5 – 30	0.5 – 4 (-15)	0.1 – 1.2	0.1 – 0.4	0.2 – 25
Holding capacity	t	n.a	n.a	1.5 – 10	0.1 – 1.5	0.1 – 1.5	0.15 – 6
Meltdown time		2 – 4	3 – 4	0.5 – 1	0.5 – 1	4 – 5	0.2 – 0.5
Refining ability		Low	Low	Low	Good	Very good	Low
Loss by burning	%	n.d	n.d	1 – 3	1 – 2	1 – 2	1 – 2
~~Dust generation~~	~~kg/t Al[4]~~	~~n.d~~	~~<1~~	~~<1~~	~~<1~~	~~Minor~~	~~Minor~~
~~NO_x[5]~~	~~kg/t Al[4]~~	~~n.d~~	~~<1 – 6~~	~~<1 – 6~~	~~<1 – 6~~	~~n.a~~	~~n.a~~
~~Investment costs[6]~~	~~EUR '000~~	~~n.d~~	~~n.d~~	~~190 – 370~~	~~20 – 50~~	~~12 – 100~~	~~190 – 500~~
~~Running costs~~	~~EUR '000~~	~~n.d~~	~~n.d~~	~~20 – 100~~	~~3 – 20~~	~~15 – 45~~	~~35 – 150~~
Abatement techniques		Fabric ~~Bag house~~ filter for bigger installations	Fabric ~~Bag house~~ filter for bigger installations	Fabric ~~Bag house~~ filter for bigger installations	Typically not necessary due to small furnace size	Not necessary	Not necessary

[1] Definition: the relationship between the heat of the molten bath and the fuel heat supplied; indicated values give an order of magnitude but largely depend on the exploitation conditions, such as the metal temperature.
[2] Efficiency of electrical power generation (fuels) assumed to be 35 %.
[3] Depends on heat recovery measures; only valid for melting; values given by [52, Eurofine 2002] *in italics.*
[4] Units 'per tonne Al' refer to tonne of molten aluminium alloy.
[5] ~~Depends on burner design and operational performance~~
[6] ~~Depends on heat recovery measures; only valid for melting~~

Sources of information: VDG internal survey; Aluminium Taschenbuch, Band 2, 15. Auflage, Aluminium Verlag GmbH, Düsseldorf, 1996; Aluminium recycling, Aluminium Verlag GmbH, Düsseldorf, 2000; [52, Eurofine 2002]; comments CTIF

Source: [52, Eurofine 2002] and comments from CTIF and VDG

2.3.1.1 Inputs/outputs in metal melting

The inputs and outputs of the main types of furnaces used in ferrous or non-ferrous foundries are summarised below. In this document, melting refers to the production of ferrous or non-ferrous molten metal using furnaces. This also includes remelting of molten metal and heat conservation of molten metal in holding furnaces.

The main inputs and outputs for cupola furnaces are presented in the following table.

Input	Output
– Ferrous material (iron pigs, sponge iron, steel scrap, foundry returns …)	– Metal alloy (cast iron)
– Alloying metal (ferro-alloys …)	– Dust (metal content)
– Flux (limestone…)	– CO/CO_2, SO_2, NO_X
– Energy (coke, gas, oil, electricity)	– HF
– Oxygen	– Dioxins, furans
– Cooling water	– Organic pollutants
– Water	– Slag
	– Waste refractory linings

In cold blast operation, the coke consumption between the charges is generally 90-120 kg/tonne metal charge, but can be less than 70 kg/tonne metal charge, e.g. in the case of counterweights. Accounting for the amount of coke in the bed gives a total coke consumption of 110-140 kg/tonne metal charge. As the calorific value of European cokes is 8.5 kWh/kg, this corresponds to a calorific input of 950-1 200 kWh/tonne metal charge.

The total coke ~~ratio~~ consumption rate in a hot blast cupola is generally 110-145 kg/tonne metal charge. However, as the average steel percentage is 50 %, and the recarburisation consumes about 1.5 %, the real burned coke ratio is 95-130 kg/tonne metal charge, which is 810-1 100 kWh/tonne metal charge. This corresponds to a thermal efficiency of 35 % to 45 %.

Depending on the plant layout, the energy consumed by the fume treatment equipment and the holding furnace, as given in Table 2.30, must be added. German data indicate a specific electricity use for the flue-gas cleaning equipment of around 20 kWh per tonne of good casting. [202, TWG, 2002]

Table 2.30: Average energy consumption for off-gas treatment and holding

Energy carrier type	Average consumption kWh/tonne metal charge
Gas for the combustion chamber	40
Electricity for the flue-gas cleaning equipment (fans, etc.)	40
Electricity for the holding furnace	60
Source: [100, TWG 2002]	

The main inputs and outputs for electric arc furnaces are presented in the following table.

Input	Output
– Ferrous material (steel scrap, foundry returns swarf, pig iron …)	– Metal alloy (cast steel)
– Alloying metal (ferro-alloys …)	– Dust (metal content, refractory)
– Flux (limestone …)	– NO_X, CO_2, CO
– Energy (electricity, gas, oil)	– Organic air pollutants, HC
– Oxygen	– Metal oxide fumes
– Electrodes	– Slag (CaO, SiO_2, MgO)
	– Waste refractories

The main inputs and outputs for rotary furnaces are presented in the following table.

Input	Output
– Ferrous material (iron pigs, steel scrap, swarf, foundry returns …)	– Metal alloy (cast iron)
– Alloying metal (ferro-alloys …)	– Dust
– Carburising agents, flux	– Organic and metallic fumes
– Energy (electric, oil, gas)	– Slag
– Cooling water	– Refractory waste

The main inputs and outputs for induction furnaces in iron and steel foundries are presented in the following table.

Input	Output
– Ferrous material (iron pigs, steel scrap, swarf, foundry returns …)	– Metal alloy (cast iron, cast steel)
– Alloying metal (ferro-alloys …)	– Dust
– Carburising agents, flux	– Organic and metallic fumes
– Energy (electric)	– CO
– Cooling water	– Slag
	– Refractory waste

The main inputs and outputs for induction furnaces in aluminium foundries are presented in the following table.

Input	Output
– Aluminium ingots, foundry returns	– Molten aluminium
– Electrical energy	– Dust
– Cooling water	– Used refractory

The main inputs and outputs for Argon Oxygen Decarburisation Converters are presented in the following table.

Input	Output
- Molten steel	- Decarburised steel
- Alloying metals (ferro-alloys)	- Metal oxide dust and fumes (Fe,Mn,Cr,Ni)
- Al, FeSi, lime	- Gases (CO_2, CO, inert gases)
- O_2, N_2, Ar	- Slag (CaO,SiO_2, AlO_3)

The main inputs and outputs for shaft furnaces are presented in the following table.

Input	Output
– Aluminium ingots, foundry returns – Energy – Deoxidation and gas removal products	– Molten aluminium – Dust – NO_X, CO – Used refractory

The main inputs and outputs for crucible furnaces are presented in the following table.

Input	Output
– Aluminium ingots, foundry returns or liquid aluminium if used as a holding furnace – Electrical energy or fuel	– Molten aluminium – Dust

2.3.1.2 Inputs/outputs in moulding and core-making

Moulding with clay-bonded sand

The main inputs and outputs in moulding with clay-bonded sand (green sand moulding) are presented in the following table.

Input	Output
– Sand – Bonding clay (e.g. bentonite) – Coal dust, dextrin – Water (to prepare moulding mix)	– Green sand moulds – Dust (silica fines, partially burnt-out clay, unburned coal dust and ash)

The composition of the bentonite added to the sand depends on the specific properties of both the sand and the bentonite, as well as on the desired strength and gas permeability of the finished mould. The table below gives some parameters of clay-bonded sand, as obtained from a selection of 105 sand samples taken from iron foundries.

Table 2.31: Typical properties of green sand, measured on 105 sand samples from 105 iron foundries

Parameter	Units	Average	% of samples in range of average ± 10 %		Maximum value	Minimum value
			Range	%		
Water content	%	4.1	3.4 – 4.5	48	6.9	2.4
Bentonite content	%	8.3	7.5 – 9.1	45	11.9	5.6
Density	g/cm³	0.940	1.00 – 0.85	75	1.06	0.73
Loss on ignition	%	5.0	4.5 – 5.5	20	15.0	1.0
Compressive strength	N/cm²	18.6	16.7 – 20.5	54	24.5	13.2
Source: [16, Winterhalter, et al., 1992]						

Further additives are mixed in the green sand mixture:

- *Coal dust*: Used mainly in iron foundries, but also to a lesser degree in some non-ferrous foundries. Coal dust levels in green sand vary from 2 % or 3 % for small castings to 7 % or 8 % for heavy section castings. Too much coal dust can give rise to holes in the castings or in misruns. Various coal dust replacement products exist. They are generally added in a slightly altered concentration compared to the coal dust.
- *Cereal binders*: Starch and dextrin are used mainly in steel foundries to avoid defects caused by silica expansion and to control moisture excess in the sand mix. Effective additions of cereal binders to new green sand facing mixes are between 0.5 % and 0.75 %. In unit-type green sands, part of the cereal is destroyed during the casting process. The recommended addition on each recycle is 0.1 % to 0.25 %, depending on the amount of cereal burn-out and on the dilution by cores and new sand.

[73, Brown, J. R. 2000]

Moulding with unbonded sand (V-process)

The main inputs and outputs for moulding with unbonded sand (V-process) are presented in the following table.

Input	Output
– Sand	– Sand moulds and cores
– Resin	– Excess reagents
– Catalyst, hardener, additives	– Reaction products
	– Dust

The consumption levels of the various types of binders, hardeners, catalysts and additives are given in Table 2.32.

Table 2.32: Consumption levels of various resins, catalysts, hardeners and additives for chemically bonded sand preparation

Hardening type	Resin type	Resin addition % on sand weight	Catalyst/ hardener type	Catalyst/ hardener addition % on resin weight	Additive type	Additive Addition % on sand weight
Cold-setting	Furan	0.8 – 1.5	Sulphonic acid	25 – 60	Silane	0.1 – 0.2
	Phenolic	1 – 2	Sulphonic acid	25 – 50	n.a	n.a
	Polyurethane	0.8 – 1.5	Pyridine derivate	2 – 6	n.a	n.a
	Resol	1.0 – 1.5	Ester	22 – 25	n.a	n.a
	Alkyd oil	1.0 – 2.0	Isocyanate	18 – 20	Catalyst	0.002 – 0.2
	Ester silicate	2.0 – 4.5	Ester	10 – 15	n.a	n.a
Hardening type	**Resin type**	**Resin addition % on sand weight**	**Catalyst type**	**Catalyst addition % on sand weight**	**Additive type**	**Additive Addition % on sand weight**
Gas hardening	Phenolic/Furan	0.8 – 1.2	SO_2	0.3 – 3	Peroxide	0.1 – 0.5
	Polyurethane Cold-box	1.0 – 1.8	Amine	0.05 – 0.15	n.a	n.a
	Resol	1.2 – 1.8	Methyl fomate	0.3 – 0.5	n.a	n.a
	Resol	2 – 2.5	CO_2	0.7 – 1.25	n.a	n.a
	Acryl/Epoxy	1.2 – 1.6	SO_2	0.02 – 0.05	Peroxide	0.05 – 0.06
	Silicate	2 – 4	CO_2	1 – 2	n.a	n.a
Hardening type	**Resin type**	**Resin addition % on sand**	**Catalyst type**	**Catalyst addition % on resin**	**Additive type**	**Additive Addition % on sand**

		weight		weight		weight
Thermosetting	Oil	0.8 – 4			n.a	n.a
	Warm-box furfuryl alcohol-based	1.0 – 1.5	Cu salts of sulphonic acids	10 – 30	n.a	n.a
	Hot-box phenolic or furan based	1.2 – 3.0	Ammonium salts	10 – 25	n.a	n.a
	Croning phenolic	1.5 – 5	Hexamethylene-tetramine	15	n.a	n.a
Source: [73, Brown, J. R. 2000], [120, TWG 2003]						

Emissions for the cold-setting processes can be described as follows:

- *Phenolic*: Vapours of formaldehyde and phenol may be emitted because of the vapour pressure of these constituents. However, as the polymerisation occurs at ambient temperature, these vapour pressures are low and, given the consumption rates, the emissions are insignificant.
- *Furan*: Vapours of formaldehyde, phenol, furfuryl alcohol and alcohols may be emitted because of the vapour pressure of these constituents. However, as the polymerisation occurs at ambient temperature, these vapour pressures are low and, given the consumption rates, the emissions are insignificant.
- *Polyurethane*: Vapours of formaldehyde, phenol, isocyanate and aromatic solvents may be emitted because of the vapour pressure of these constituents. As the polymerisation occurs at ambient temperature, the vapour pressures of the components are low and, given the consumption rates, the emissions are insignificant. Obnoxious odours may be generated in the moulding area but are not likely to cause external nuisance.
- *Resol-ester:* The resin contains unreacted phenol and formaldehyde, but their emissions are extremely low and environmentally insignificant.
- *Alkyd-oil:* During production of the moulds and cores, there are no emission problems, unless they are cured by heat, in which case odour problems may occur.
- *Ester silicate*: This process does not generate any emission problems.

[14, CAEF 1997]

Emissions for the gas-hardened processes can be described as follows:

- *Cold-box*: Vapours of formaldehyde, phenol, isocyanate and aromatic solvents are emitted in low quantities, in spite of their low vapour pressures. Aromatic solvent emissions are highest during purging. The most significant emission is that of amines, which have low odour detection thresholds and can create an external nuisance. Amines are hazardous, with a relatively low exposure value limit, and possess a strong characteristic smell at very low concentrations.
- *Resol-ester*: The resin contains unreacted phenol and formaldehyde, but their emission levels, even during the gassing and purging periods, are very low. Methyl formate is not toxic, does not have an unpleasant smell and its exposure value limit is relatively high.
- *Resol-CO_2:* The resin has low contents of unreacted phenol and formaldehyde, and their emission levels, even during the gassing and purging periods, are very low.
- *SO_2 hardened phenolic and furan resin*: The resins and the prepared sands generate formaldehyde emissions. The major emission problem is caused by sulphur dioxide, which is very hazardous.
- *SO_2 hardened epoxy/acrylic*: Minimal emissions are generated during the core-making process.
- *CO_2 silicate*: This process does not generate any emission problems during moulding or core-making.

[14, CAEF 1997]

Emissions for the hot curing processes can be described as follows:

- *Hot-box emissions*: The patterns are generally heated by open air gas burners, producing combustion gas emissions. The off-gas may contain phenol, ammonia, formaldehyde and monoisocyanates (if the resin contains nitrogen).
- *Warm-box emissions*: Compared to the hot-box process, the emissions are significantly lower. The emissions do not contain phenol or ammonia, and also formaldehyde emissions are diminished by a factor of 4. As the pattern temperature is also lower compared to the one used for the hot-box process, the working conditions are also improved. The environmental impact is considered to be relatively low.
- *Shell emissions*: Compared to the hot-box process, cured sand consumption is very low. However, the pre-coated sand contains two to three times more resin, but as the pattern temperatures are approximately the same, the resulting impact on working conditions is similar.
- *Linseed oil emissions*: As the oils are often in solution in organic solvents such as naphtha or kerosene, a large amount of VOCs are generated by curing, which may result in an external odour nuisance. This problem is even more persistent during pouring. These problems, as well as poor productivity, are some of the reasons for the reduction in interest in the use of this process.

[14, CAEF 1997]

2.3.2 Emissions to air

2.3.2.1 Metal melting and ladle preheating

2.3.2.1.1 Dust emissions

The reported levels of dust emissions to air from metal melting and ladle preheating are presented in the following figures:

- Figure 2.60 and Figure 2.61: cast iron foundries;
- Figure 2.62 and Figure 2.63: NFM foundries;
- Figure 2.64: steel foundries, combined emissions from different types of foundries (e.g. cast iron and NFM) and emission points associated with other processes besides only metal melting.

Some statistical data on the reported dust emission data in relation to the furnace type are presented in the following table.

Table 2.33: Statistical evaluation of the reported dust emission data

Parameter /Furnace type	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
CBC	16	6	6	5.0	2.1	1.0	0.2
HBC	41	19	16	19.0	8.4	4.3	0.6
Crucible	22	14	5	9.3	4.1	2.0	1.2
EAF	7	3	2	-	0.8	1.0	-
Induction (electric coreless)	57	25	18	12.0	3.7	1.7	0.4
Medium-frequency crucible induction	29	11	11	3.8	1.9	1.0	0.1
Net/mains frequency crucible induction	4	2	1	-	2.1	0.5	-
Rotary	1	1	1	-	2.1	-	-
Radiant roof	4	2	2	-	1.8	1.4	-
Resistance	3	1	1	-	5.0	3.0	-
Reverbatory (hearth)	31	14	5	11.8	4.6	2.8	1.3

NB: The data above refer to EPs that are associated with only one process.
Source: [169, TWG 2021]

For cupola furnaces, particle sizes range from less than 1 µm up to 10 mm, with 50 % less than 100 µm. However, 5 % to 20 % are smaller than 2 µm, which makes the dust collection more difficult. Cupola dust is primarily made up of coke, silica, rust and limestone, as shown in Table 2.34.

Table 2.34: Typical composition of cupola dust ~~(in weight per cent)~~

Substance	Composition (wt%)	
	[14, CAEF 1997]	[61, Charbonnier, et al. 1998]
Iron oxide	30 – 60	15 – 25
SiO_2	± 25	15 – 30
Coke dust	3 – 15	n.d
MnO	3 – 10	2 – 5
Al_2O_3	1 – 3	2 – 5
MgO	1 – 3	0 – 2
CaO	<1	5 – 10
S	<2	n.d
ZnO, depending on the charge	<3	0 – 30 Zn*
PbO, depending on the charge	<1	0 – 5 Pb*

* In the form of oxides and silicates; applicable for Zn-enriched dusts.
Source: [14, CAEF 1997], [61, Charbonnier, et al. 1998]

2.3.2.1.2 Metal emissions

The reported levels of metal (i.e. Cd, Cr, Ni and Pb) emissions to air from metal melting and ladle preheating are presented in the following figures:

- Figure 2.79 and Figure 2.80: Ni emissions;
- Figure 2.81 and Figure 2.82: Pb emissions;
- Figure 2.83 and Figure 2.84: Cd emissions;
- Figure 2.85 and Figure 2.86: Cr emissions.

2.3.2.1.3 PCDD/F emissions

In melting processes, dioxins may be produced if the conditions that give rise to such pollutants are present at the same location and time in the process. These conditions are:

- the presence of chloride ions – these can arise from contaminated scrap, from the use of coal, coke, fuel oil or from certain fluxes;
- the presence of organic carbon – this may arise from contaminated scrap and from coal, coke or oil used as a fuel;
- temperature conditions between 250 ºC and 450 ºC, with a sufficient gas residence time in this temperature interval;
- the presence of a catalyst such as copper;
- the presence of oxygen.

In evaluating the risk of dioxin formation, a distinction can be made between non-ferrous and ferrous foundries:

- Non-ferrous foundries: In as far as when only ingots and internal scrap are melted, the risk of dioxin formation in the melting stage is very low. The melting of pure non-ferrous metals lacks the presence of both the chlorine and carbon required for dioxin (re)formation. However, the remelting of external non-ferrous scrap materials for metal production may involve a risk of dioxin formation. This action, however, falls beyond the scope of this document and is considered in [1, COM 2017]]
- Ferrous foundries: Depending on the furnace type and metal load the conditions for dioxin formation could occur. Considering the high temperatures in the melting furnace, dioxin emission (if occurring at all) will mainly generate from de-novo synthesis. The abovementioned conditions can be used to evaluate the risk of dioxin formation.

Dioxin emission data have been gathered in the SF BREF data collection from a broad range of melting furnaces. The data are summarised in **Table** 2.35.

Reported levels of polychlorinated dibenzo-p-dioxins/furans (PCCD/F) emissions to air from metal melting and ladle preheating are presented in Figure 2.87.

Some statistical data on the reported PCDD/F emission data are presented in the following table.

Table 2.35: Statistical evaluation of the reported PCDD/Fs emission data

Furnace type	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				ng WHO-TEQ/Nm^3			
All furnace types	92	37	30	0.23	0.14	0.01	1
CBC	22	8	8	0.07	0.04	0.02	0.001
HBC	19	7	6	1.91	0.56	0.03	0.001
Induction (electric coreless and medium-frequency crucible) in cast iron foundries	30	13	10	0.01	0.01	0.01	0.001
Source: [169, TWG 2021]							

Additional data on PCDD/F emissions are available through the DIOFUR[3] project. Dioxin emission range for various furnace type are presented in Table 2.36 for cupolas (HBC and CBC), Table 2.37 for rotary furnaces and Table 2.38 for electric arc furnaces.

Table 2.36: Dioxin emission range for cupolas

Furnace type	ng I-TEQ/Nm³ (EU Project goal: <0.1)
Hot blast cupola	0.0017÷0.4166
Cold blast cupola	0.0010÷0.3290
Source: [180, DIOFUR 2010]	

Table 2.37: Dioxin emission range for rotary furnaces

Furnace type	ng I-TEQ/Nm³ (EU Project goal: <0.1)
Rotary (small)	0.0160÷0.0190
Rotary (big)	0.0019÷0.0022
Source: [180, DIOFUR 2010]	

Table 2.38: Dioxin emission range for electric arc furnaces

Furnace type	ng I-TEQ/Nm³ (EU Project goal:<0.1)
Electric Arc 1	0.0019÷0.0023
Electric Arc 2	0.0020÷0.0370
Source: [180, DIOFUR 2010]	

2.3.2.1.4 NO_X emissions

The reported levels of NO_X emissions to air from metal melting and ladle preheating are presented in the following figures:

- **Figure 2.67**: cast iron foundries, combined emissions from different types of foundries (e.g. cast iron and NFM) and emission points associated with other processes besides only metal melting;
- Figure 2.62 and Figure 2.63: NFM foundries.

Some statistical data on the reported NO_X emission data in relation to the furnace type are presented in the following table.

[3] More information on the DIOFUR project and its deliverables is available at the following link: https://cordis.europa.eu/project/id/30298

Table 2.39: Statistical evaluation of the reported NO_X emission data

Parameter /Furnace type	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
CBC	15	6	6	48.3	25.8	18.4	8.0
HBC	18	9	9	143.9	88.6	77.0	40.6
Crucible	19	13	4	53.8	31.0	28.0	13.7
EAF	8	4	3	147.5	80.3	96.0	20.5
Induction (electric coreless)	23	10	5	123.5	26.6	4.0	2.4
Medium-frequency crucible induction	8	3	3	-	2.1	1.0	-
Net/main frequency crucible induction	NI	NI	NI	NI	NI	NI	NI
Rotary	1	1	1	-	14.0	-	-
Radiant roof	4	2	2	-	10.3		
Resistance	NI	NI	NI	NI	NI	NI	NI
Reverbatory (hearth)	21	9	5	76.6	38.1	25.8	12.2

NB: The data above refer to EPs that are associated with only one process (i.e. metal meting).
NI: No information provided.
Source: [169, TWG 2021]

2.3.2.1.5 CO emissions

The reported levels of CO emissions to air from metal melting and ladle preheating are presented in the following figures:

- Figure 2.70: Emission points (EPs) associated with cupola furnaces (cast iron foundries);
- Figure 2.71: EPs not associated with cupola furnaces (cast iron foundries);
- Figure 2.72: EPs associated with shaft furnaces (NFM foundries);
- Figure 2.73: EPs not associated with shaft furnaces (NFM foundries).

Some statistical data on the reported CO emission data in relation to the furnace type are presented in the following table.

Table 2.40: Statistical evaluation of the reported CO emission data

Parameter /Furnace type	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
CBC	4	2	2	-	8 840.0 ([1])	-	-
HBC	23	12	12	504.4	162.2	53.5	14.1
Crucible	11	7	3	224.6	76.9	23.7	11.3
EAF	NI	NI	NI	NI	NI	NI	NI
Induction (electric coreless)	20	8	4	21.2	10.8	8.1	5.0
Medium-frequency crucible induction	8	3	3	20.4	18.0	19.2	14.7
Net/main frequency crucible induction	NI	NI	NI	NI	NI	NI	NI
Rotary	NI	NI	NI	NI	NI	NI	NI
Radiant roof	3	1	1	-	3.8	-	-
Resistance	3	1	1	-	5.90	-	-
Reverbatory (hearth)	13	5	3	221.6	44.9	11.0	10.5

NB: The data above refer to EPs that are associated with only one process.
([1]) 2 EPs, the first with CO values between 13 and 86 mg/Nm³ and the second with CO values between 7 000 and 14 920 mg/Nm³.
NI: No information provided.
Source: [169, TWG 2021]

2.3.2.1.6 SO_2 emissions

The reported levels of SO_2 emissions to air from metal melting and ladle preheating are presented in Figure 2.74.

Some statistical data on the reported SO_2 emission data in relation to the furnace type are presented in the following table.

Table 2.41: Statistical evaluation of the reported SO2 emission data

Parameter /Furnace type	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
CBC	15	6	6	126.3	67.1	57.0	17.5
HBC	20	10	10	161.0	75.9	41.3	21.7
Crucible	5	3	2	-	3.5	-	-
EAF	NI	NI	NI	NI	NI	NI	NI
Induction (electric coreless)	4	2	2	-	3.5	-	-
Medium-frequency crucible induction	8	3	3	-	4.6	1.5	-
Net/main frequency crucible induction	NI	NI	NI	NI	NI	NI	NI
Rotary	NI	NI	NI	NI	NI	NI	NI
Radiant roof	3	1	1	-	28.5	-	-
Resistance	3	1	1	-	15.2	-	-
Reverbatory (hearth)	11	4	2	22.8	11.6	6.0	5.4

NB: The data above refer to EPs that are associated with only one process.
NI: No information provided.
Source: [169, TWG 2021]

2.3.2.1.7 TVOC emissions

The reported levels of TVOC emissions to air from metal melting and ladle preheating are presented in Figure 2.77 and Figure 2.78.

Some statistical data on the reported TVOC emission data in relation to the furnace type are presented in the following table.

Table 2.42: Statistical evaluation of the reported TVOC emission data

Parameter /Furnace type	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
CBC	6	2	2	-	9.6	-	-
HBC	8	4	4	-	15.5	8.7	-
Crucible	15	11	4	18.5	7.4	4.9	2.6
EAF	4	2	1	10.6	6.2	4.5	3.3
Induction (electric coreless)	15	6	4	434.1	144.8	19.0	3.0
Medium-frequency crucible induction	3	1	1	-	28.3	-	-
Net/main frequency crucible induction	2	1	1	-	8.0	-	-
Rotary	1	1	1	-	2.0	-	-
Radiant roof	NI	NI	NI	NI	NI	NI	NI
Resistance	NI	NI	NI	NI	NI	NI	NI
Reverbatory (hearth)	12	7	2	31.7	15.2	12.2	5.2

NB: The data above refer to EPs that are associated with only one process.
NI: No information provided.
Source: [169, TWG 2021]

2.3.2.1.8 HCl emissions

The reported levels of HCl emissions to air from metal melting and ladle preheating are presented in Figure 2.76.

Some statistical data on the reported HCl emission data are presented in the following table.

Table 2.43: Statistical evaluation of the reported HCl emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
HCl	121	57	22	14.28	2.72	0.30	0.09
Source: [169, TWG 2021]							

2.3.2.1.9 HF emissions

The reported levels of HF emissions to air from metal melting and ladle preheating are presented in Figure 2.75.

Some statistical data on the reported HF emission data are presented in the following table.

Table 2.44: Statistical evaluation of the reported HF emission data

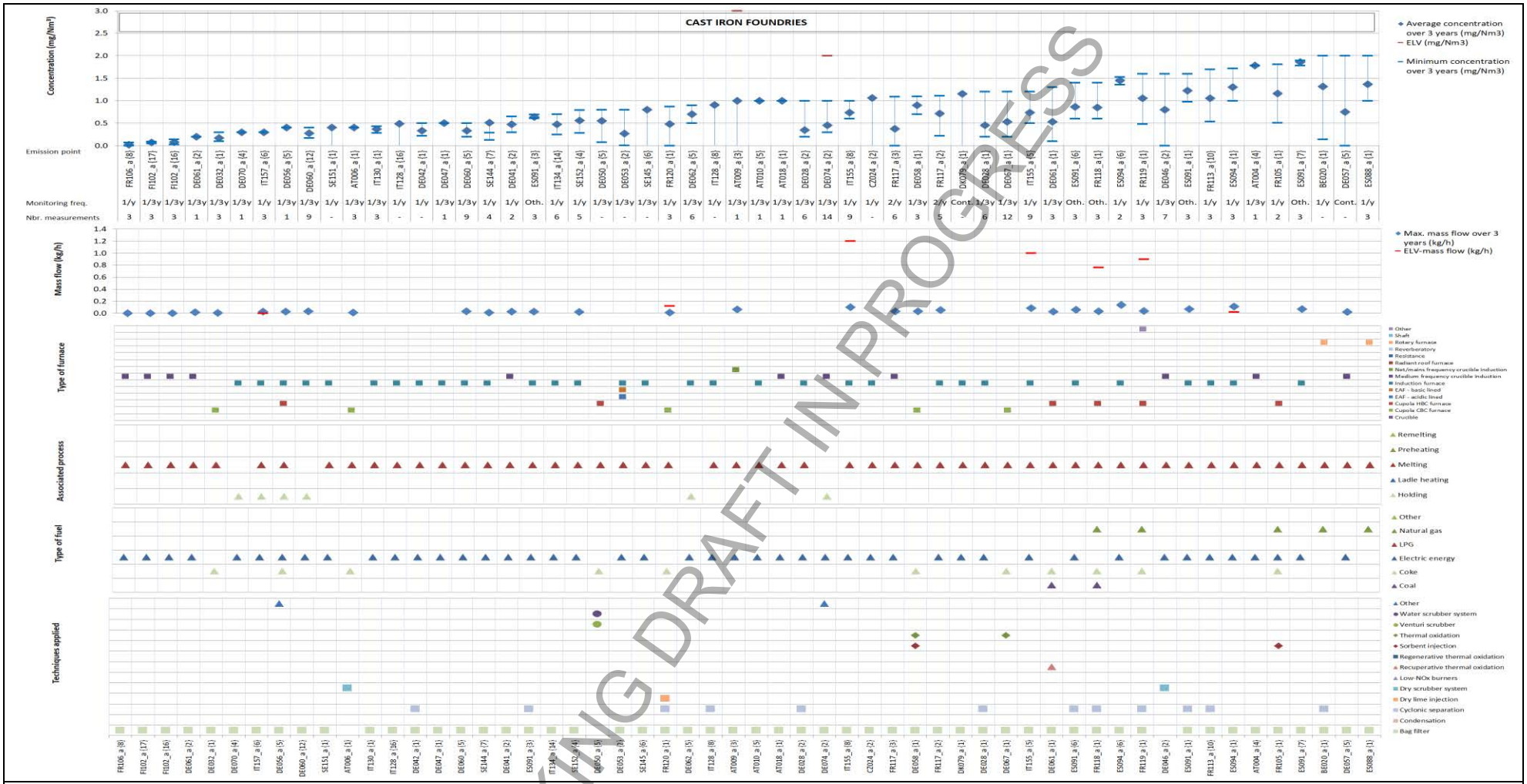
Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
HF	138	65	27	4.19	0.88	0.20	0.03
Source: [169, TWG 2021]							

2.3.2.1.10 Figures for emissions to air

The figures related to emissions to air which are presented in this section and the following relevant sections are composed of several parts (sections):

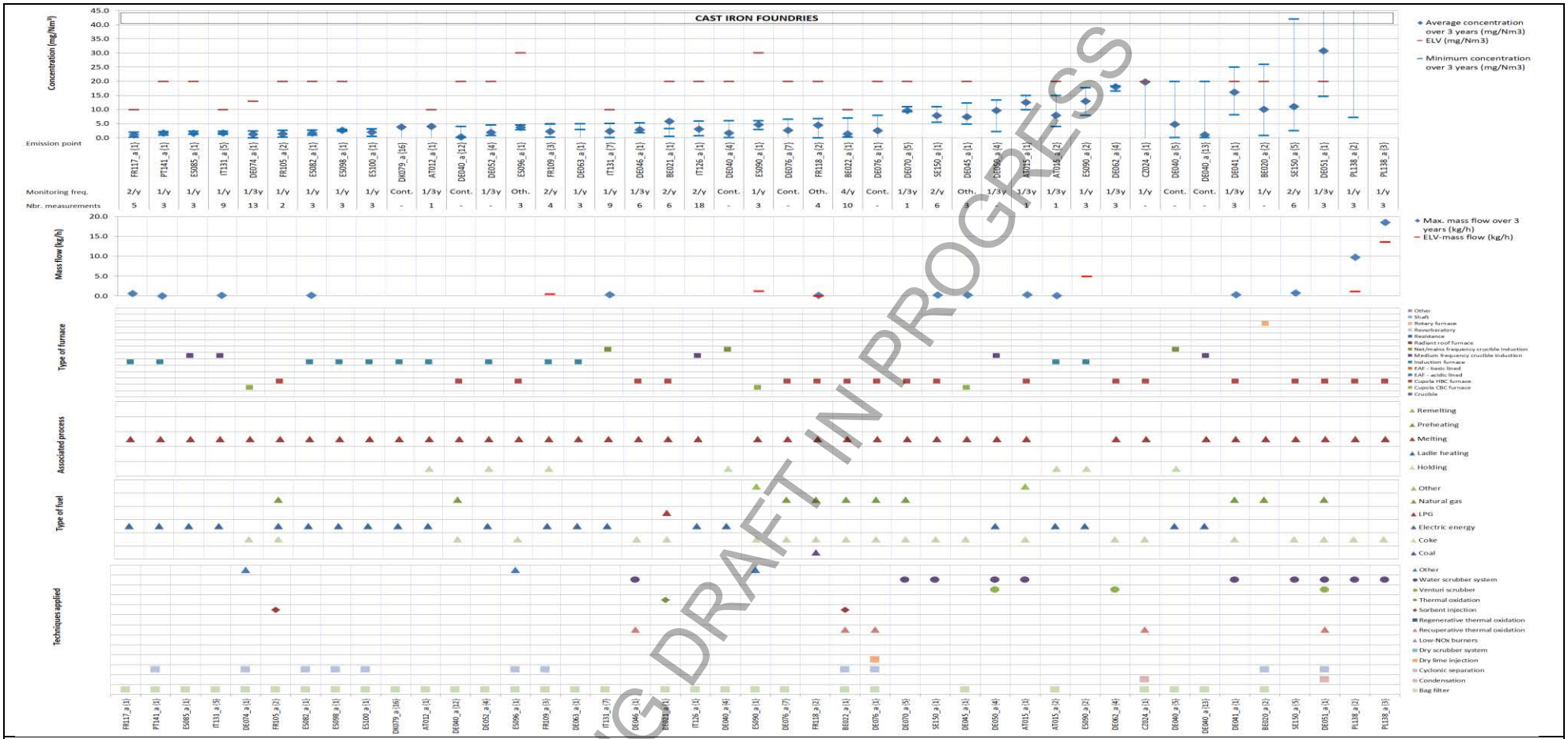
- The upper part (first section) of the figure always shows the maximum, average and minimum concentrations for the reporting period. Below the x-axis, additional contextual information is included such as the emission point code, the monitoring frequency and the number of measurements done each year.
- In the second part (section) of the figure, additional information is given such as the maximum mass flow values over the 3 reporting years.
- The third part (section) of the figure contains contextual information (e.g. the type of furnace used in the case of metal melting, the type of resins used in the case of moulding). In the case of furnaces, this information is complemented by two additional figure sections providing information on the associated process(es) (melting, remelting, holding, preheating, ladle heating) and the type of fuel used.
- The last section of the figure contains information on the applied techniques.

The explanations for the abbreviations used in the graphs can be found in the Glossary.



NB: For better visualisation, the ELVs over 3 mg/Nm^3 are not shown. The range of ELVs not shown is from 5 mg/Nm^3 to 20 mg/Nm^3.
Source: [169, TWG 2021]

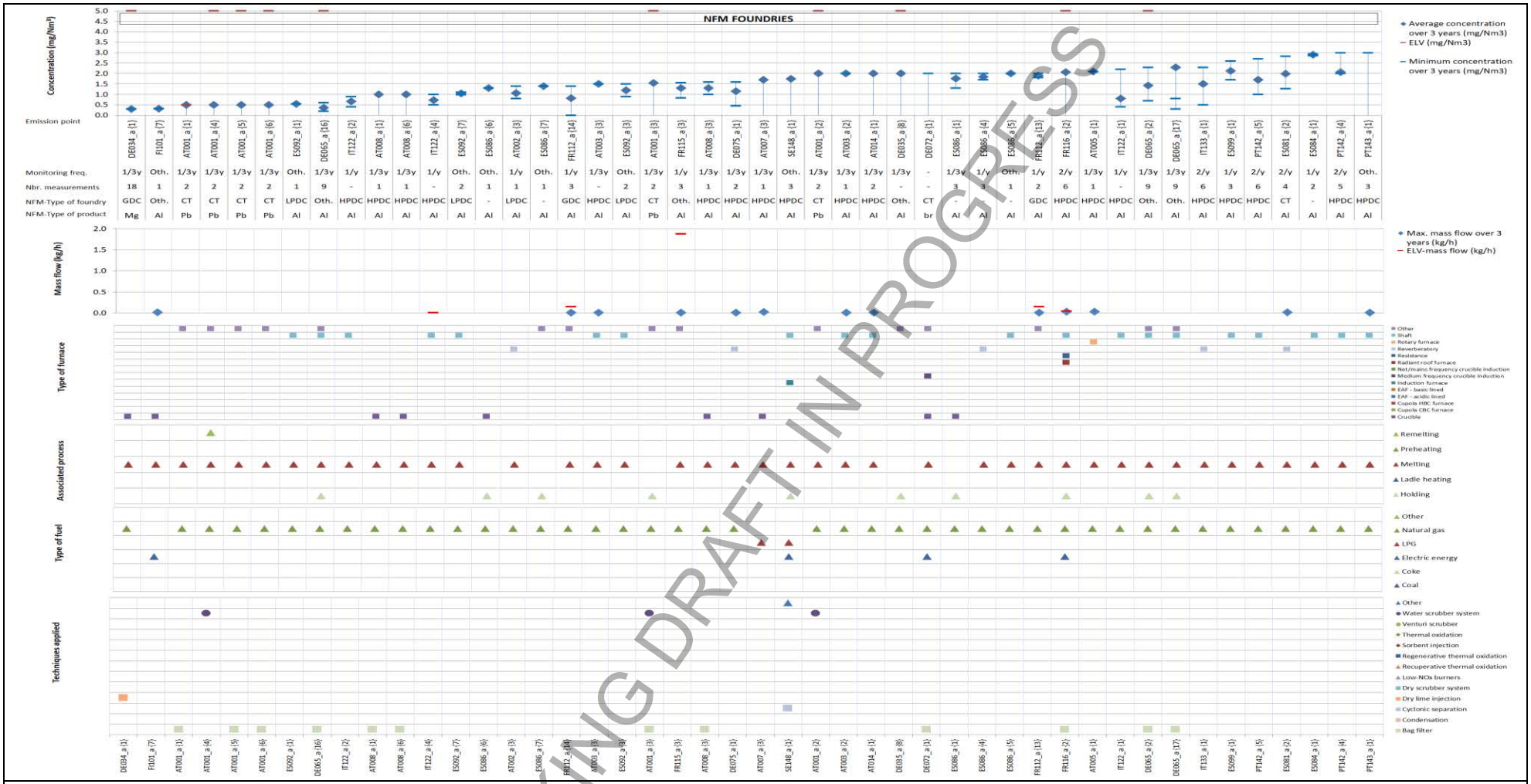
Figure 2.60: Dust emissions from metal melting and ladle preheating (sorted by type of foundry) (1/5)



NB: For better visualisation, the ELV reported by ES100_a {1} and ES090_a {2} of 150 mg/Nm^3 is not shown in the figure. In addition, the values reported by DE051_a{1} (max. = 62.2 mg/Nm^3), PL138_a{2} (avg. = 391 mg/Nm^3, max. = 1 119 mg/Nm^3) and PL138_a{3} (min. = 607 mg/Nm^3, avg. = 2 557 mg/Nm^3, max. = 18 519 mg/Nm^3) are not shown in the figure.

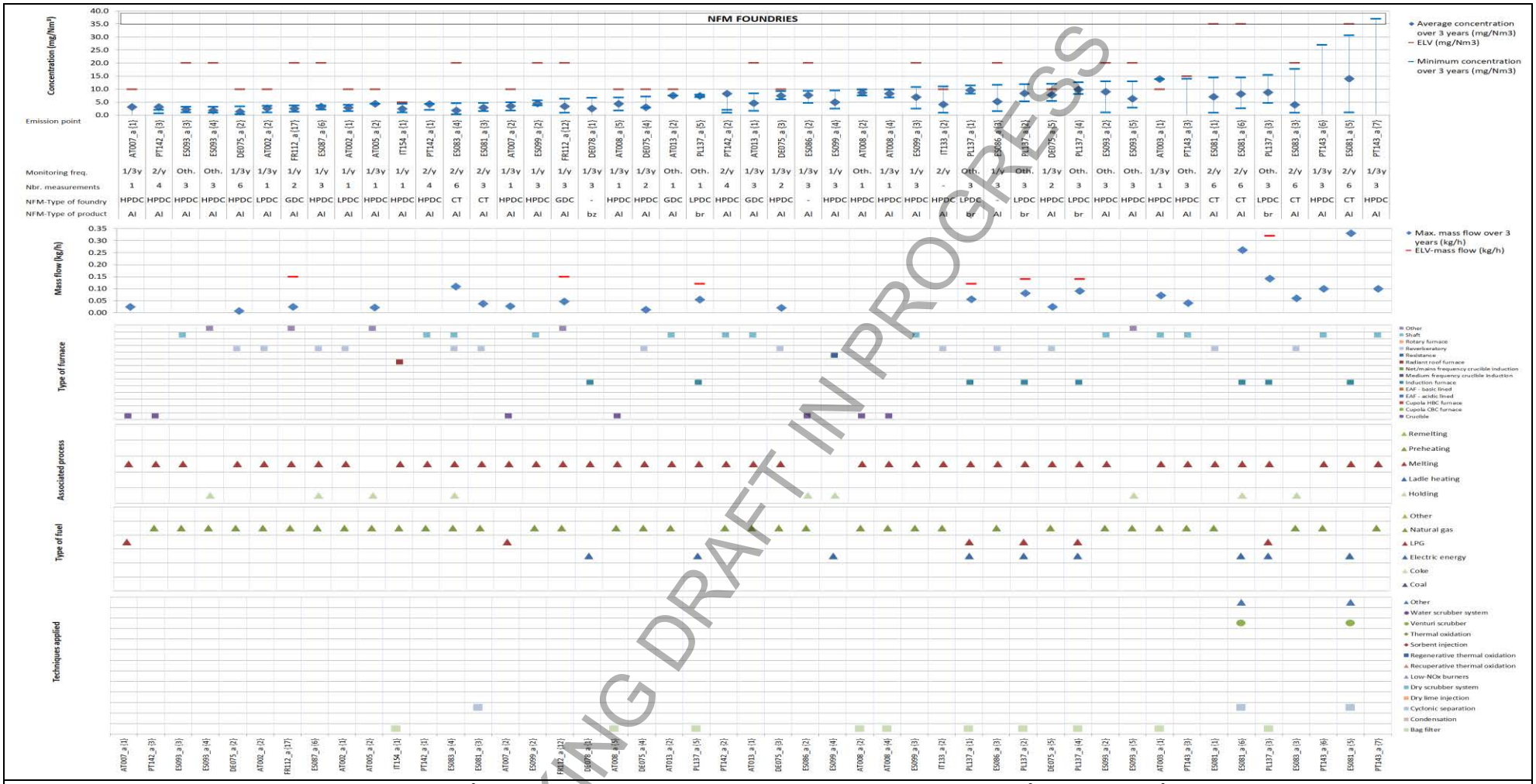
Source: [169, TWG 2021]

Figure 2.61: Dust emissions from metal melting and ladle preheating (sorted by type of foundry) (2/5)



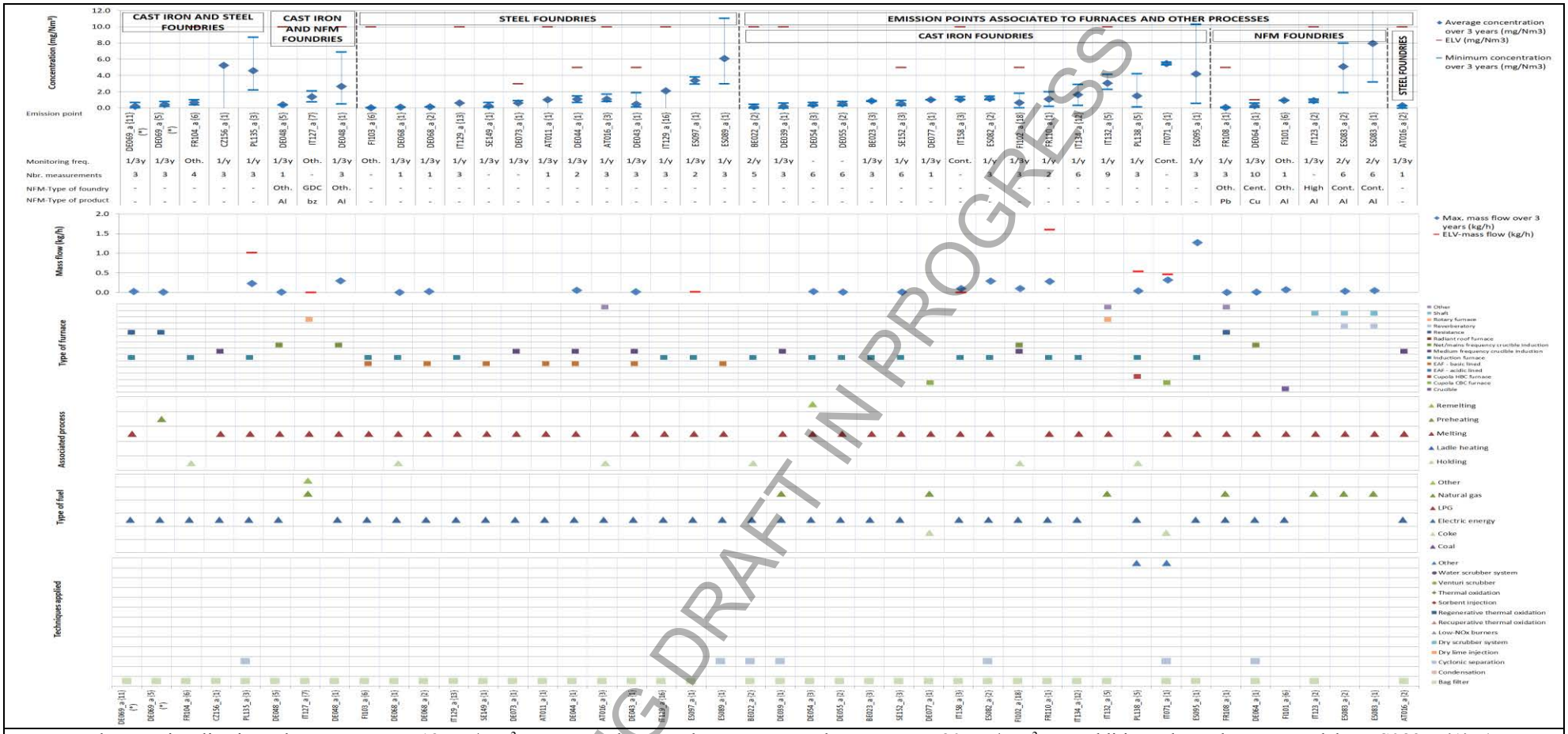
NB: For better visualisation, the ELVs over 3 mg/Nm^3 are not shown. The range of ELVs not shown is from 10 mg/Nm^3 to 150 mg/Nm^3.
Source: [169, TWG 2021]

Figure 2.62: Dust emissions from metal melting and ladle preheating (sorted by type of foundry) (3/5)



NB: For better visualisation, the ELVs over 40 mg/Nm³ are not shown. The range of ELVs not shown is from 100 mg/Nm³ to 150 mg/Nm³.
Source: [169, TWG 2021]

Figure 2.63: Dust emissions from metal melting and ladle preheating (sorted by type of foundry) (4/5)



NB: For better visualisation, the ELVs over 12 mg/Nm³ are not s hown. The ELVs not shown are at 20 mg/Nm³. In addition, the value reported by ES083_a{1} (max. = 13.7 mg/Nm³) is not shown in the figure.
(*) DE069_a {11} and DE069_a {5} also reported heat treatment as an associated process.
Source: [169, TWG 2021]

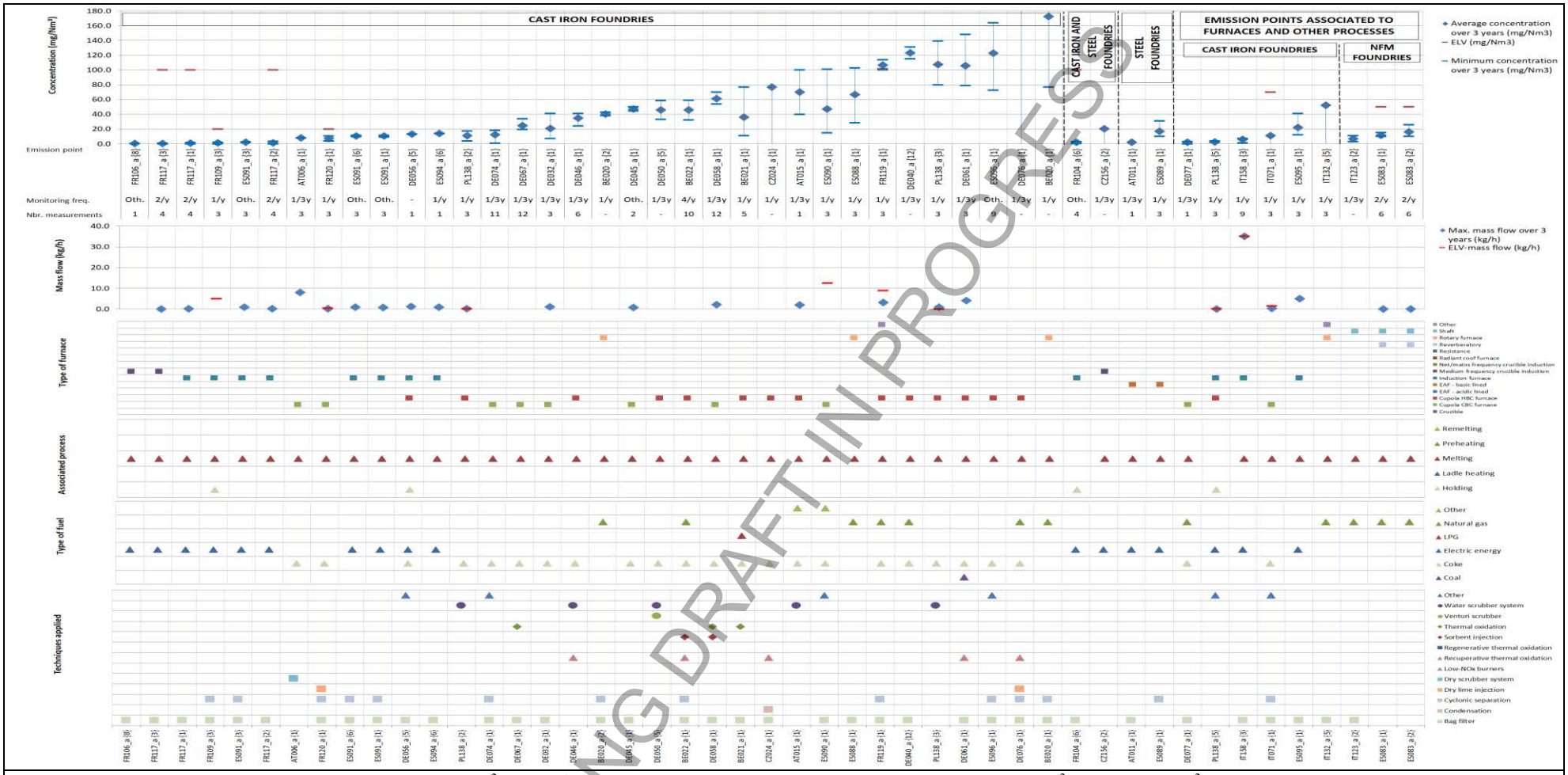
Figure 2.64: Dust emissions from metal melting and ladle preheating (sorted by type of foundry) (5/5)

NB: For better visualisation, the ELVs over 0.007 mg/Nm^3 are not shown. The range of ELVs not shown is from 0.01 mg/Nm^3 to 0.25 mg/Nm^3. In addition, the value reported by BE021_a{1} (max. = 0.01 mg/Nm^3) is not shown in the figure.
Source: [169, TWG 2021]

Figure 2.65: B[a]P emissions from metal melting and ladle preheating (sorted by type of foundry)

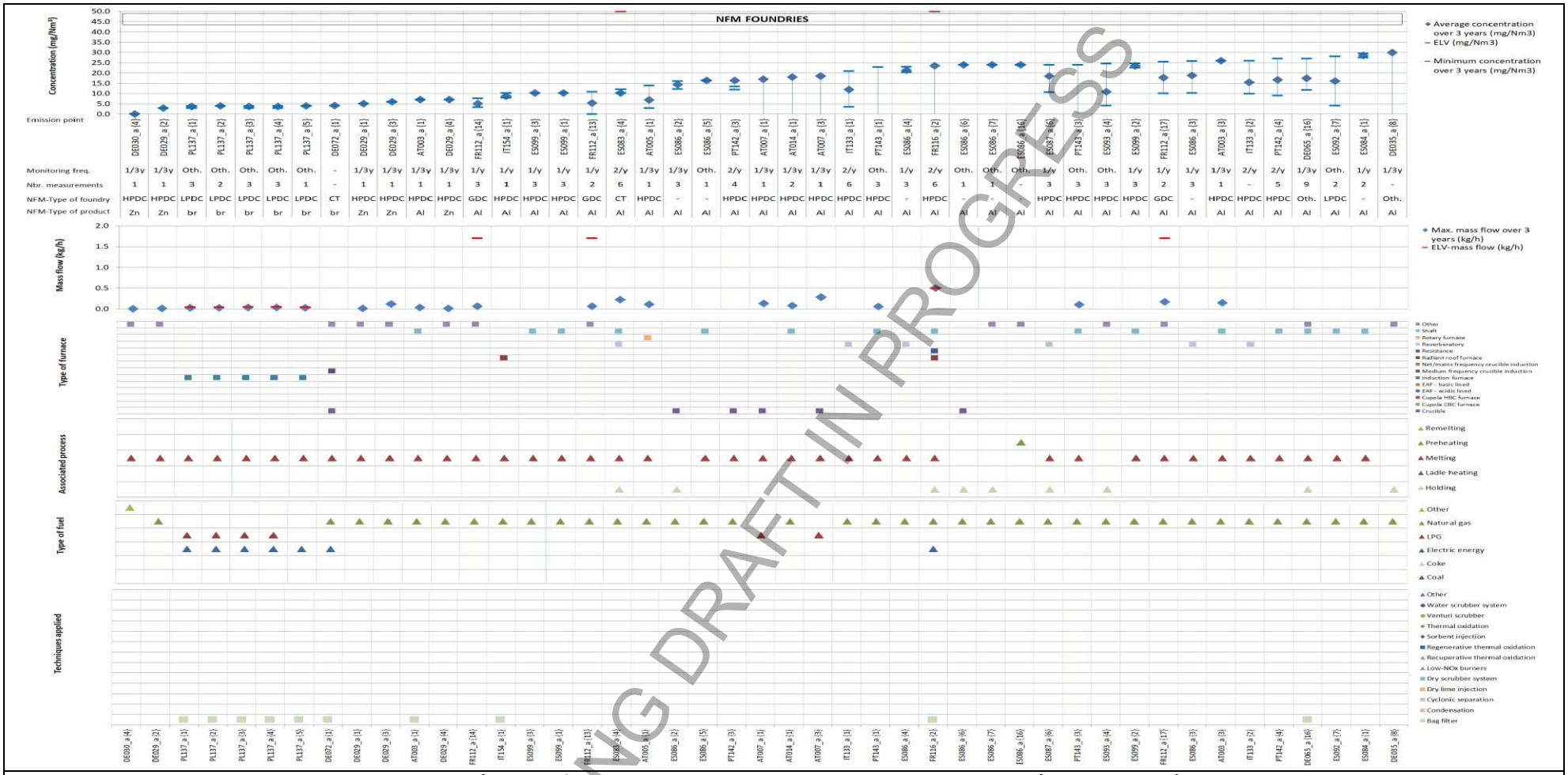
NB: For better visualisation, the ELVs over 0.007 mg/Nm^3 are not shown. The range of ELVs not shown is from 0.01 mg/Nm^3 to 0.25 mg/Nm^3. In addition, the value reported by BE021_a{1} (max. = 0.01 mg/Nm^3) is not shown in the figure.
Source: [169, TWG 2021]

Figure 2.66: B[a]P emissions from metal melting and ladle preheating (sorted by type of foundry)



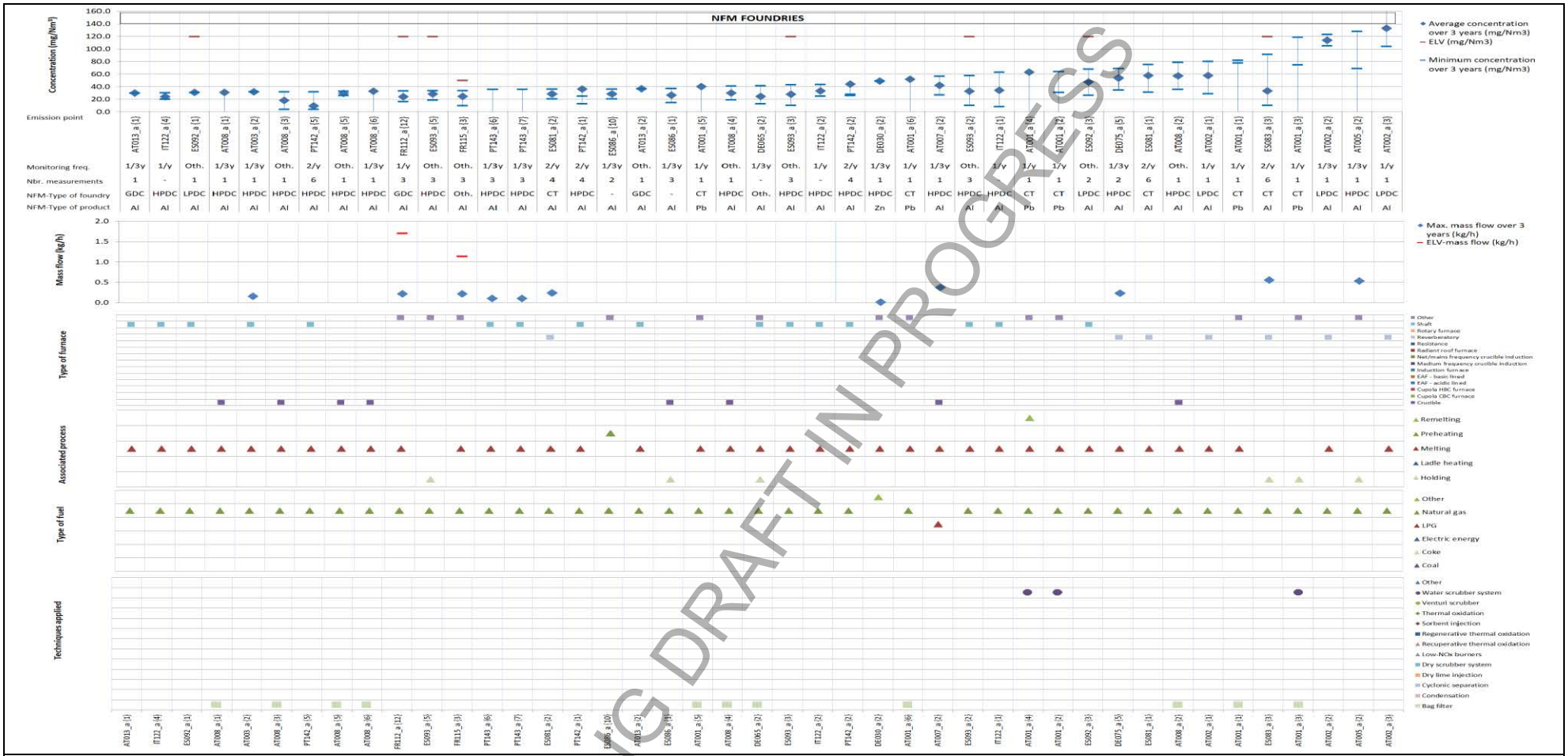
NB: For better visualisation, the ELVs over 180 mg/Nm³ are not shown. The range of ELVs not shown is from 200 mg/Nm³ to 615 mg/Nm³.
For better visualisation, the values reported by DE076_a {1} (avg. = 190.1 mg/Nm³, max. = 200.4 mg/Nm³) and BE020_a {1} (max. = 320 mg/Nm³) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.67: NOX emissions from metal melting and ladle preheating (sorted by type of foundry) (1/3)



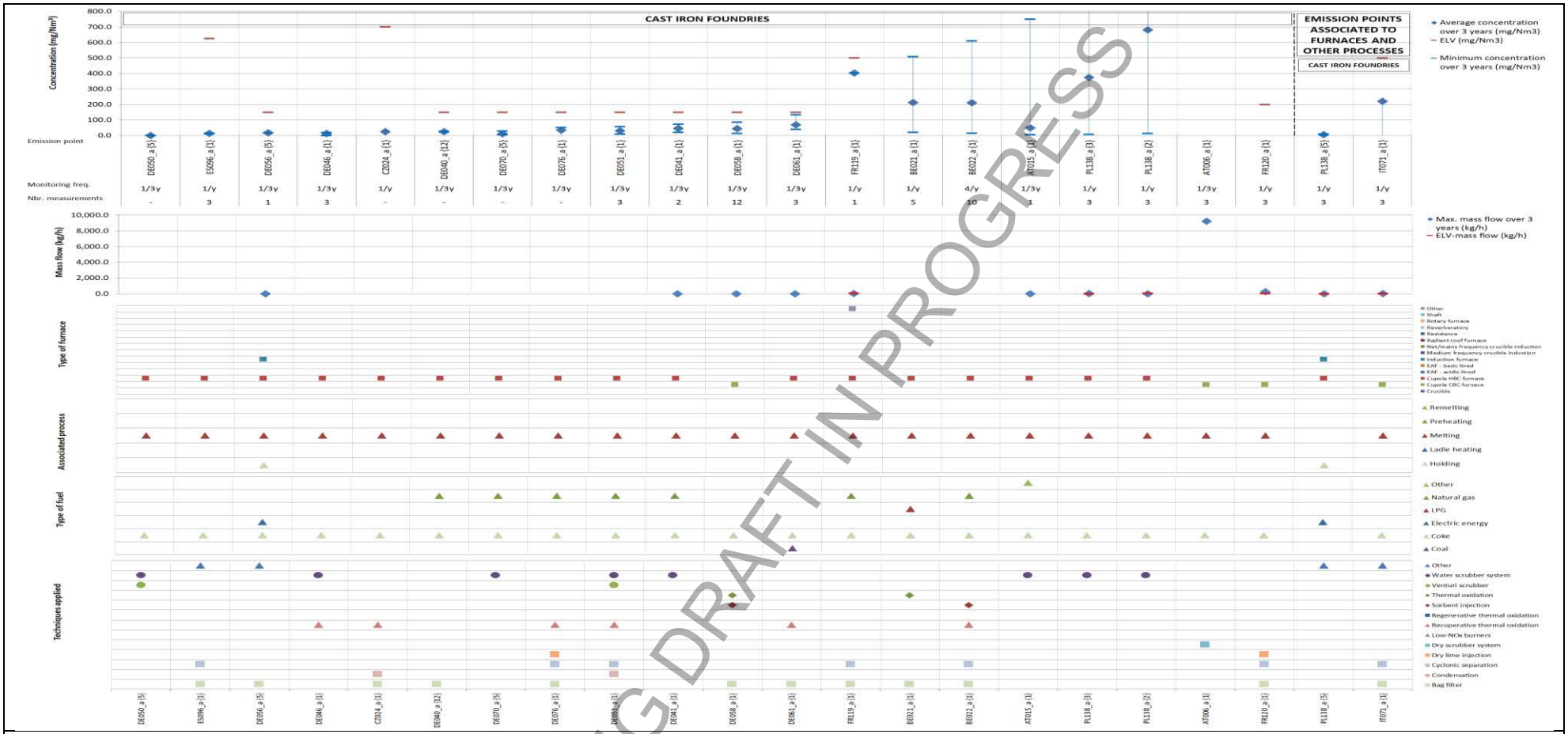
NB: For better visualisation, the ELVs over 35 mg/Nm^3 are not shown. The range of ELVs not shown is from 50 mg/Nm^3 to 615 mg/Nm^3.
Source: [169, TWG 2021]

Figure 2.68: NOX emissions from metal melting and ladle preheating (sorted by type of foundry) (2/3)



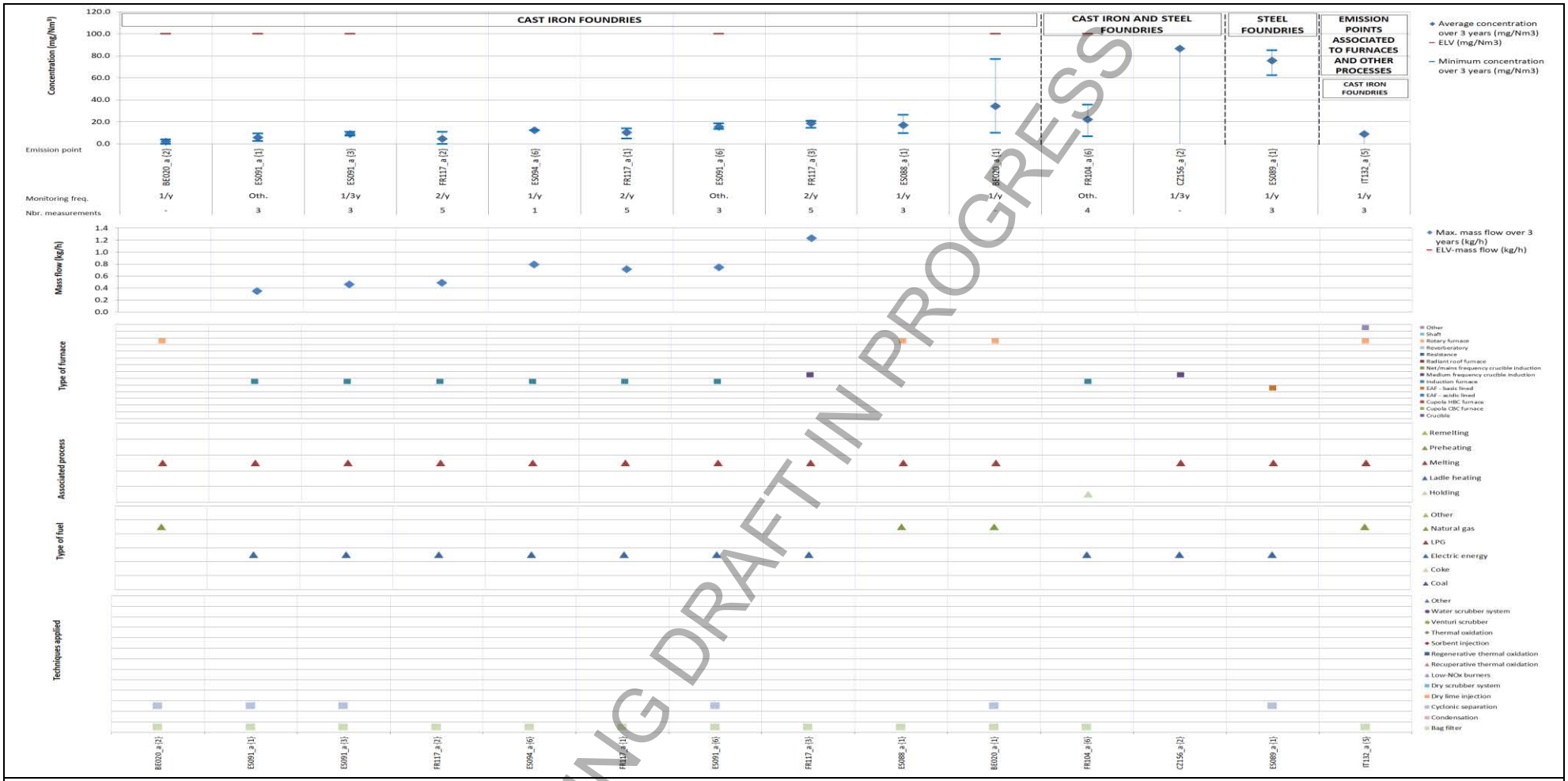
NB: For better visualisation, the ELVs over 160 mg/Nm³ are not shown. The range of ELVs not shown is from 200 mg/Nm³ to 615 mg/Nm³.
For better visualisation, the value reported by AT002_a {3} (max. = 162 mg/Nm³) is not shown in the figure.
Source: [169, TWG 2021]

Figure 2.69: NOX emissions from metal melting and ladle preheating (sorted by type of foundry) (3/3)



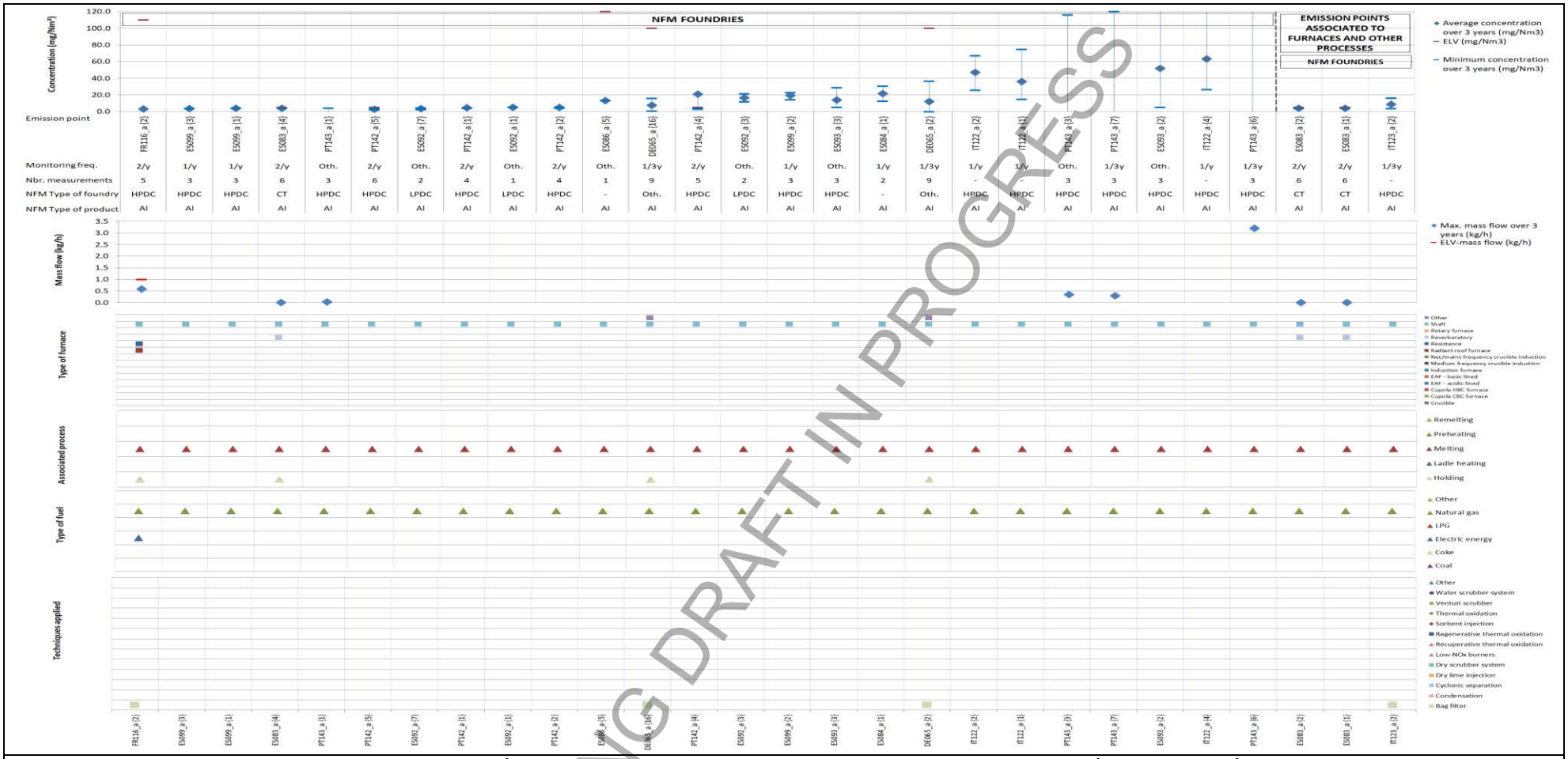
NB: For better visualisation, the ELVs reported by BE021_a {1}, BE022_a {1} and AT015_a {1} of 1 000 mg/Nm³ are not shown.
For better visualisation, the values reported by PL138_a {3} (max. = 1 188 mg/Nm³), PL138_a {2} (max. = 2 444 mg/Nm³), AT006_a {1} (min. = 8 490 mg/Nm³, avg. = 8 549 mg/Nm³, max. = 8 621 mg/Nm³) and FR120_a {1} (min. = 7 023 mg/Nm³, avg. = 11 758 mg/Nm³, max. = 14 923 mg/Nm³) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.70: CO emissions from metal melting and ladle preheating (sorted by EPs associated with cupola furnaces)



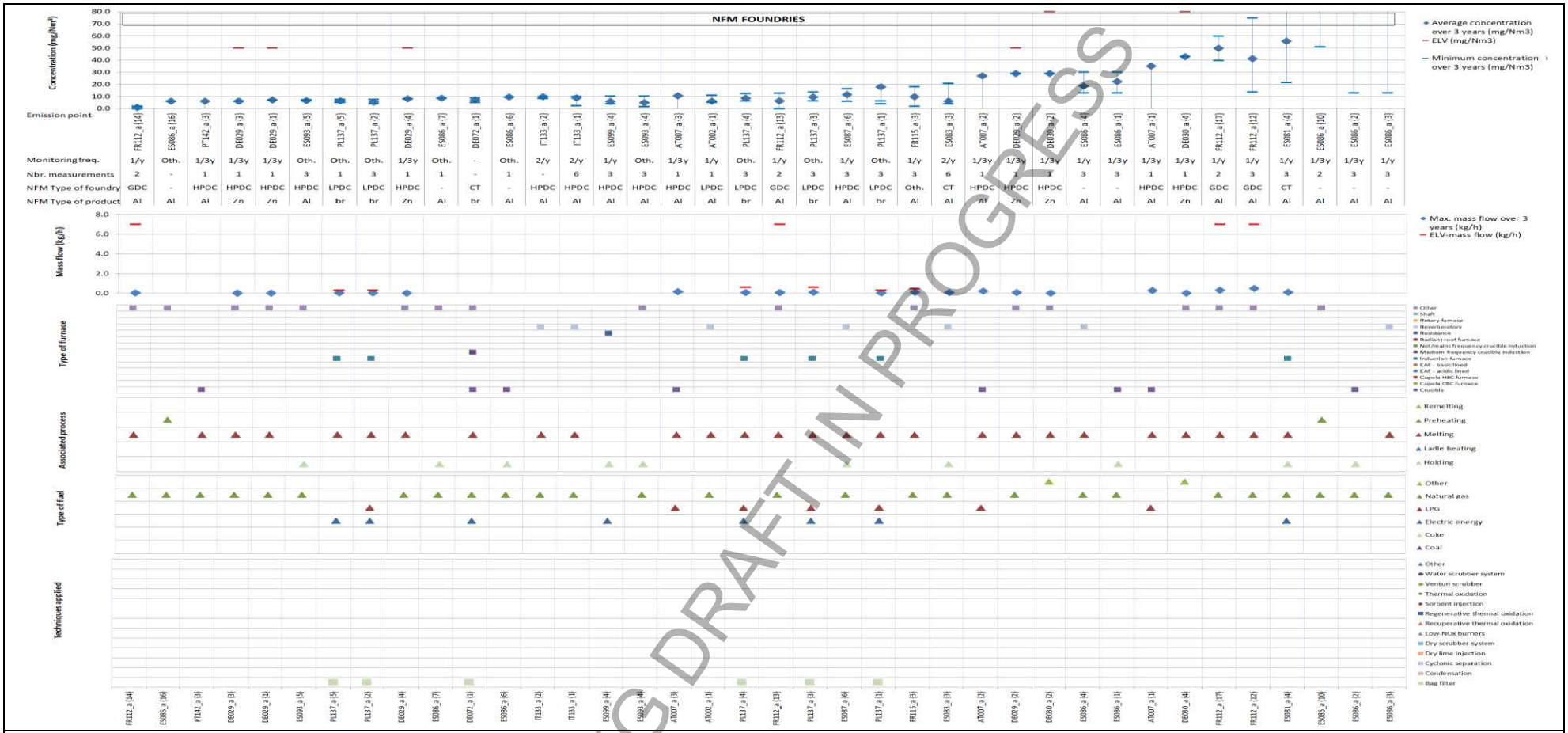
NB: For better visualisation, the ELVs over 100 mg/Nm^3 are not shown. The range of ELVs not shown is from 200 mg/Nm^3 to 800 mg/Nm^3.
Source: [169, TWG 2021]

Figure 2.71: CO emissions from metal melting and ladle preheating (sorted by EPs not associated with cupola furnaces)



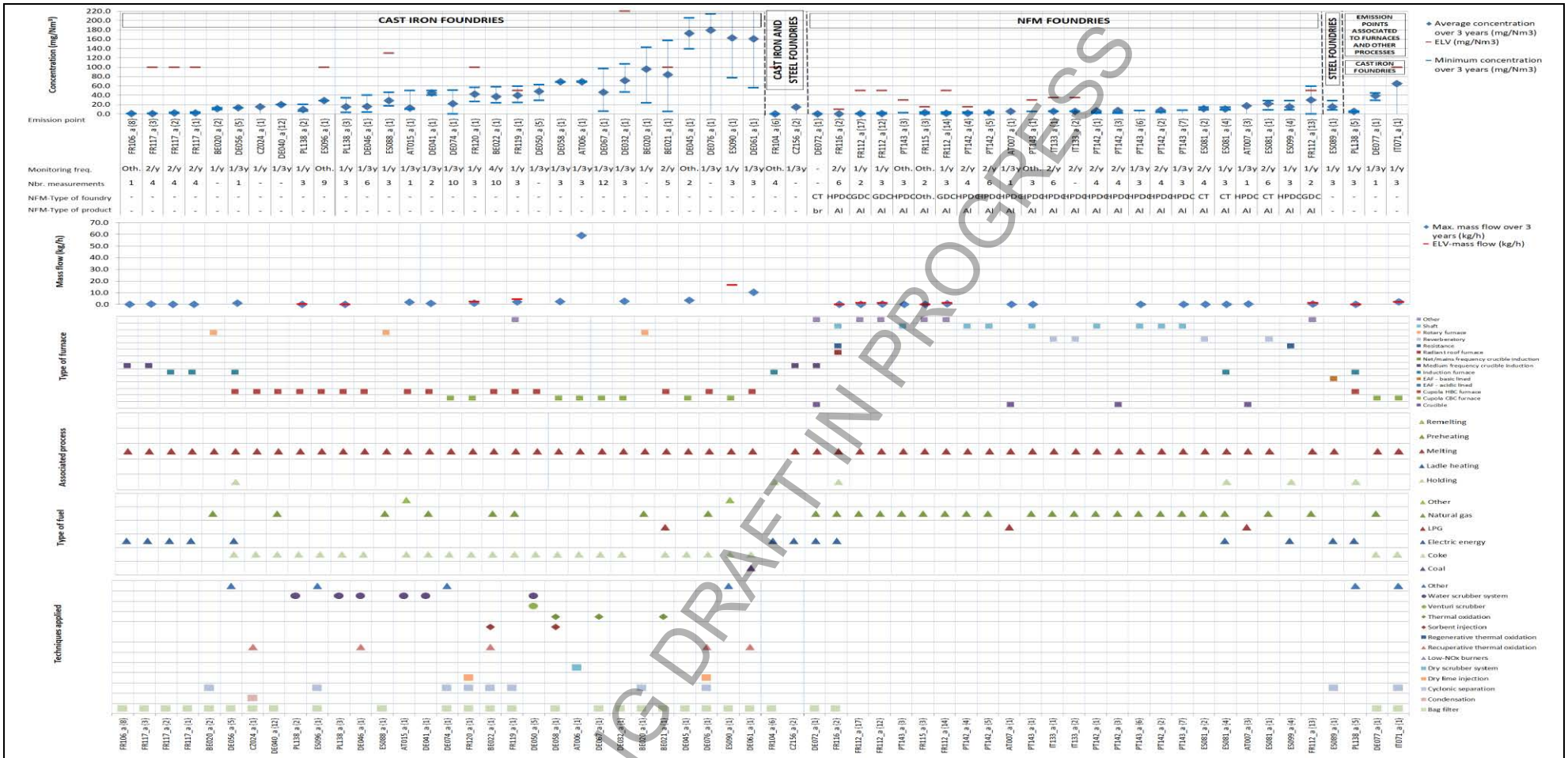
NB: For better visualisation, the ELVs over 120 mg/Nm³ are not shown. The range of ELVs not shown is from 150 mg/Nm³ to 625 mg/Nm³. In addition, the values reported by ES093_a{2} (max. = 136.3 mg/Nm³), IT122_a {4} (max. = 156 mg/Nm³) and PT143_a {6} (max. = 1 020 mg/Nm³) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.72: CO emissions from metal melting and ladle preheating (sorted by EPs associated with shaft furnaces in NFM foundries)



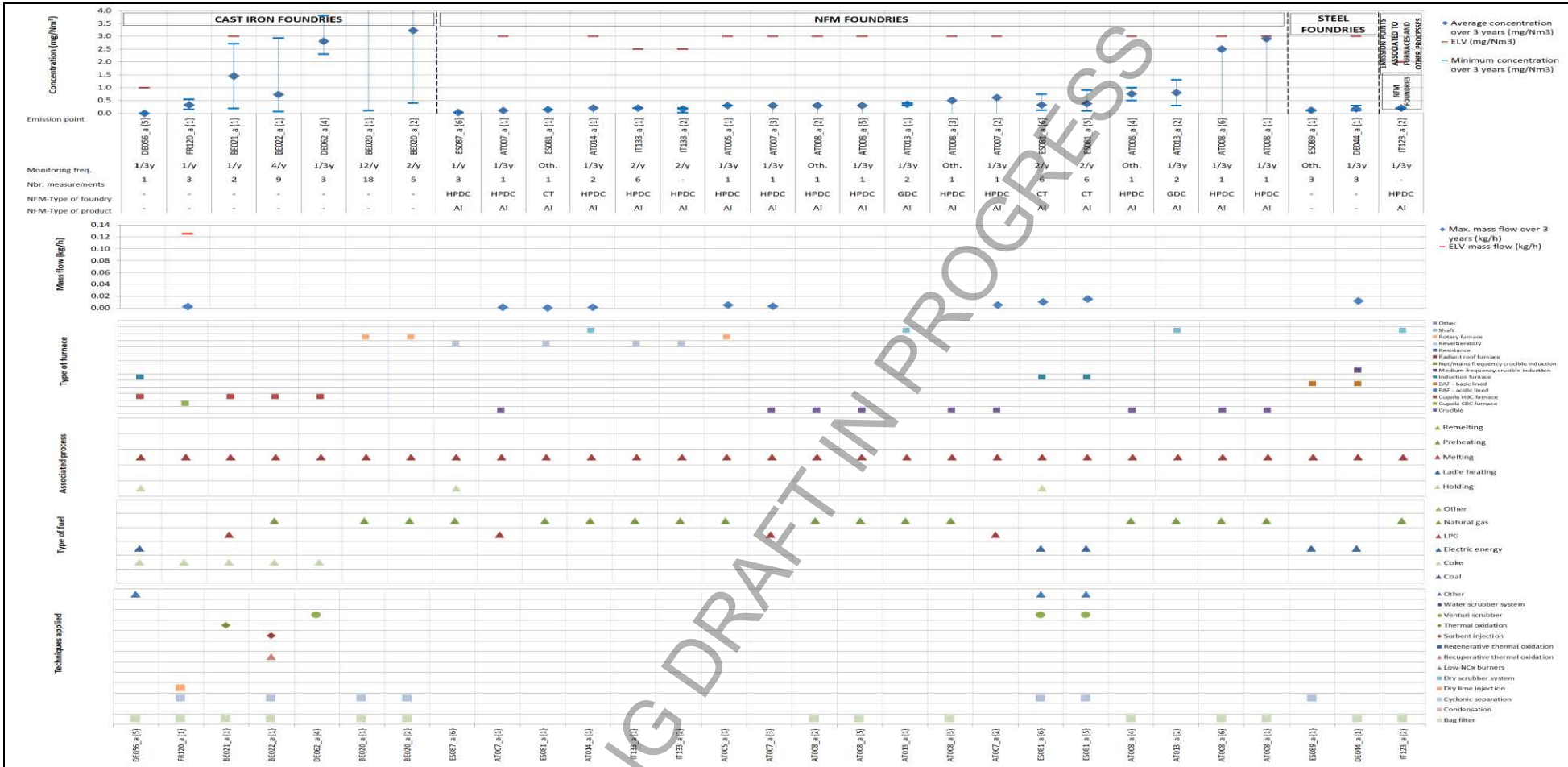
NB: For better visualisation, the ELVs over 80 mg/Nm³ are not shown. The range of ELVs not shown is from 100 mg/Nm³ to 1 806 mg/Nm³.
For better visualisation, the values reported by ES081_a {4} (max. = 116.7 mg/Nm³), ES086_a {10} (avg. = 138.7 mg/Nm³, max. = 226.5 mg/Nm³), ES086_a {2} (avg. = 154.1 mg/Nm³, max. = 300.3 mg/Nm³) and ES086_a {3} (avg. = 152.1 mg/Nm³, max. = 373.3 mg/Nm³) are not shown
Source: [169, TWG 2021]

Figure 2.73: CO emissions from metal melting and ladle preheating (sorted by EPs not associated with shaft furnaces in NFM foundries)



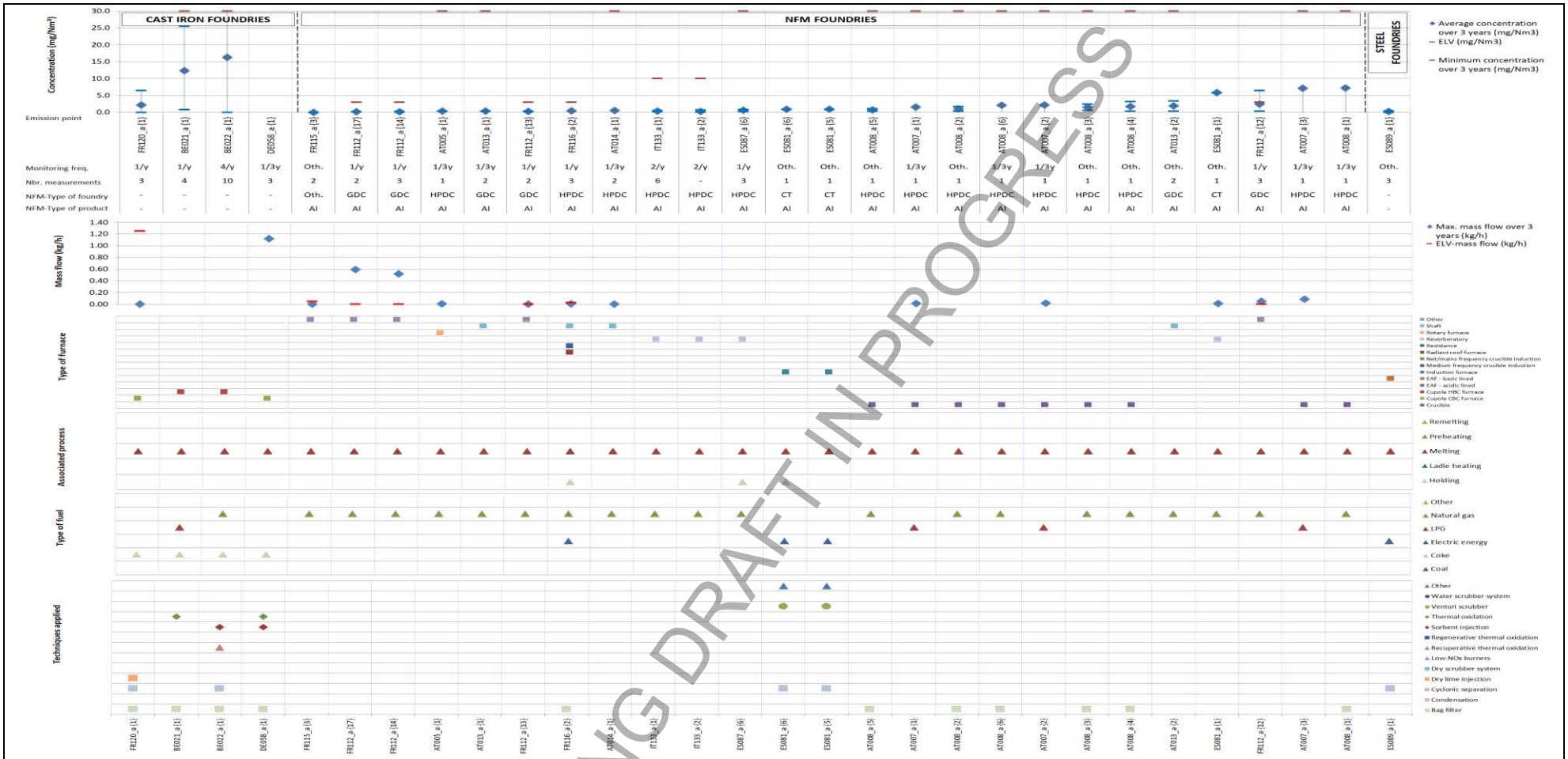
NB: For better visualisation, the ELVs over 200 mg/Nm^3 are not shown. The range of ELVs not shown is from 250 mg/Nm^3 to 1 700 mg/Nm^3.
For better visualisation, the values reported by ES090_a {1} (max. = 248 mg/Nm^3) and DE061_a {1} (max. = 377 mg/Nm^3) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.74: SO2 emissions from metal melting and ladle preheating (sorted by type of foundry)



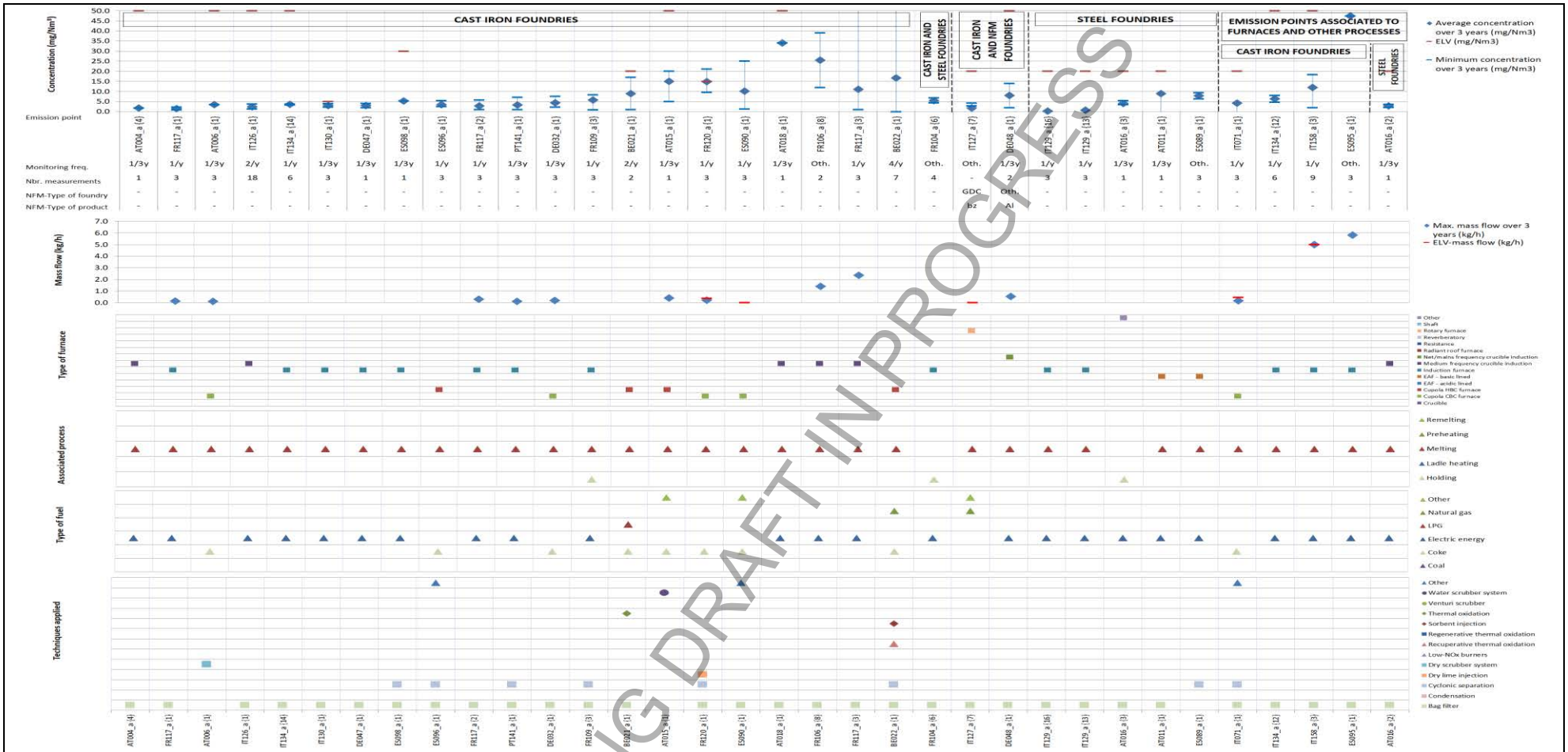
NB: For better visualisation, the ELVs over 4 mg/Nm³ are not shown. The ELVs not shown are at 5 mg/Nm³.
For better visualisation, the values reported by BE020_a {1} (avg. = 5.1 mg/Nm³, max. = 10 mg/Nm³) and BE020_a {2} (max. = 14.2 mg/Nm³) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.75: HF emissions from metal melting and ladle preheating (sorted by type of foundry)



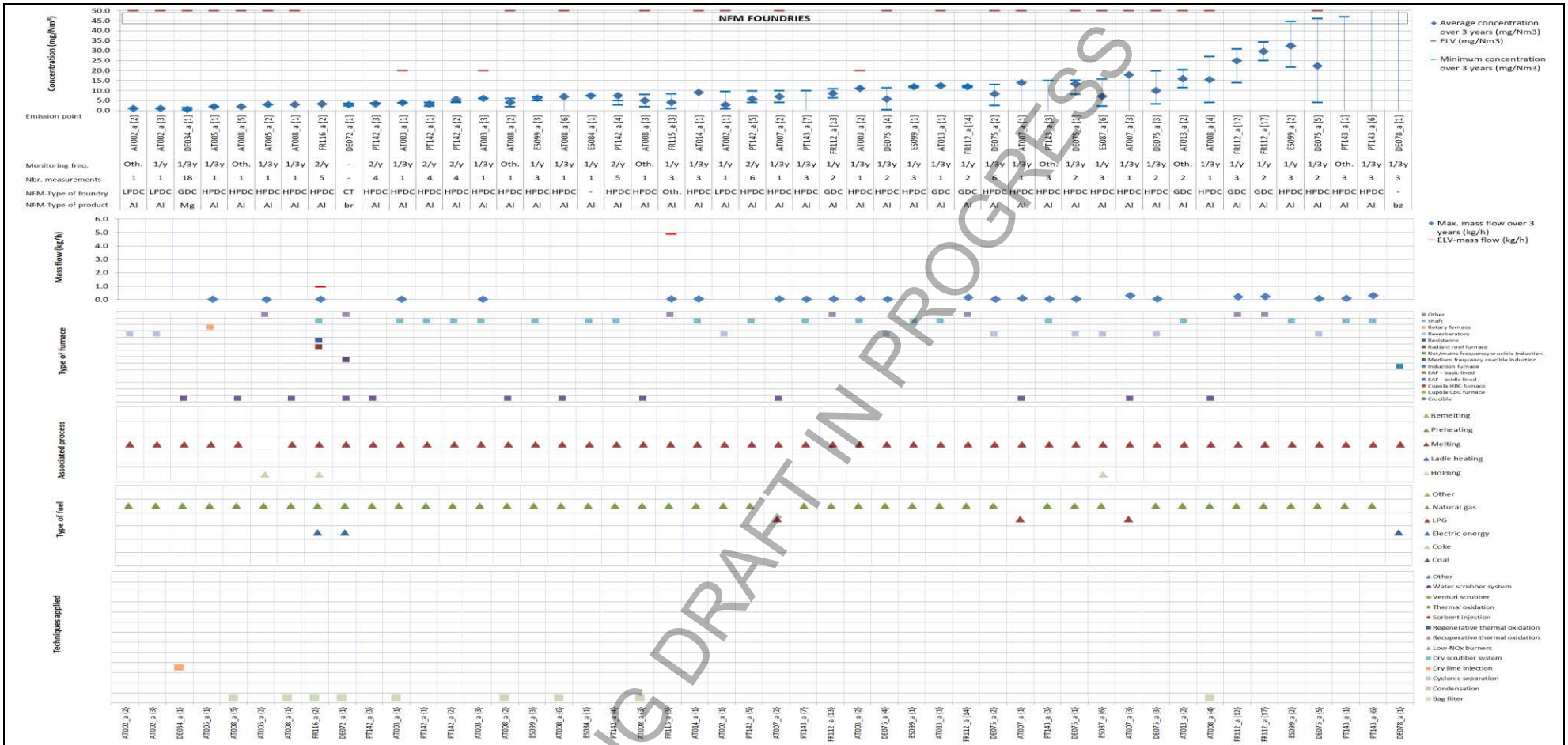
NB: For better visualisation, the ELVs over 30 mg/Nm^3 are not shown. The range of ELVs not shown is from 40 mg/Nm^3 to 50 mg/Nm^3. In addition, the values reported by BE022_a {1} (max. = 33.5 mg/Nm^3) and DE058_a {1} (min. = 34 mg/Nm^3, avg. = 34.6 mg/Nm^3, max. = 35.6 mg/Nm^3) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.76: HCl emissions from metal melting and ladle preheating (sorted by type of foundry)



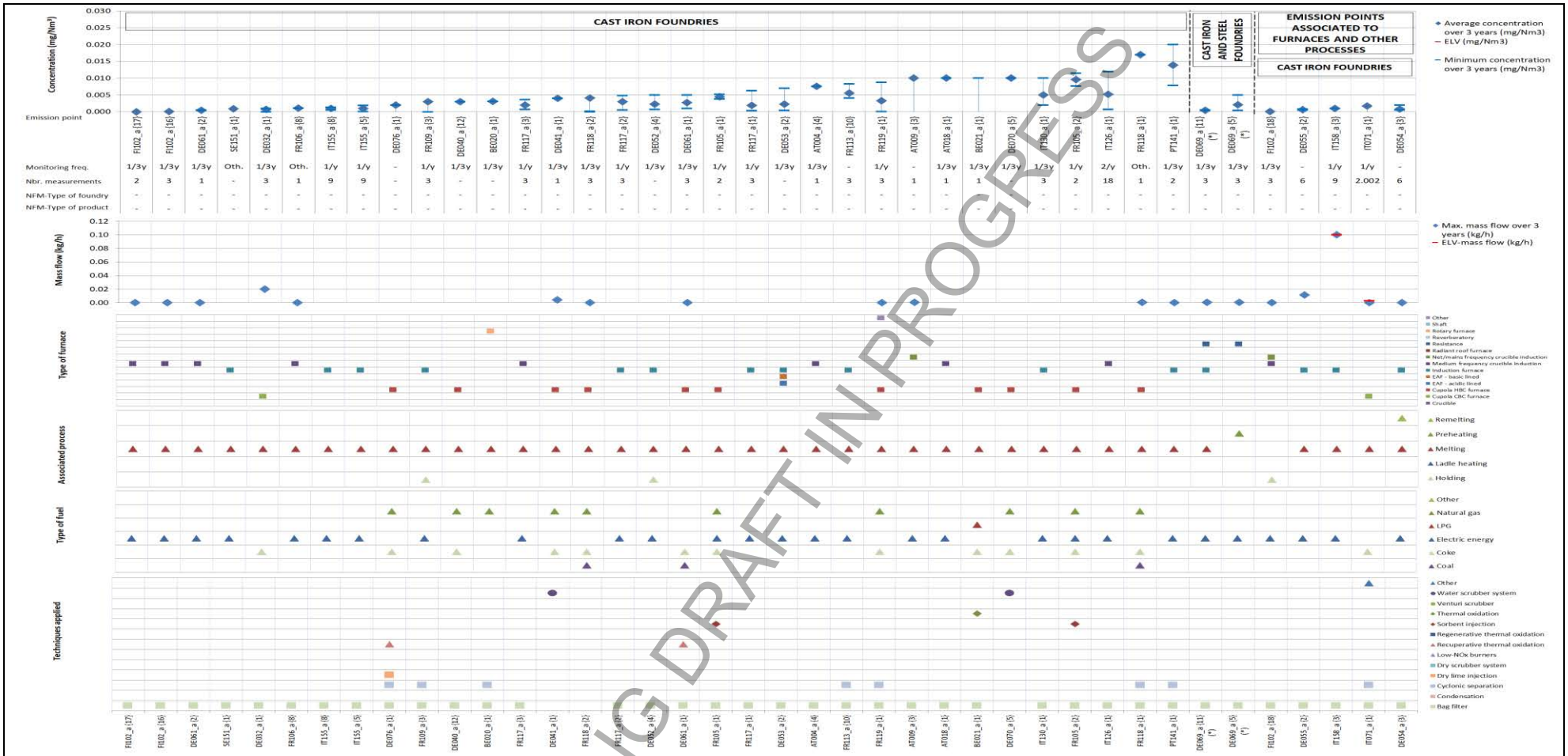
NB: For better visualisation, the ELV (75 mg/Nm^3) reported by ES096_a {1}and the ELV (200 mg/Nm^3) reported by PT141_a {1} are not shown in the figure.
For better visualisation, the values reported by FR117_a {3} (max. = 63.4 mg/Nm^3) and BE022_a {1} (max. = 63.7 mg/Nm^3) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.77: TVOC emissions from metal melting and ladle preheating (sorted by type of foundry) (1/2)



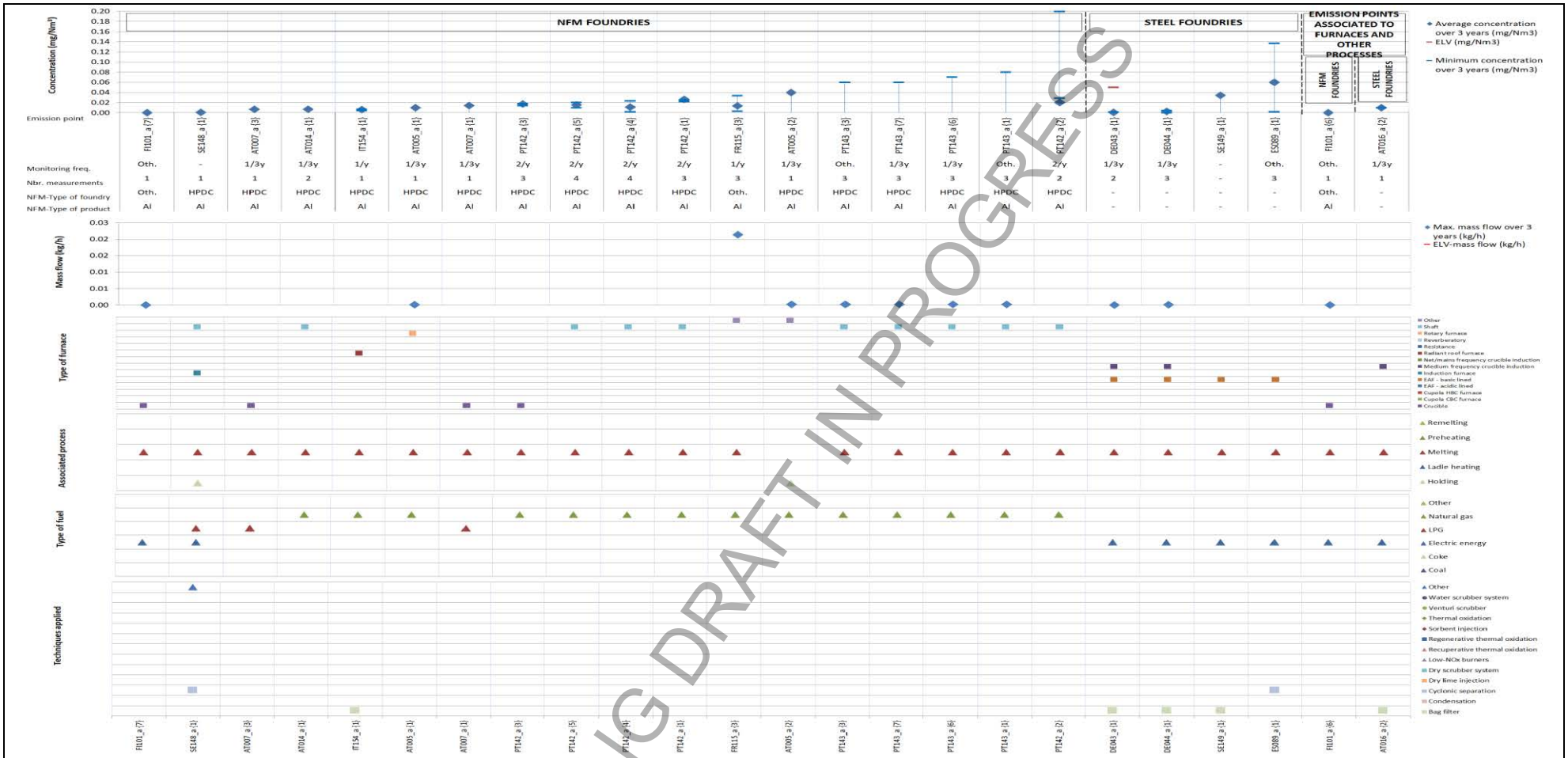
NB: For better visualisation, the ELVs over 50 mg/Nm³ are not shown. The range of ELVs not shown is from 100 mg/Nm³ to 200 mg/Nm³.
For better visualisation, the values reported by PT143_a {6} (max. = 69.0 mg/Nm³) and DE078_a {1} (avg. = 2171.1 mg/Nm³, max. = 1 272 mg/Nm³) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.78: TVOC emissions from metal melting and ladle preheating (sorted by type of foundry) (2/2)



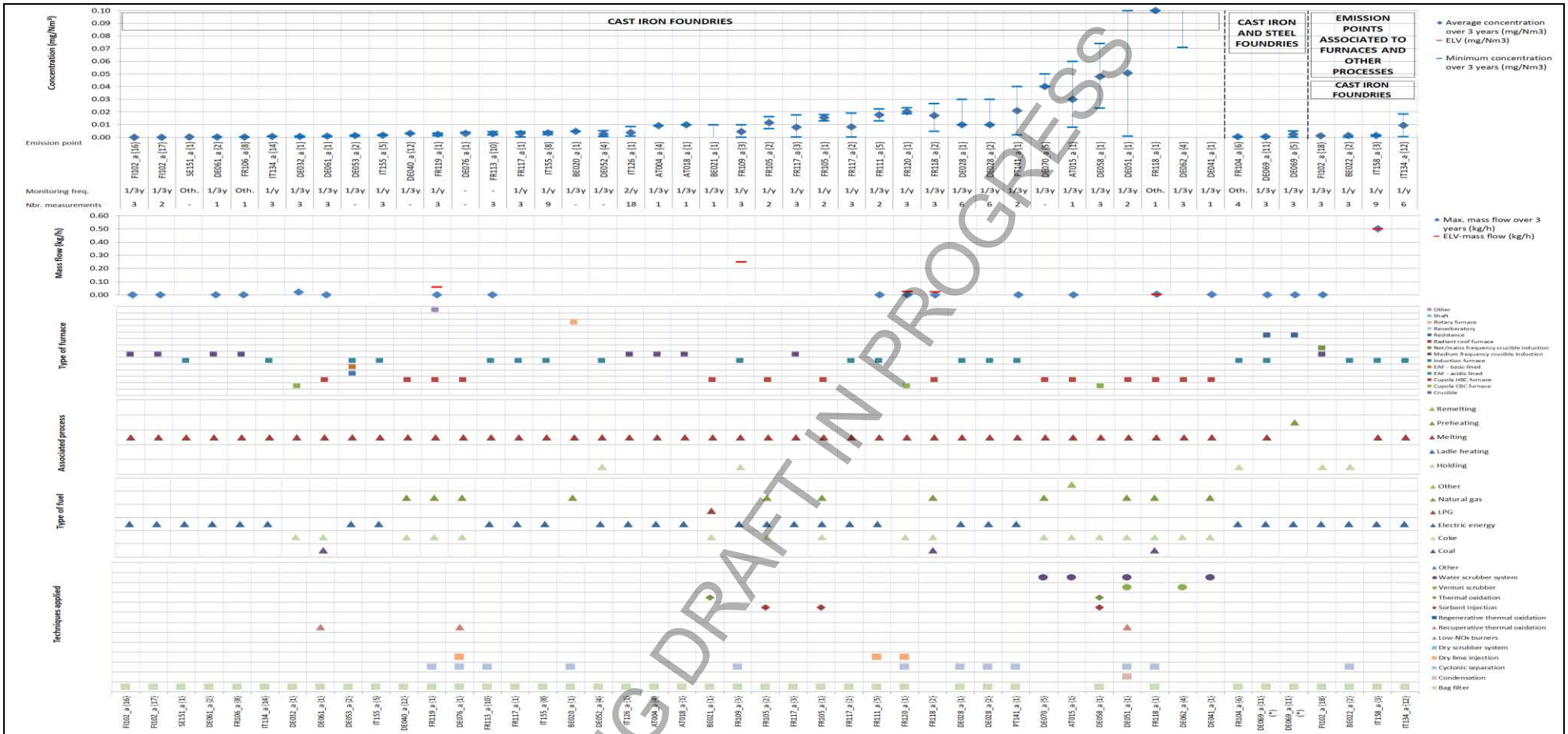
NB: For better visualisation, the ELVs over 0.03 mg/Nm³ are not shown. The range of ELVs not shown is from 0.125 mg/Nm³ to 5 mg/Nm³.
(*) DE069_a {11} and DE069_a {5} also reported heat treatment as an associated process.
Source: [169, TWG 2021]

Figure 2.79: Nickel emissions from metal melting and ladle preheating (sorted by type of foundry) (1/2)



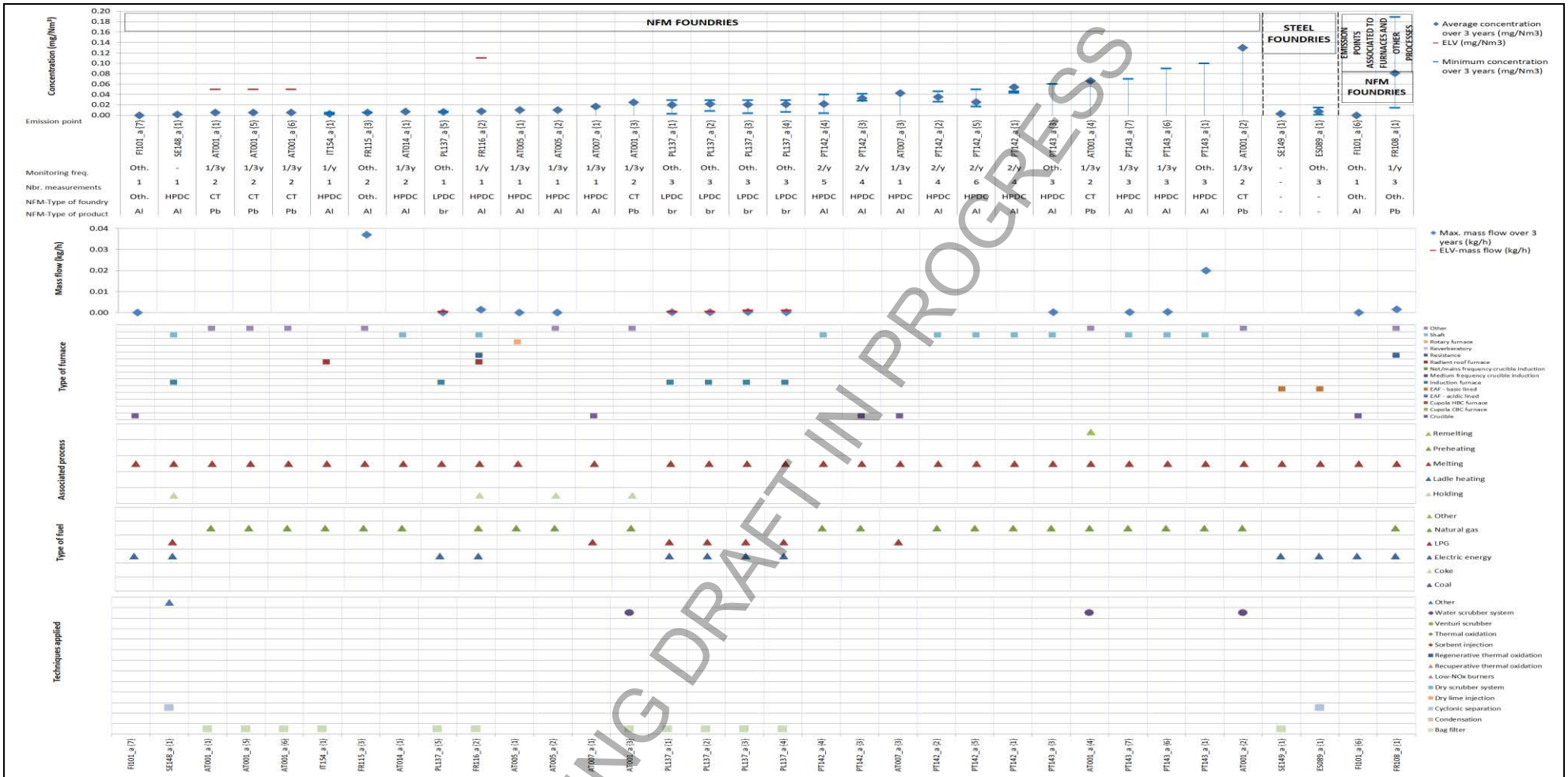
NB: For better visualisation, the ELVs over 0.2 mg/Nm³ are not shown. The range of ELVs not shown is from 0.5 mg/Nm³ to 5 mg/Nm³.
Source: [169, TWG 2021]

Figure 2.80: Nickel emissions from metal melting and ladle preheating (sorted by type of foundry) (2/2)



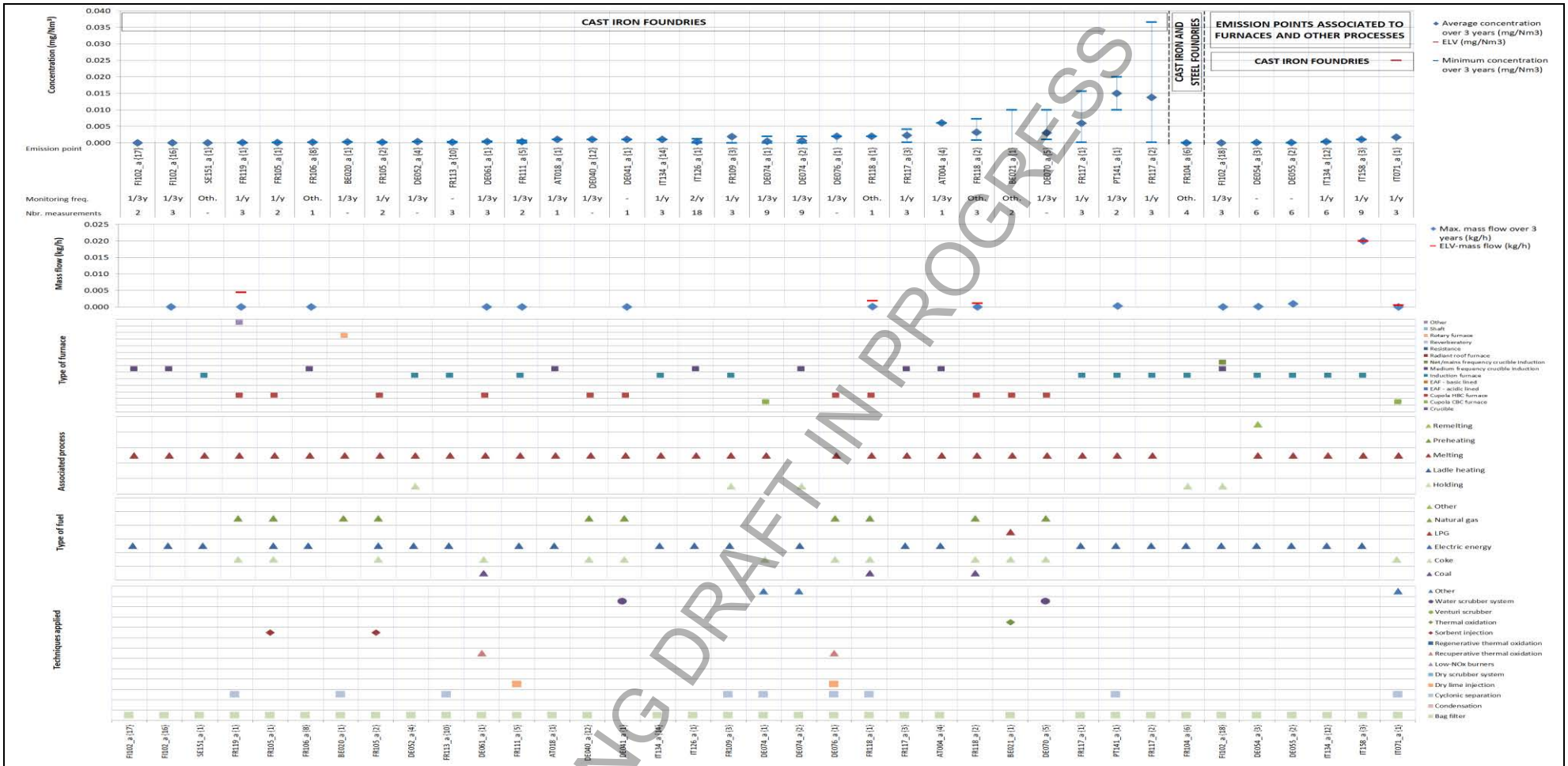
NB: For better visualisation, the ELVs over 0.1 mg/Nm³ are not shown. The range of ELVs not shown is from 0.2 mg/Nm³ to 5 mg/Nm³. In addition, the values reported by DE062_a {4} (avg. = 0.1 mg/Nm³, max. = 0.12 mg/Nm³) and DE041_a {1} (min. = 0.26 mg/Nm³, avg. = 0.26 mg/Nm³, max. = 0.26 mg/Nm³) are not shown in the figure.
(*) DE069_a {11} and DE069_a {5} also reported heat treatment as an associated process.
Source: [169, TWG 2021]

Figure 2.81: Lead emissions from metal melting and ladle preheating (sorted by type of foundry) (1/2)



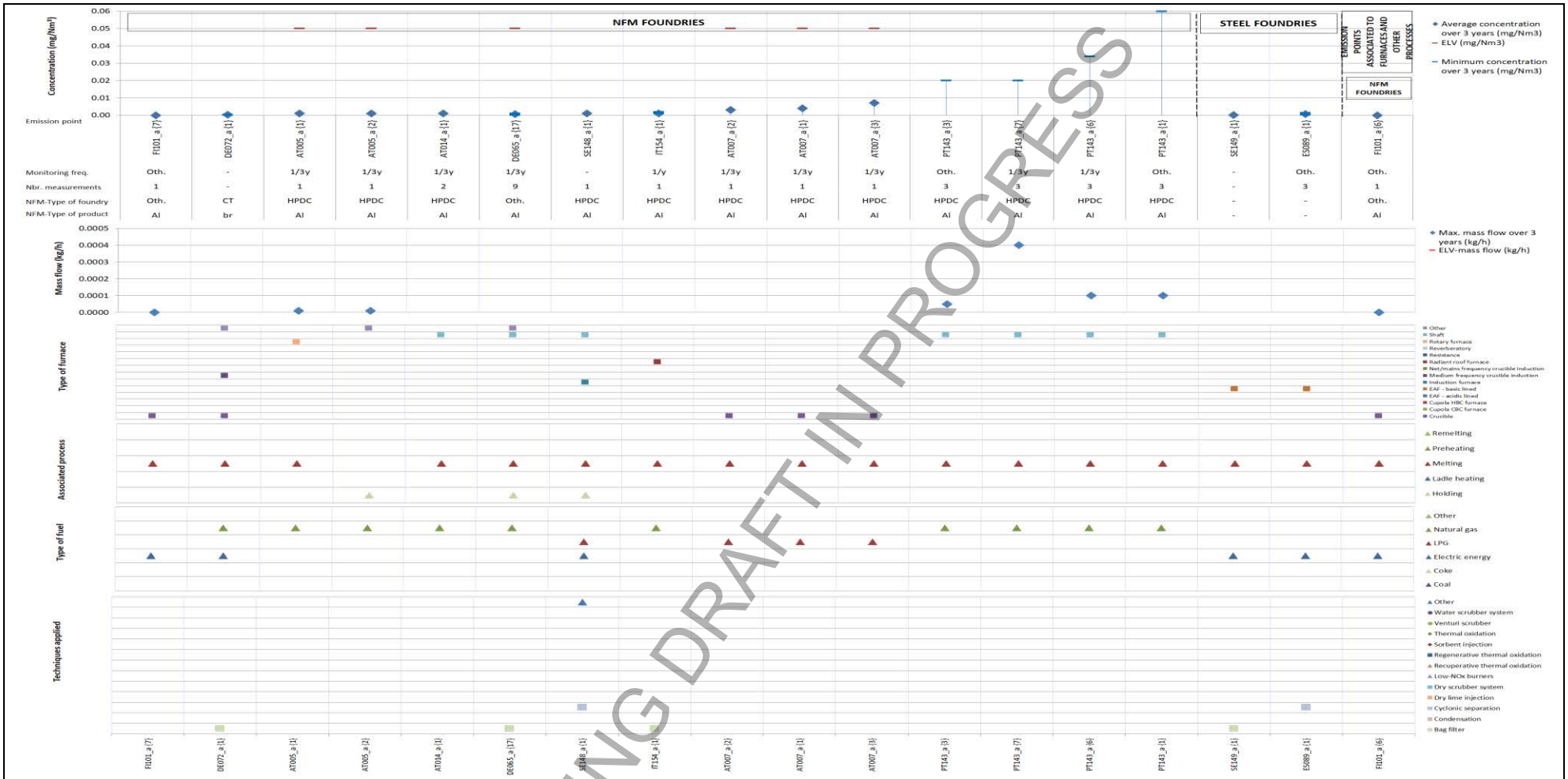
NB: For better visualisation, the ELVs over 0.2 mg/Nm^3 are not shown. The range of ELVs not shown is from 0.3 mg/Nm^3 to 5 mg/Nm^3.
Source: [169, TWG 2021]

Figure 2.82: Lead emissions from metal melting and ladle preheating (sorted by type of foundry) (2/2)



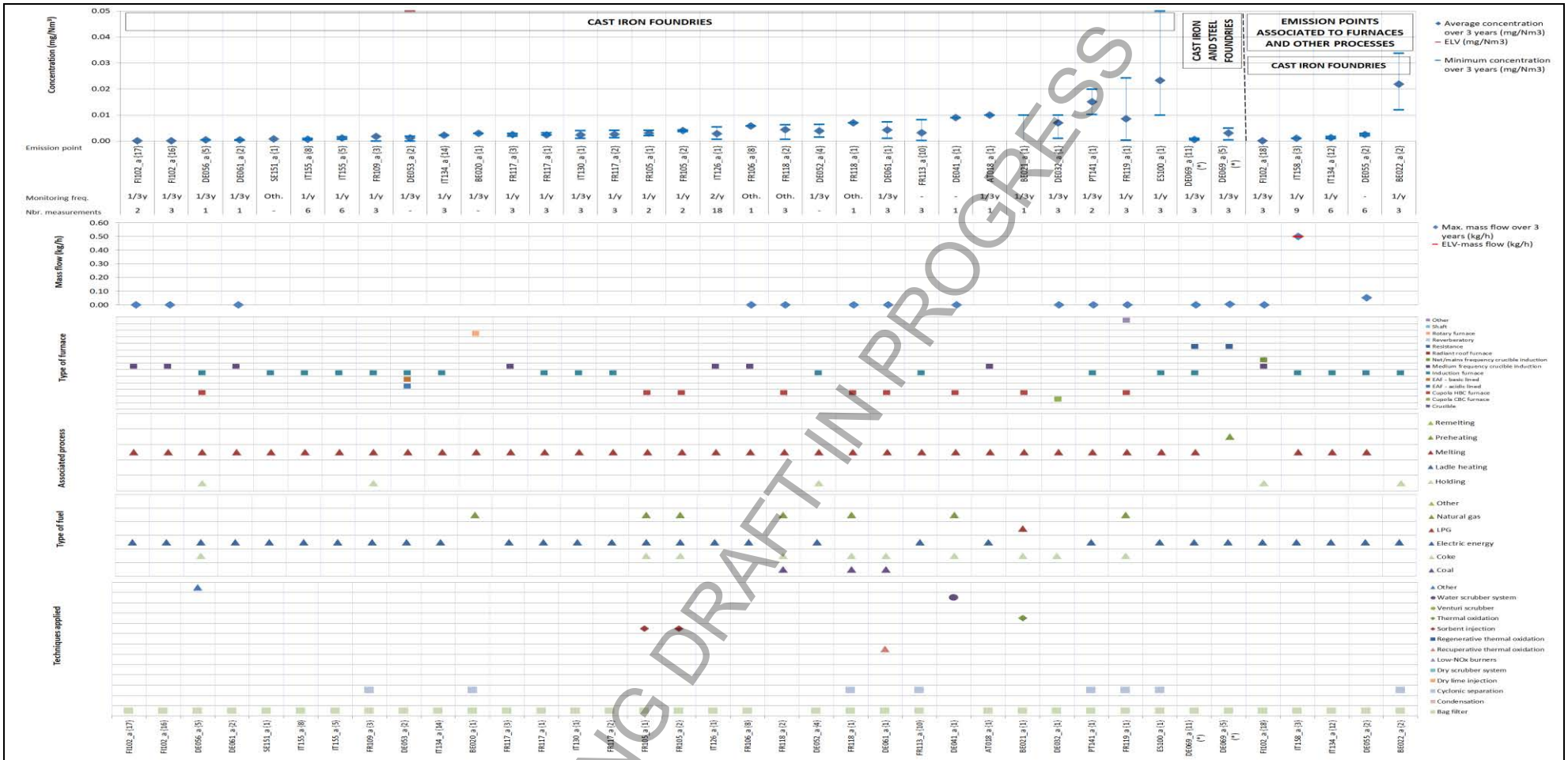
NB: For better visualisation, the ELVs over 0.04 mg/Nm³ are not shown. The range of ELVs not shown is from 0.05 mg/Nm³ to 1 mg/Nm³.
Source: [169, TWG 2021]

Figure 2.83: Cadmium emissions from metal melting and ladle preheating (sorted by type of foundry) (1/2)



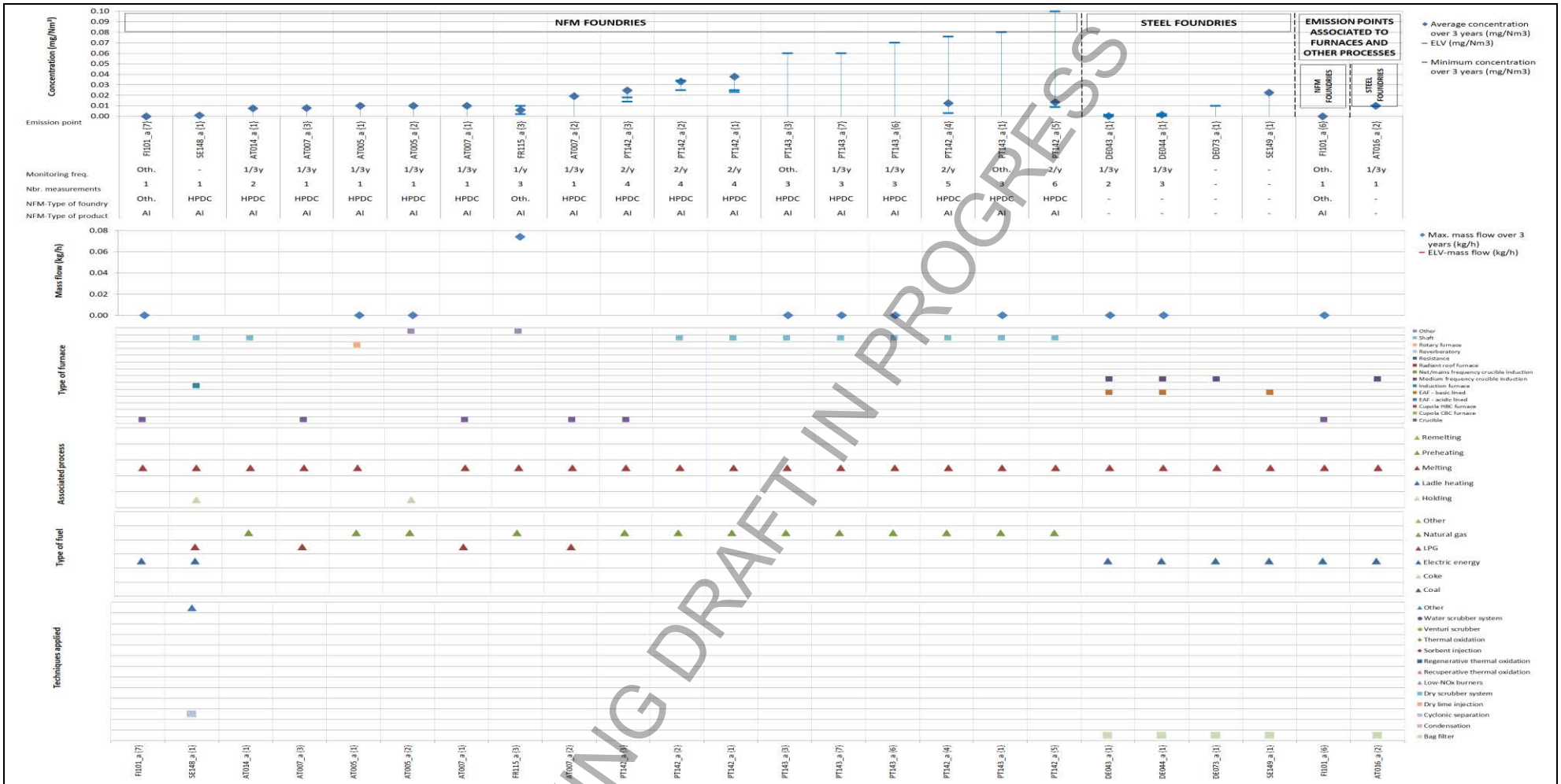
NB: For better visualisation, the ELVs (0.2 mg/Nm^3) reported by PT143_a {3}, PT143_a {7}, PT143_a {6} and PT143_a {1} are not shown.
Source: [169, TWG 2021]

Figure 2.84: Cadmium emissions from metal melting and ladle preheating (sorted by type of foundry) (2/2)



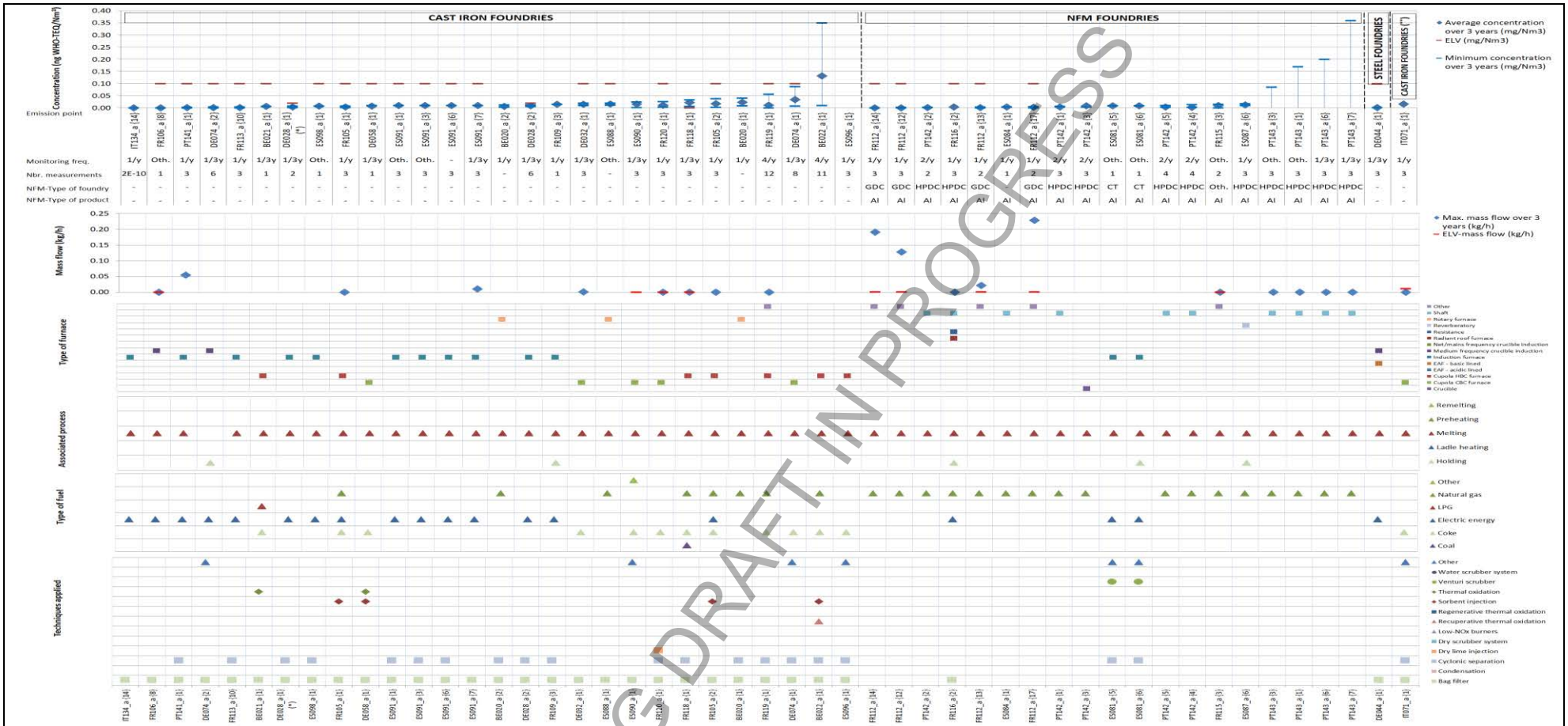
NB: For better visualisation, the ELV (0.5 mg/Nm^3) reported by IT158_a {3}is not shown.
(*) DE069_a {11} and DE069_a {5} also reported heat treatment as an associated process.
Source: [169, TWG 2021]

Figure 2.85: Chromium emissions from metal melting and ladle preheating (sorted by type of foundry) (1/2)



Source: [169, TWG 2021]

Figure 2.86: Chromium emissions from metal melting and ladle preheating (sorted by type of foundry) (2/2)



NB: For better visualisation, the ELVs over 0.4 ng WHO-TEQ/Nm³ are not shown. The range of ELVs not shown is from 0.5 mg/Nm³ to 20 ng WHO-TEQ/Nm³. In addition, the values reported by ES096_a {1} (min. = 1.4 ng WHO-TEQ/Nm³, avg. = 3.2 ng WHO-TEQ/Nm³, max. = 4.3 ng WHO-TEQ/Nm³) are not shown in the figure.
(*) The values reported by DE028_a {1} refers to the parameter: dioxin-like PCBs.
(**) Emission point associated with furnaces and other processes.
Source: [169, TWG 2021]

Figure 2.87: PCDD/F emissions from metal melting and ladle preheating (sorted by type of foundry)

2.3.2.2 Nodularisation of cast iron

In the nodularisation of cast iron, significant amounts of magnesium oxide may be generated depending on the nodularisation method employed. The efficiency, the qualitative assessment of flue-gas production and the complexity of the various nodularisation methods are compared in Table 2.45.

Table 2.45: Comparison of various nodularisation procedures

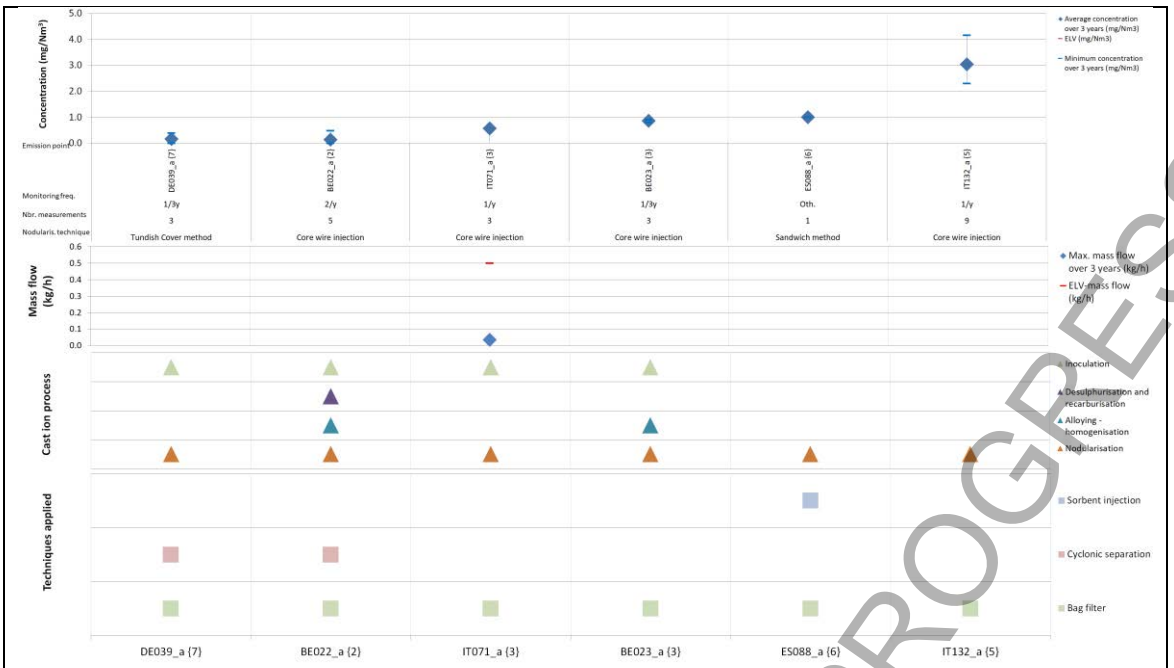
	Sandwich	Tundish cover	Plunging	Flow through	Wire injection	Inmold	Ductilator
Mg- take-up efficiency (%)	35 – 50	45 – 60	40 – 60	40 – 50	20 – 50	70 – 90	60 – 75
Flue-gas production	High	Low	Low	Low	Low	No	High
Comment	Easy operation	Optimised sandwich but more mainte-nance	High mainte-nance	High mainte-nance	Expensive installation	Different design of pouring system	High mainte-nance
Source: [38, VITO 2001], [120, TWG 2003]							

The list of plants which reported applying nodularisation is presented in the following table.

Table 2.46: List of plants reported nodularisation

Applied process for nodularisation	Number of plants	Plant codes
Ductilator method	1	AT004.
Core wire injection	20	AT017, IT132, PL138, AT018, BE022, BE023, CZ156, DE028, DE032, DE042, DE045, DE051, DE056, DE074, ES100, FR106, FR110, IT071, IT124, PL135.
G Fischer converter method	3	DE049, DE050, DE051.
Sandwich method	14	ES088, FI102, DE060, DE069, DK079, ES095, ES098, FR104, FR106, IT130, IT131, PL135, PT140, PT141.
Tundish Cover method	13	AT009, DE028, DE039, ES082, ES094, FR109, IT131, IT134, IT155, IT158, SE144, SE145, SE152.
Pour over technique	9	BE019, CZ026, CZ156, DE041, DE048, DE057, DE067, ES091, IT124.
Inmold process	5	BE021, DE028, DE069, FR106, IT126.
Plunging method	1	ES096.
Flow through treatment method	2	FR109, IT155.
NI	2	IT127, IT125.
Source: 169, TWG 2021		

The reported levels of dust emissions to air from the nodularisation of cast iron are presented in Figure 2.88.



Source: [169, TWG 2021]

Figure 2.88: Dust emissions from nodularisation of cast iron

2.3.2.3 Steel refining

2.3.2.3.1 Argon Oxygen Decarburisation (AOD) converter

Input	Output
- Molten steel	- Decarburised steel
- Alloying metals (ferro-alloys)	- Metal oxide dust and fumes (Fe,Mn,Cr,Ni)
- Al, fesi, lime	- Gases (CO_2, CO, inert gases)
- O_2, N_2, Ar	- Slag (CaO, SiO_2, AlO_3)

2.3.2.3.1.1 Input

The AOD converter is used mainly in the production of low-carbon stainless steels and, in special cases, carbon and low-alloy steels: to remove impurities such as carbon, sulphur and oxides and also to decarburise high-chromium stainless steels. The processed material is liquid steel that has been melted in EAFs or in induction furnaces and afterwards poured off into the vessel through ladles. The technique is most common in the steel industry, but it is also applied in foundries, although to only a limited extent. For decarburisation, oxygen is injected in the converter and oxidises carbon into CO gas, which escapes from the liquid metal. No energy source is used except for the energy from the combustion reaction between oxygen and carbon during oxidation and, afterwards, between oxygen and aluminium (and/or silicon) during reduction.

The consumption of carbon ranges from 0.4 % to 1 %, being about 50-120 m^3 of CO per tonne of steel and 25-60 m^3 oxygen. To eliminate sulphur it is necessary to use a high-basicity slag in a completely reduced liquid steel. Reduction materials, such as aluminium or silicon, and lime are charged in the AOD converter. The consumption levels depend on the quality of the steel grade and are given in Table 2.47.

Table 2.47: Consumption levels for the AOD treatment of steel

Compound	Consumption (per tonne of steel)
CO	50 – 120 m³
O_2	25 – 60 m³
Al	1 – 2.5 kg
Lime	10 – 20 kg
Si	1 – 2 kg
Ar	1 – 5 m³
Source: [100, TWG 2002]	

2.3.2.3.1.2 Emissions

Dust emissions are comparable to EAFs' dust emissions, both in quantity and quality. AOD dust emissions have lower levels of residuals (organic) from the scrap charge, but on the other hand have a higher level of metal oxide (Cr, Ni), as it is mainly stainless steel which is processed in AOD vessels.

The ~~effluent from the mouth~~ exhaust gases of an AOD consist of carbon monoxide and inert gas. The rate of carbon monoxide evolution depends on the tuyères' oxygen injection rate and the oxygen efficiency, or per cent of oxygen which reacts with carbon. This oxygen efficiency, or 'carbon removal efficiency', as it is traditionally labelled in AOD operation, varies during the course of an AOD blow, in response to combined variables of the bath carbon level, temperature, bath chemistry, and the mixture of injected gases.

The CO and inert gas mixture leaves the vessel approximately at the bath temperature. The CO mixture exiting the vessel is mixed with excess air in order to fully burn the CO to CO_2 very early in the exhaust duct. This is done to prevent the presence of combustible or explosive mixtures persisting downstream into the duct to the filter equipment.

In addition, the generated slag is particularly 'clean' from metal oxides, since, due to the peculiarity of the process, they are usually consumed. The slag composition is given in **Table 2.48.**

Table 2.48: AOD slag composition

Compound	%
CaO	50 – 70
Al_2O_3	5 – 25
SiO_2	10 – 25
MgO	5 – 15
Source: [100, TWG 2002]	

Two plants (AT017 and FR104) reported the use of AOD for steel refining. The reported dust emissions are presented in the following table.

Table 2.49: Reported dust emissions from the AOD converter

Plant/ Emission point (EP)	Associated process	Applied dust abatement technique	Reported dust emission levels (mg/Nm³)
FR104_a_2	AOD converter	Fabric filter	2.3-2.6
Source: [169, TWG 2021]			

2.3.2.3.2 Vacuum Oxygen Decarburisation Converter (VODC)

The VODC process involves decarburisation under reduced pressure. It is much less used than the AOD process. Vacuum processes (EAF/vacuum) accounted for 5.8 % of the Western world's stainless steel production in 1991. The technique consumes 1 Nm^3 Ar per tonne of steel, shows low chromium oxidation and has a silicon consumption of 3-5 kg/tonne. The VODC allows the production of ultra-low-carbon and nitrogen grades. [100, TWG 2002]

The use of VODC was reported by two plants (DE068 and FR103). The reported dust emissions are presented in the following table.

Table 2.50: Reported dust emissions from the VODC

Plant/ Emission point (EP)	Associated processes	Applied dust abatement technique	Reported dust emission levels (mg/Nm^3)
FR103_a_6	Electric arc furnaces A and D, induction furnace KJ, VODC, ladle heatings	Fabric filter	0.02-0.05
Source: [169, TWG 2021]			

2.3.2.3.3 Steel deoxidation ~~refining and treatment~~

For deoxidation, aluminium is commonly used in the form of a stick. Additions vary from 0.1 % for medium-carbon steel to 0.2 % for low-carbon steel. Recovery is between 35 % and 80 %. Mechanical feeding of aluminium wire is also used. [73, Brown, J. R. 2000].

Six plants in the SF data collection reported the use of deoxidation (not occurred into the furnace): BE019, DE044, PL135, PT140 and SE146. [169, TWG 2021]

2.3.2.4 Aluminium melt treatment

For the combination of degassing and cleaning in an impeller station, a mixture of argon or nitrogen with 3 % Cl_2 is generally used. For degassing alone, the gases Ar or N_2 are generally used without Cl_2. The applied flow and degassing time depend on the type of alloy used and the size of the treatment vessel.

The consumption of modification agents, grain refiners and fluxes depends on the type of alloy, but is generally in the order of 100 g to 1 kg per 50 kg of molten metal.

Three plants reported the use of Cl_2 in aluminium melt degassing. In particular, Plant DE048 reported the use of N_2-Cl_2 as degassing agent while Plants IT154 and SE148 reported the use of Ar-Cl_2. It is noted that eight plants reported the use of pure N_2 (either as tablet or as gas) for aluminium degassing/cleaning. [169, TWG 2021]
[TWG members, please check the reported Cl_2 emission levels for plants DE066, PT142 and PT143 as in the respective questionnaires it is not clearly specified the use of Cl_2.]

2.3.2.5 Core-making and moulding using lost moulds

Mould and core production involves mixing sand with various chemicals, in some cases followed by a heating step. Gaseous or volatile reaction-products and excess reagents are emitted. Table 2.51 presents a survey of the emissions and other environmental impacts during the mixing, setting and storage of the moulds and cores.

Table 2.51: Environmental impact from binder systems

System name and binder constituents	Setting method and relative energy requirement	Emissions to air during mixing and setting	Other environmental impacts
GREEN SAND Clay Coal dust or substitute Water	Pressure – low	Particulate matter – no significant emission to the environment	Sand spillage around conveyors needs to be avoided to reduce the likelihood of fugitive emissions. Abatement from the mixing process is not essential (the process is usually self-contained with displaced air vented to the foundry)
SHELL SAND Phenol - formaldehyde (Novalak) Resin	Heat - high	Formaldehyde* Ammonia* Phenol* Aromatics HCN	Odour can be an issue as the shell machines are normally extracted to air
ALKALINE PHENOLIC Resol - Alkaline phenol-formaldehyde resin 1. Gas hardened (alkaline phenolic cold-box) 2. Self-setting (alkaline phenolic no bake)	 Gas hardened with methyl formate vapour – low Cold-set with esters - low	 Formaldehyde* Phenol* Methyl formate Formaldehyde* Phenol* Esters	
PHENOLIC URETHANE 1. Gas hardened: Cold-box 2. Self-setting (phenolic urethane no bake)	Amine vapour – low Self-set with substituted pyridine – low	Isocyanate (MDI) Amine* Formaldehyde* Phenol Isocyanates (MDI) Formaldehyde* Phenol	Odour is frequently a problem – where DMEA is used odours arise and abatement is essential. This may be incineration or gas scrubbing (using sulphuric or phosphoric acids) – the latter gives rise to liquors, which are a special waste. Where TEA is used scrubbing is only required if odour problems arise
FURAN Combination resins of: Phenol Urea Furfuryl alcohol Formaldehyde	Cold-set with acids – low	Formaldehyde* Phenol* Furfuryl alcohol* Hydrogen sulphide Acid mists	Resins and acids must be kept apart (unless sand is present) as they are vigorously exothermic when in contact
HOT-BOX Combination resins of: Phenol Urea Furfuryl alcohol Formaldehyde	Heat – high	Formaldehyde* Acids Furfuryl alcohol* Phenol* Ammonia Isocyanic acid Methyl isocyanate	Odour can be an issue as the shell machines are normally extracted to air
System name and binder constituents	**Setting method and relative energy requirement**	**Emissions to air during mixing and setting**	**Other environmental impacts**
OIL SAND Linseed oil and starch	Heat – high	Acrolein* Complex organics	Odour can be an issue as the core ovens are often extracted to air
CO_2 PROCESS Sodium silicate	Gas hardened with CO_2 gas – low	None	
SILICATE ESTER Sodium silicate	Cold-set with esters – low	Esters	

Note 1: All the above processes give rise to spent sand (including broken cores, spillage and mixer residues) that may go to landfill. Note 2: Substances marked with * are those most likely to give rise to odour from the process referred to. Note 3: Any resin binder component would be regarded as special waste for disposal purposes and if spilled could give rise to a risk of contamination of water systems. Note 4: Amines and methyl formates used for gas hardening are highly flammable and odorous. The avoidance of leaks in storage is essential. *Source*: [41, Teknologisk 2000], [62, UK Environment Agency 2002], [120, TWG 2003], [124, Lilja et al. 2000]

2.3.2.5.1 Dust emissions

The reported levels of dust emissions to air from core-making and moulding using lost moulds are presented in Figure 2.88, Figure 2.89, Figure 2.90, Figure 2.91 and Figure 2.92.

Some statistical data on the reported dust emission data are presented in the following table.

Table 2.52: Statistical evaluation of the reported dust emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Moulding	137	60	29	8.34	3.37	1.83	0.22
Core-making	128	56	31	6.62	1.96	1.06	0.33
NB: The data above refer to EPs that are associated with only one process, either moulding or core-making. *Source:* [169, TWG 2021]							

2.3.2.5.2 Amines emissions

The reported levels of amines emissions to air from core-making and moulding using lost moulds are presented in Figure 2.93 and Figure 2.94.

Some statistical data on the reported amines emission data are presented in the following table.

Table 2.53: Statistical evaluation of the reported amines emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Moulding	7	3	3	-	0.56	-	-
Core-making	88	45	24	2.06	0.79	0.39	0.04
NB: The data above refer to EPs that are associated with only one process, either moulding or core-making. *Source:* [169, TWG 2021]							

2.3.2.5.3 Formaldehyde emissions

The reported levels of formaldehyde emissions to air from core-making and moulding using lost moulds are presented in Figure 2.95 and Figure 2.96.

Some statistical data on the reported formaldehyde emission data are presented in the following table.

Table 2.54: Statistical evaluation of the reported formaldehyde emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Moulding	28	12	8	2.80	0.83	0.16	0.04
Core-making	53	24	16	4.93	1.29	0.25	0.03
NB: The data above refer to EPs that are associated with only one process, either moulding or core-making. *Source:* [169, TWG 2021]							

2.3.2.5.4 Benzene emissions

The reported levels of benzene emissions to air from core-making and moulding using lost moulds are presented in Figure 2.97.

Some statistical data on the reported benzene emission data are presented in the following table.

Table 2.55: Statistical evaluation of the reported benzene emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Moulding	27	13	9	4.22	1.63	0.95	0.05
Core-making	16	8	6	0.20	0.11	0.11	0.01
NB: The data above refer to EPs that are associated with only one process, either moulding or core-making. *Source:* [169, TWG 2021]							

2.3.2.5.5 Phenol emissions

The reported levels of phenol emissions to air from core-making and moulding using lost moulds are presented in Figure 2.98.

Some statistical data on the reported phenol emission data are presented in the following table.

Table 2.56: Statistical evaluation of the reported phenol emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Moulding	32	12	8	5.17	1.80	0.86	0.05
Core-making	23	11	9	1.06	0.35	0.15	0.01
NB: The data above refer to EPs that are associated with only one process, either moulding or core-making. *Source:* [169, TWG 2021]							

2.3.2.5.6 TVOC emissions

The reported levels of TVOC emissions to air from core-making and moulding using lost moulds are presented in Figure 2.99 and Figure 2.100.

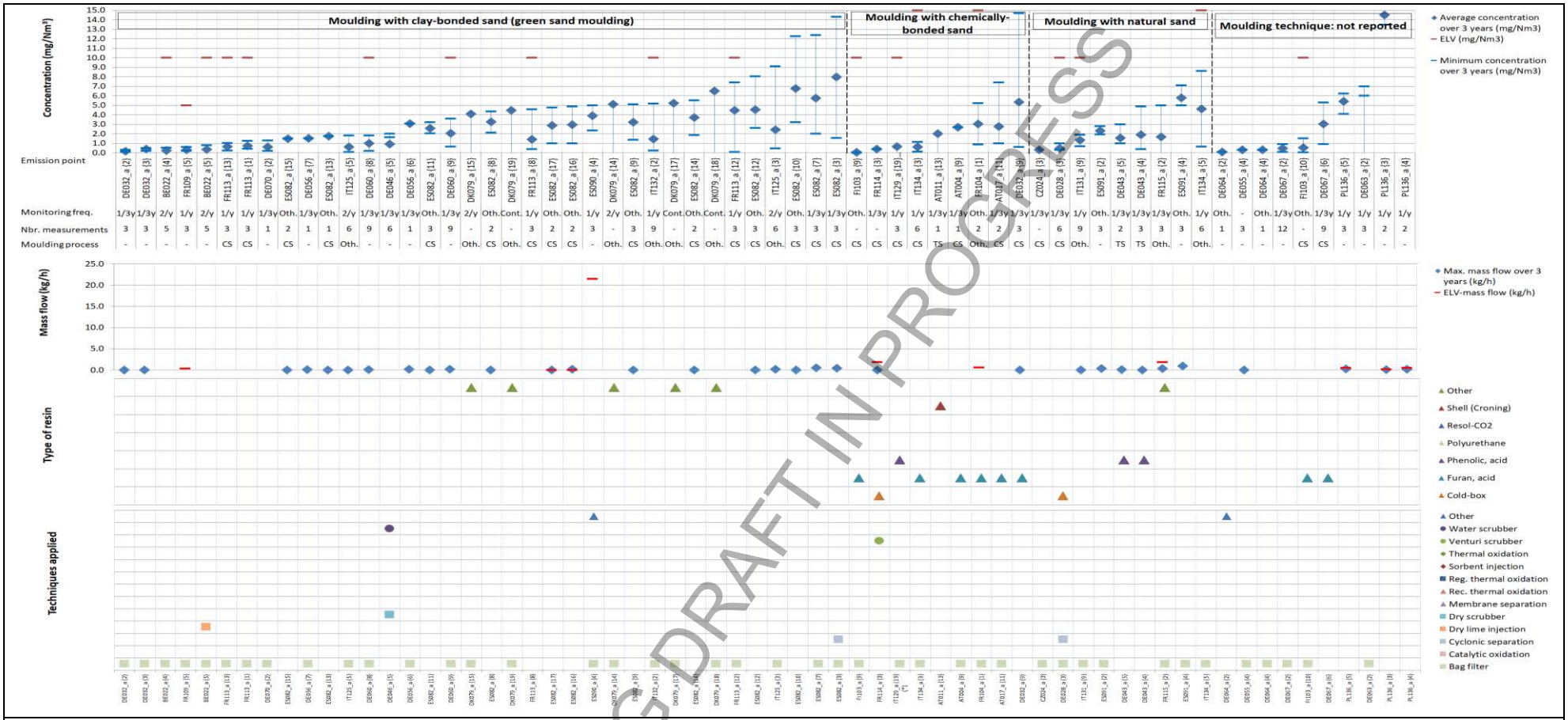
Some statistical data on reported TVOC emission data are presented in the following table.

Table 2.57: Statistical evaluation of the reported TVOC emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Moulding	25	11	9	47.64	26.93	19.35	9.92
Core-making	67	29	12	297.42	108.81	56.00	11.96
NB: The data above refer to EPs that are associated with only one process, either moulding or core-making. *Source:* [169, TWG 2021]							

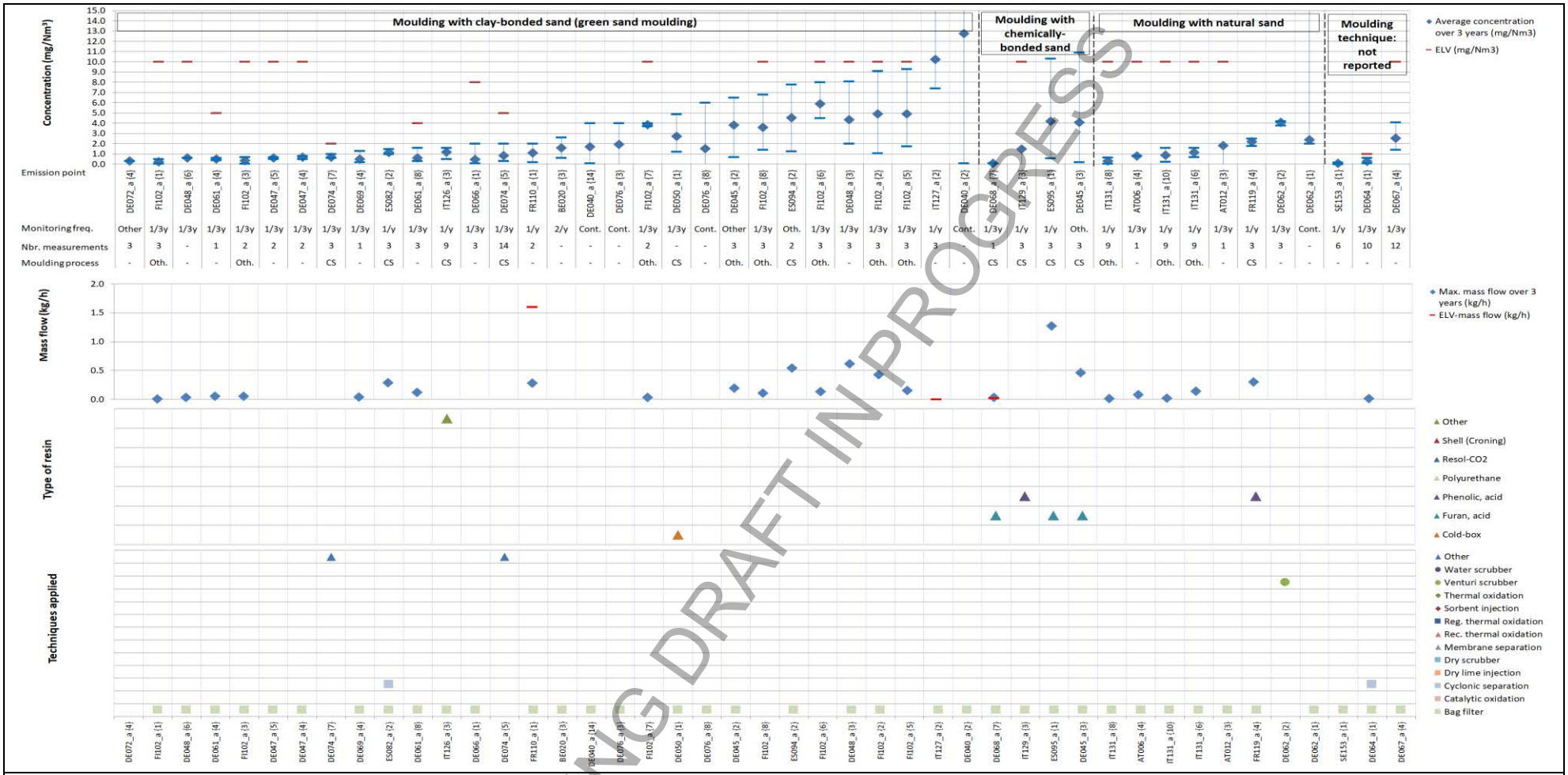
2.3.2.5.7 Figures for emissions to air

The structure of the figures presented in this section is explained in Section 2.3.2.1.10.



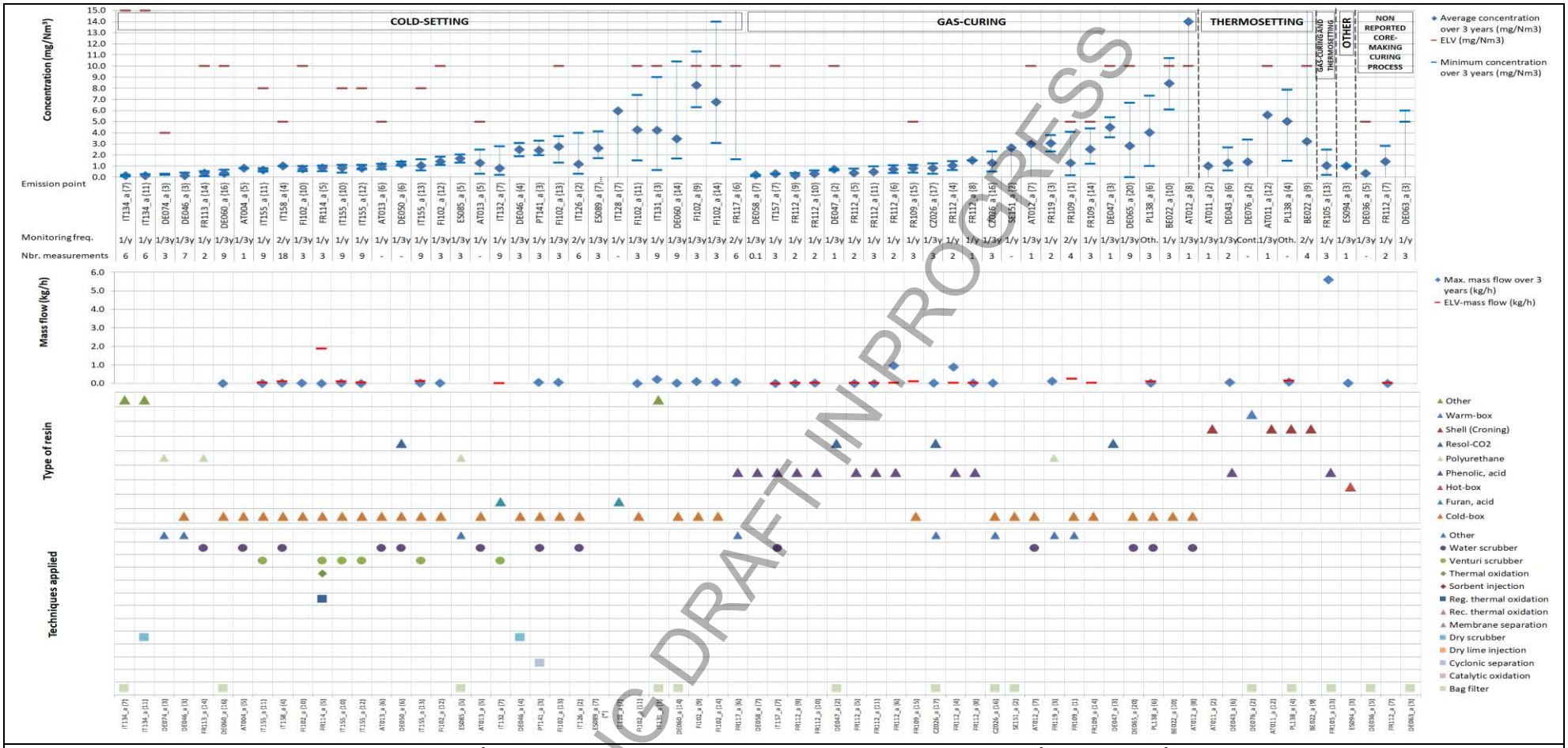
NB: For better visualisation, the ELVs over 15 mg/Nm³ are not shown. The range of ELVs not shown is from 20 mg/Nm³ to 150 mg/Nm³.
For better visualisation, the values reported by PL136_a {3} (max. = 15.8 mg/Nm³) and PL136_a {4} (min. = 24.6 mg/Nm³, avg. = 27.0 mg/Nm³, max. = 29.6 mg/Nm³) are not shown in the figure.
(*) EP IT129_a {19} reported the use of 2 moulding techniques: lost foam process with chemically bonded sand and moulding with chemically bonded sand.
Source: [169, TWG 2021]

Figure 2.89: Dust emissions from moulding using lost moulds



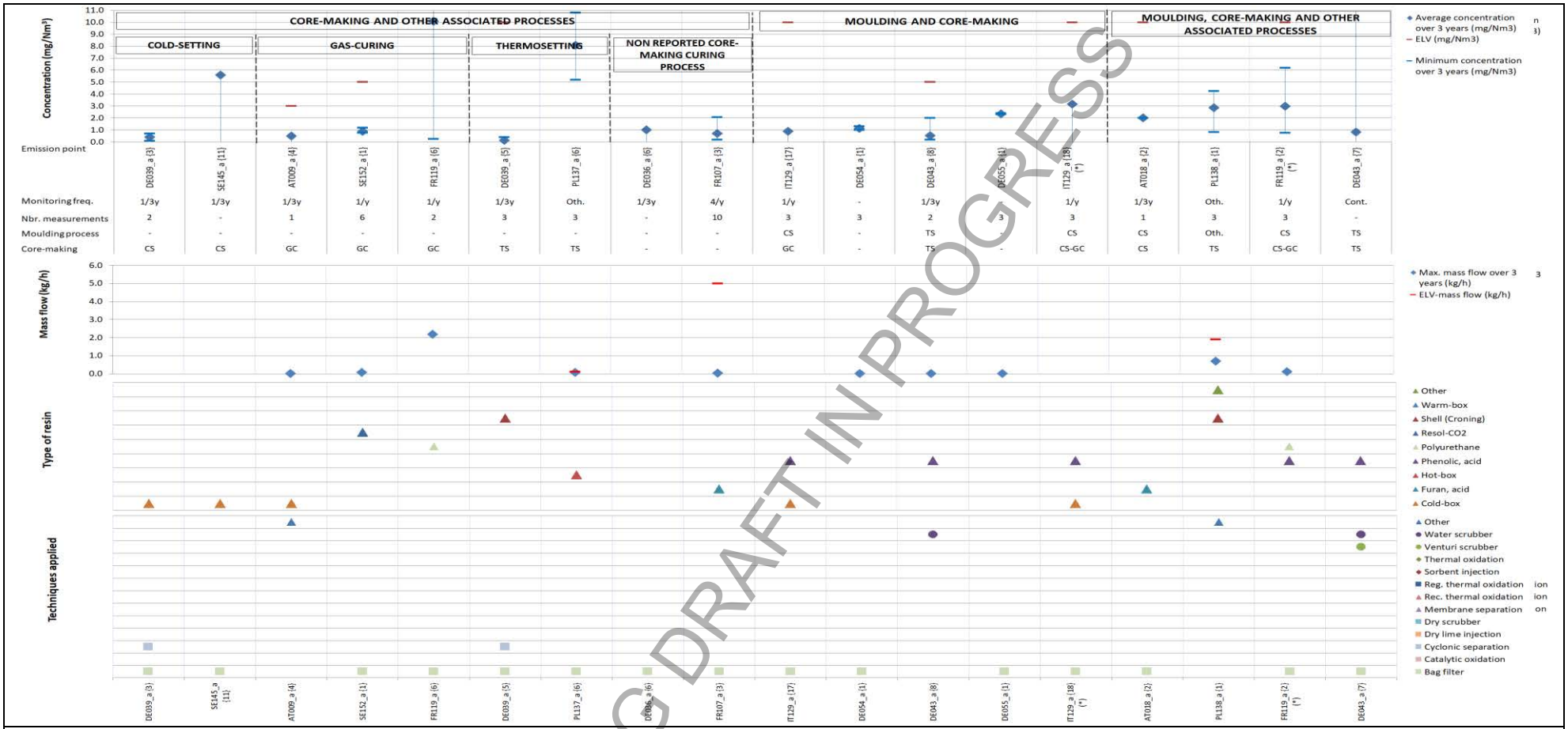
NB: For better visualisation, the ELVs over 15 mg/Nm³ are not shown. The range of ELVs not shown is from 20 mg/Nm³ to 150 mg/Nm³. In addition, the values reported by IT127_a {2} (max. = 16.3 mg/Nm³), DE040_a {2} (max. = 19.0 mg/Nm³) and DE062_a {1} (max. = 20.0 mg/Nm³) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.90: Dust emissions from moulding and other associated processes using lost moulds



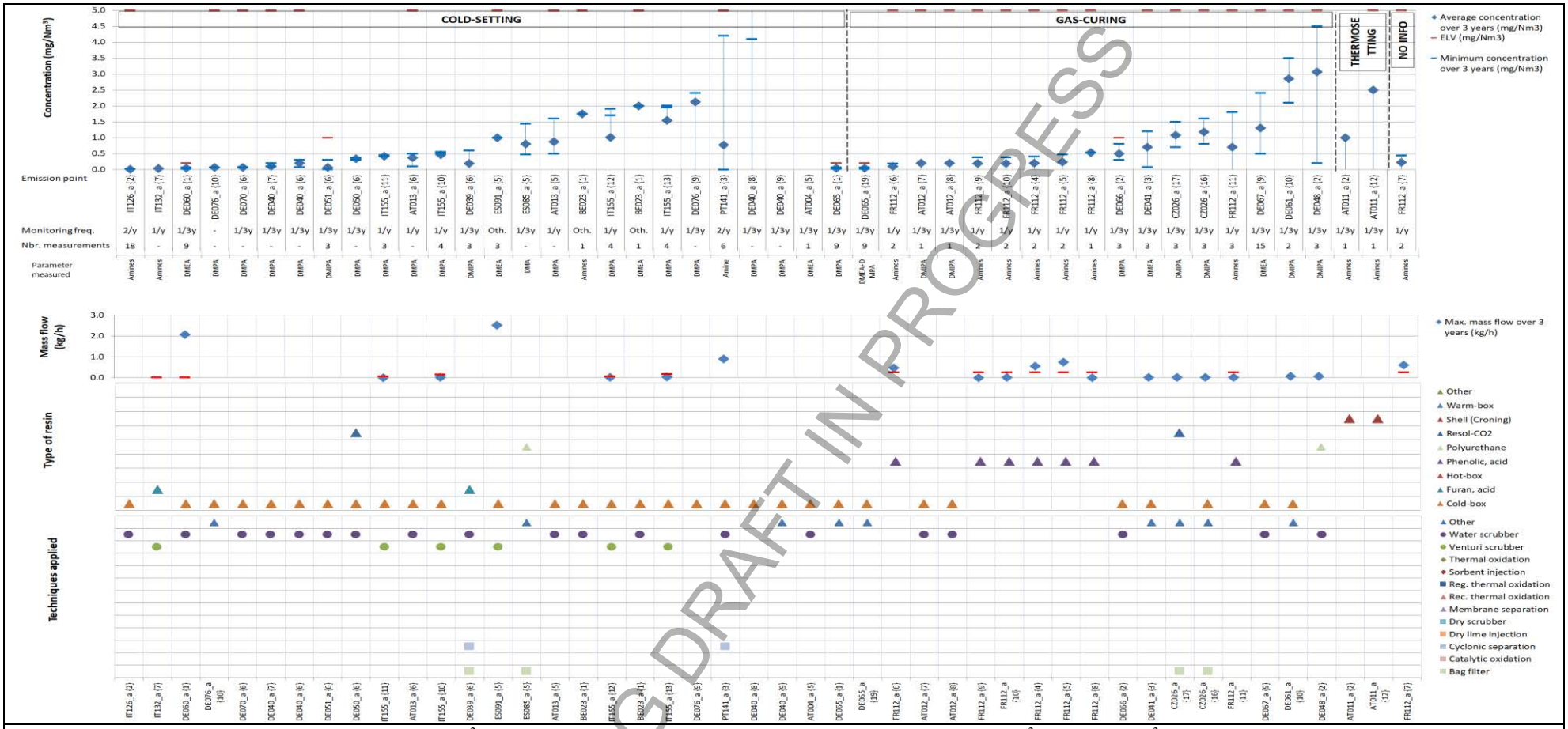
NB: For better visualisation, the ELVs over 15 mg/Nm³ are not shown. The range of ELVs not shown is from 20 mg/Nm³ to 40 mg/Nm³.
For better visualisation, the values reported by FR117_a {6} (avg. = 20.9 mg/Nm³, max. = 88 mg/Nm³) and BE022_a {9} (max. = 15.2 mg/Nm³) are not shown in the figure.
(*) EP ES089_a {7} reported the use of resol – ester (alkaline phenolic ester hardened) as type of resin.
Source: [169, TWG 2021]

Figure 2.91: Dust emissions from core-making



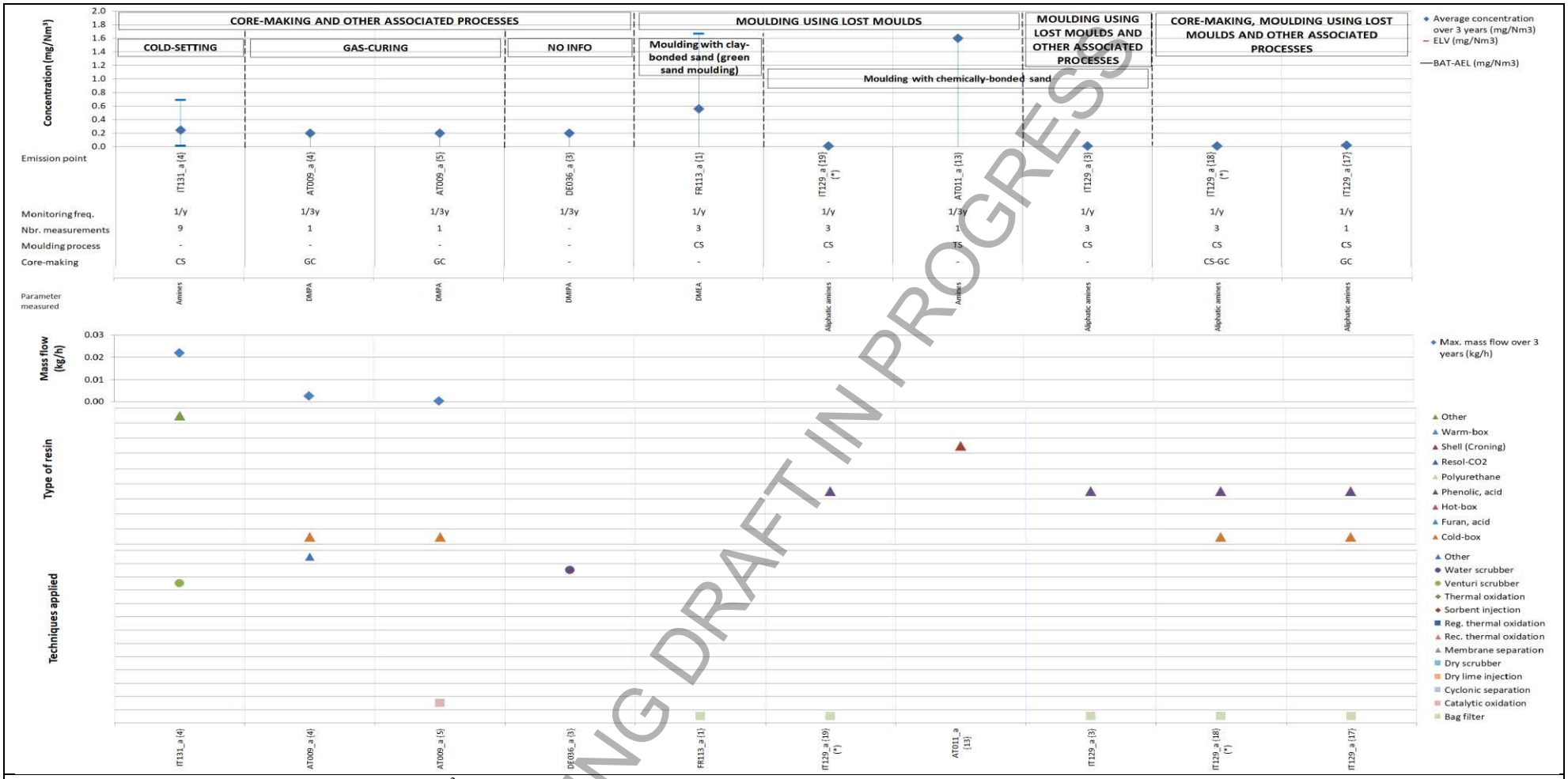
NB: For better visualisation, the ELVs over 11 mg/Nm^3 are not shown. The range of ELVs not shown is from 20 mg/Nm^3 to 40 mg/Nm^3.
For better visualisation, the values reported by FR119_a {6} (max. = 19.9 mg/Nm^3) and DE043_a {7} (max. = 27.02 mg/Nm^3) are not shown in the figure.
(*) EP IT129_a {18} reported the use of 2 moulding techniques: lost foam process with chemically bonded sand and moulding with chemically bonded sand.
(*) EP FR119_a {2} reported the use of 2 moulding techniques: moulding with natural sand and moulding with unbonded sand (V-process).
Source: [169, TWG 2021]

Figure 2.92: Dust emissions from core-making, moulding using lost moulds and other associated processes



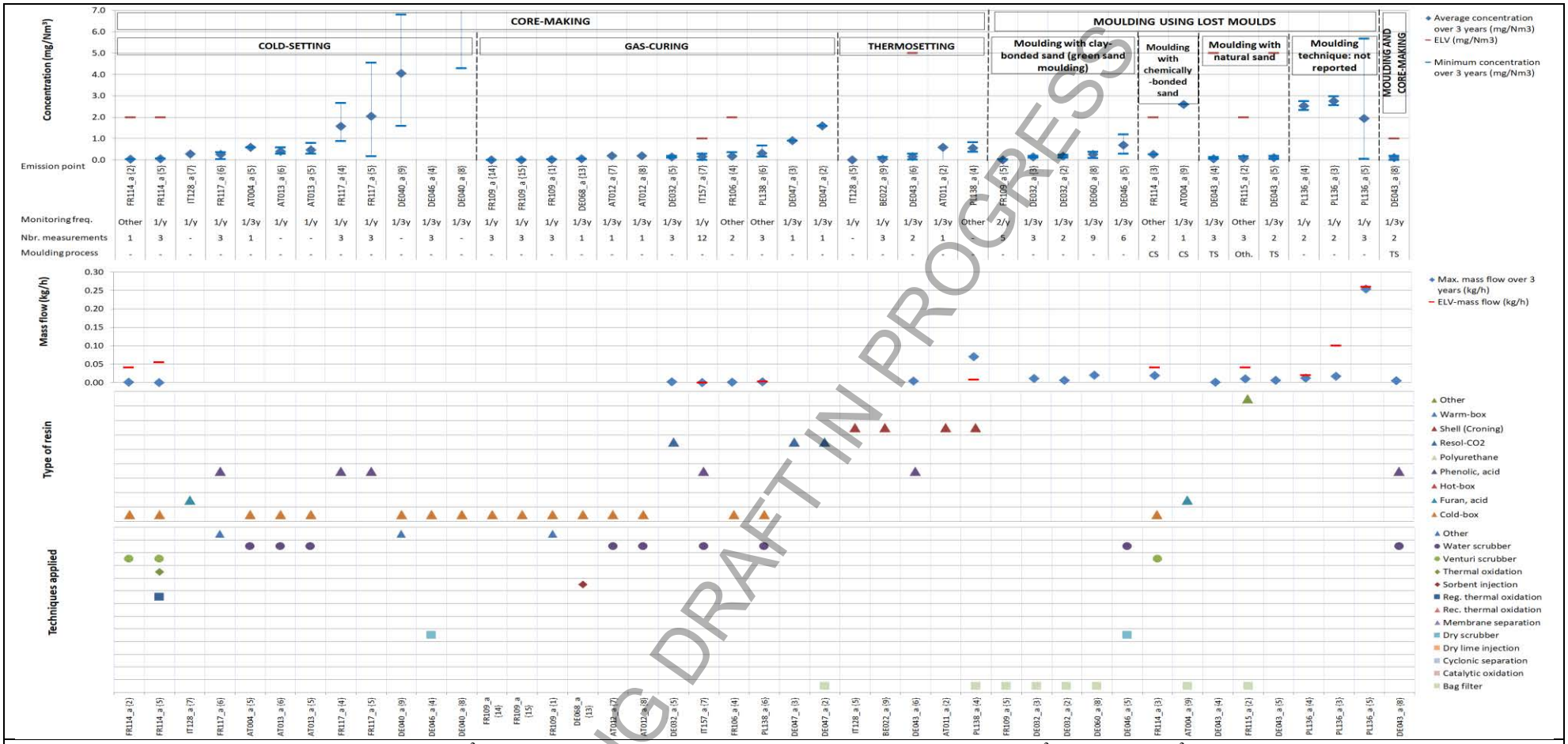
NB: For better visualisation, the ELVs over 5 mg/Nm³ are not shown. The range of ELVs not shown is from 10 mg/Nm³ to 20 mg/Nm³.
For better visualisation, the values reported by DE040_a {8} (max. = 5.8 mg/Nm³), DE040_a {9, (min. = 6.4 mg/Nm³, avg. = 7.1 mg/Nm³, max. = 7.4 mg/Nm³) }and AT004_a {5} (min. = 10.1 mg/Nm³, avg. = 10.1 mg/Nm³, max. = 10.1 mg/Nm³) are not shown in the figure.
(*) EP IT129_a {19} and EP IT129_a {18} reported the use of 2 moulding techniques: lost foam process with chemically bonded sand and moulding with chemically bonded sand.
Source: [169, TWG 2021]

Figure 2.93: Amines emissions from core-making



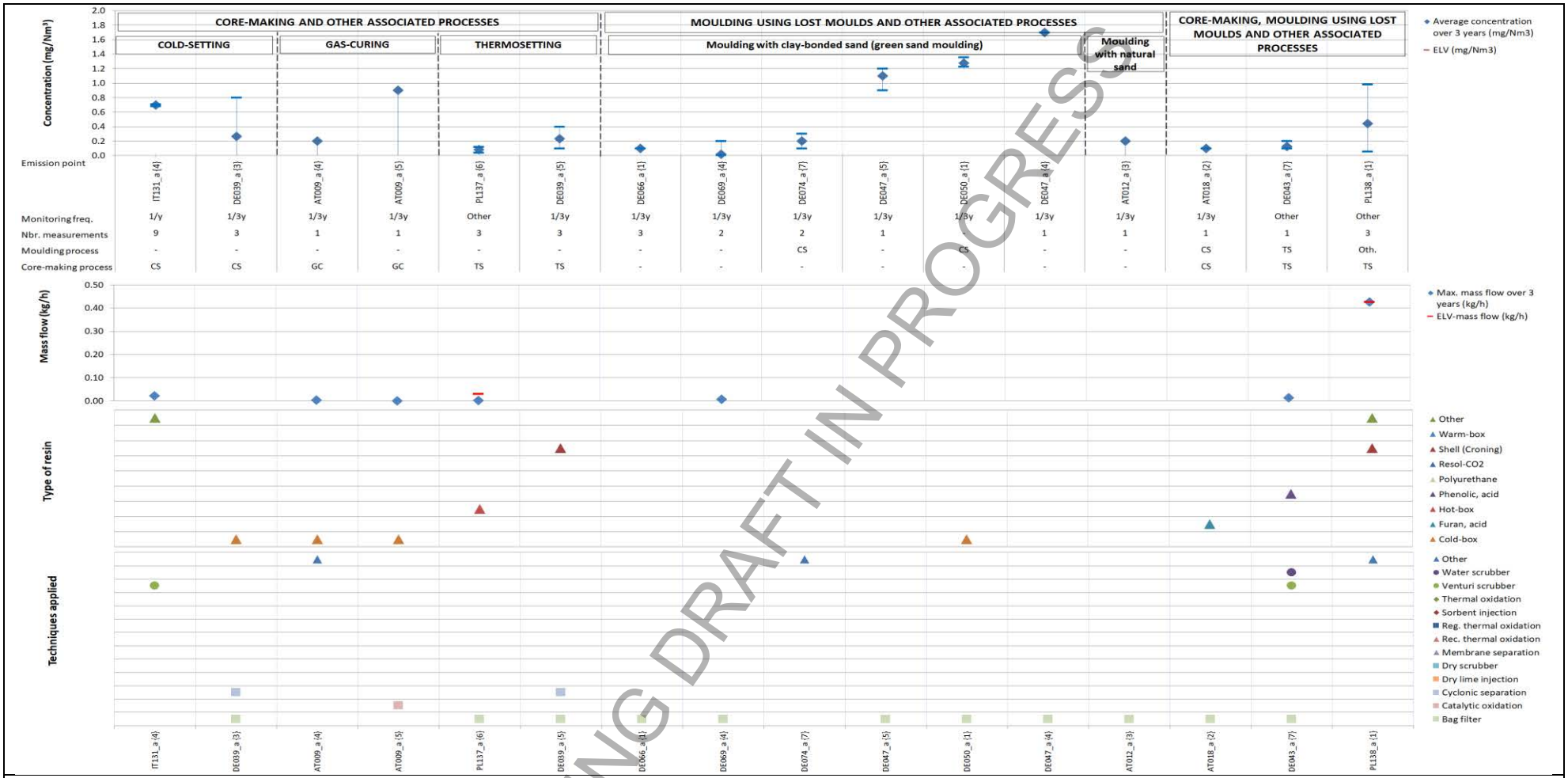
NB: For better visualisation, the ELVs of 5 mg/Nm³ are not shown.
(*) EP IT129_a {19} and EP IT129_a {18} reported the use of 2 moulding techniques: lost foam process with chemically bonded sand and moulding with chemically bonded sand
Source: [169, TWG 2021]

Figure 2.94: Amines emissions from core-making, moulding using lost moulds and other associated processes



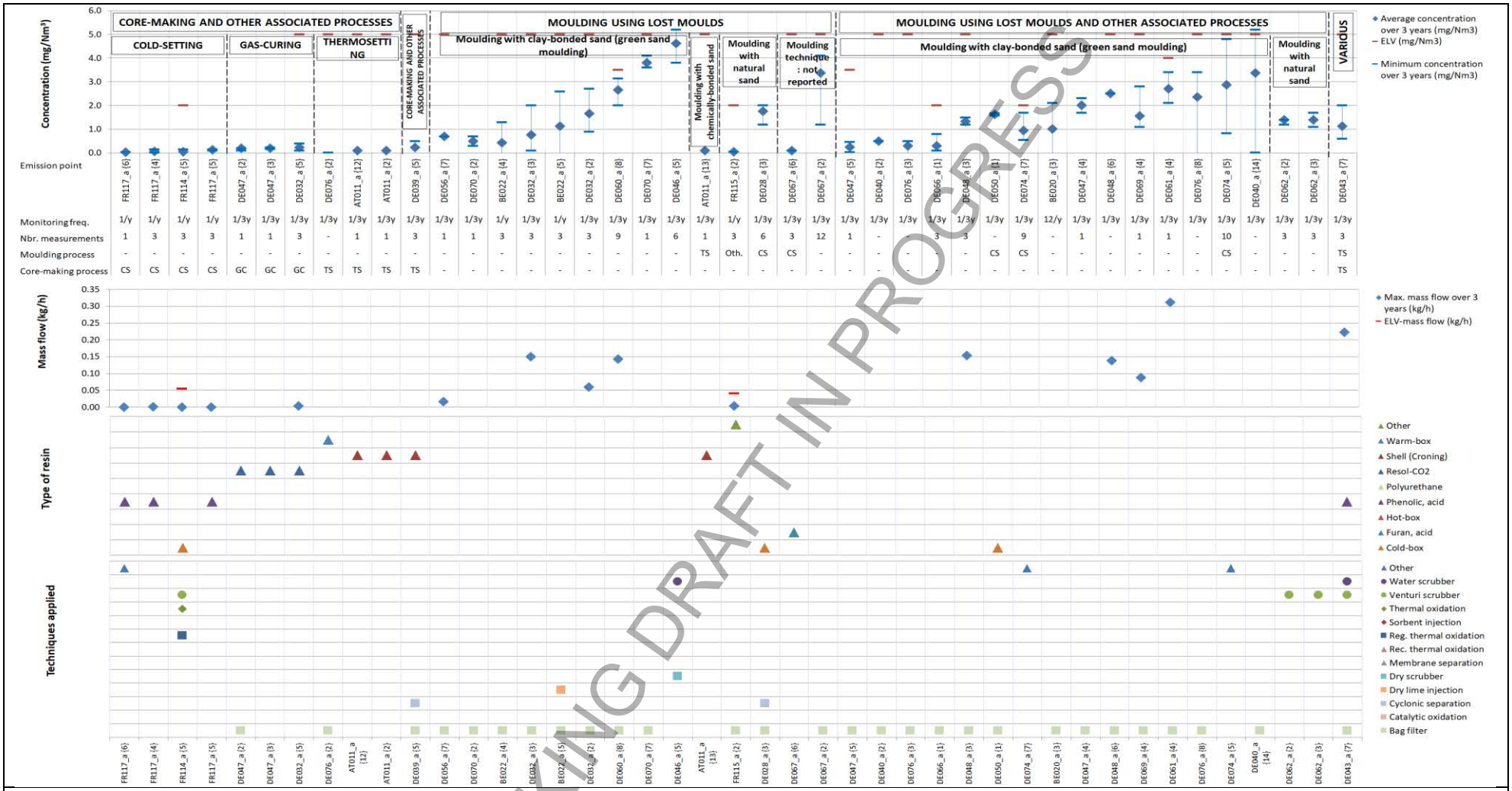
NB: For better visualisation, the ELVs over 7 mg/Nm³ are not shown. The range of ELVs not shown is from 14.5 mg/Nm³ to 200 mg/Nm³.
For better visualisation, the values reported by DE046_a {4} (min. = 7.2 mg/Nm³, avg. = 9.5 mg/Nm³, max. = 11.7 mg/Nm³) and DE040_a {8} (avg. = 9.3 mg/Nm³, max. = 16.1 mg/Nm³) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.95: Formaldehyde emissions from core-making and moulding using lost moulds



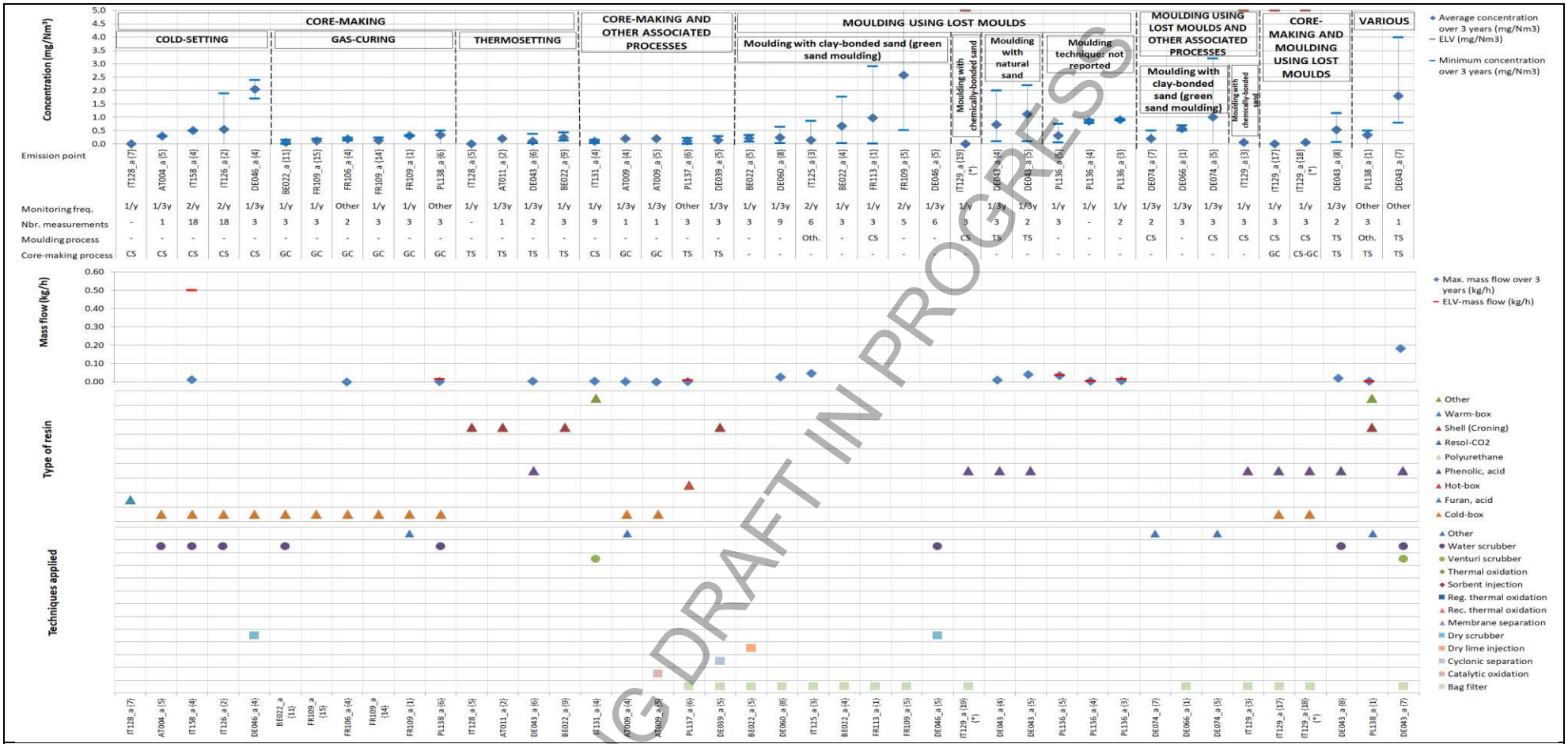
NB: For better visualisation, the ELVs over 2 mg/Nm^3 are not shown. The range of ELVs not shown is from 5 mg/Nm^3 to 20 mg/Nm^3.
Source: [169, TWG 2021]

Figure 2.96: Formaldehyde emissions from core-making, moulding using lost moulds and other associated processes



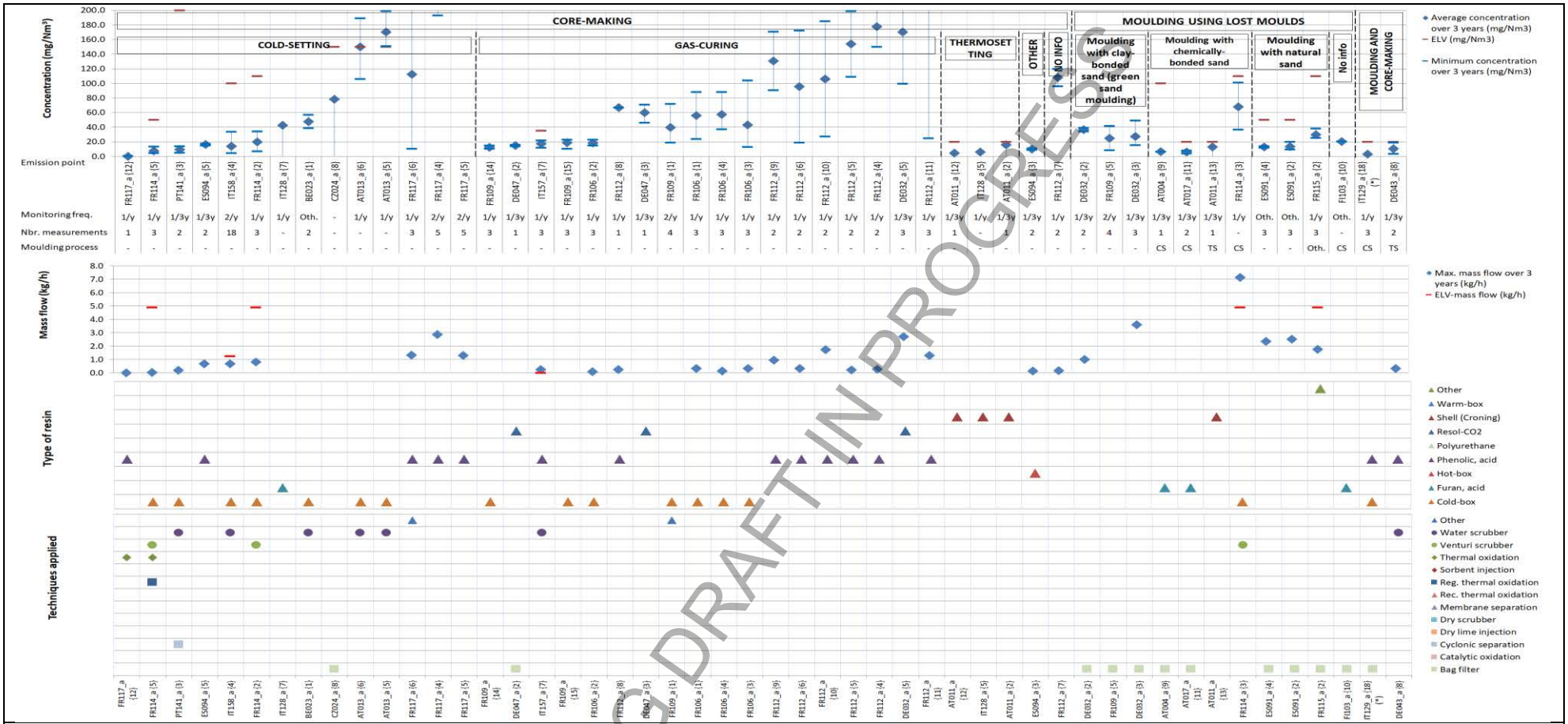
Source: [169, TWG 2021]

Figure 2.97: Benzene emissions from core-making, moulding using lost moulds and other associated processes



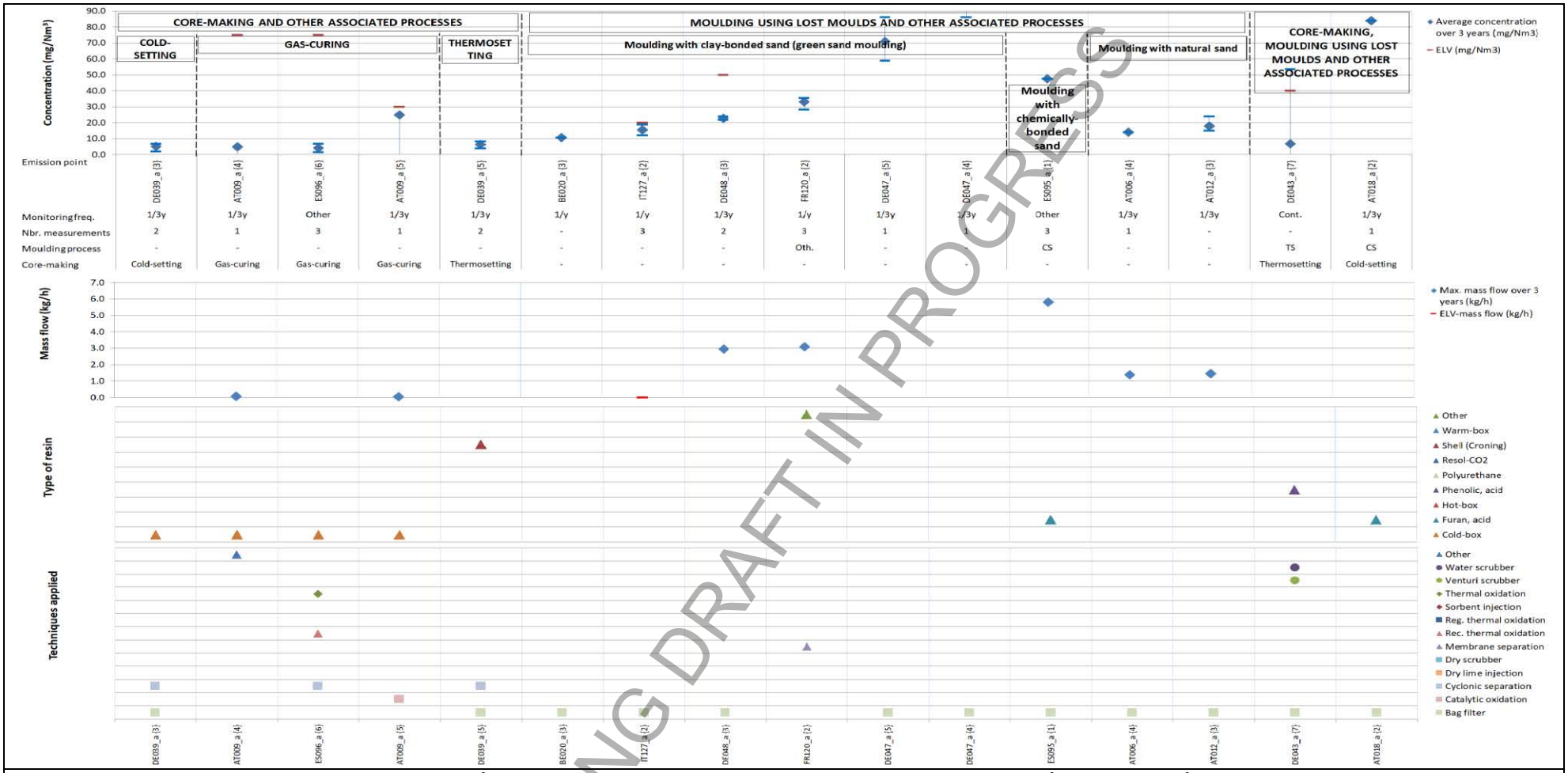
NB: For better visualisation, the ELVs over 5 mg/Nm³ are not shown. The range of ELVs not shown is from 10 mg/Nm³ to 20 mg/Nm³. In addition, the values reported by FR109_a {5} (max. = 8.8 mg/Nm³) and DE046_a {5} (min. = 7.2 mg/Nm³, avg. = 10.4 mg/Nm³, max. = 13.5 mg/Nm³) are not shown in the figure.
(*) EP IT129_a {19} and EP IT129_a {18} reported the use of 2 moulding techniques: lost foam process with chemically bonded sand and moulding with chemically bonded sand.
Source: [169, TWG 2021]

Figure 2.98: Phenol emissions from core-making, moulding using lost moulds and other associated processes



NB: For better visualisation, the values reported by FR117_a {6} (max. = 241 mg/Nm^3), FR117_a {4} (avg. = 281 mg/Nm^3, max. = 455 mg/Nm^3), FR117_a {5} (min. = 262 mg/Nm^3, avg. = 341 mg/Nm^3, max. = 516 mg/Nm^3), FR112_a {4} (max. = 205 mg/Nm^3), DE032_a {5} (max. = 295 mg/Nm^3) and FR112_a {11} (avg. = 255 mg/Nm^3, max. = 486 mg/Nm^3) are not shown in the figure.
(*) EP IT129_a {18} reported the use of 2 moulding techniques: moulding with chemically bonded sand and lost foam process with chemically bonded sand.
Source: [169, TWG 2021]

Figure 2.99: TVOC emissions from core-making and moulding using lost moulds



NB: For better visualisation, the ELVs over 90 mg/Nm³ are not shown. The range of ELVs not shown is from 110 mg/Nm³ to 150 mg/Nm³.
For better visualisation, the values reported by DE047_a {4} (avg. = 98 mg/Nm³, max. = 112 mg/Nm³) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.100:TVOC emissions from core-making and moulding using lost moulds and other associated processes

2.3.2.6 Coating of moulds and cores

The inputs/outputs for the processes of coating of chemically bonded moulds and cores are presented in the following table.

Input	Output
– Coatings ready to use or mass to be diluted with water or alcohol – Heat for solvent evaporation	– VOCs (alcohol-based)

2.3.2.6.1 Dust and TVOC emissions

Some statistical data on the reported dust and TVOC emission data are presented in the following table.

Table 2.58: Statistical evaluation of the reported dust and TVOC emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Dust	9	6	4	-	1.96	2.00	-
TVOC	14	7	4	327.60	98.96	20.41	2.79
NB: The data above refer to EPs that are only associated with the coating process. *Source:* [169, TWG 2021]							

2.3.2.7 Casting, cooling and shake-out using lost moulds

The inputs/outputs for the casting, cooling and shake-out processes are presented in the following table.

Input	Output
– Finished moulds – Molten metal	– Castings – Used sand – Combustion products (from preheating of pouring ladles) – Organic pollutants from pyrolysis and thermal degradation of binder, blackening moulds, etc. (phenol, formaldehyde, amine, hydrogen cyanide, PAH, benzene, VOC) – Odour – Waste from exhaust air cleaning (dry/sludge) – Dust from shake-out

Whilst **preheating** ladles, combustion gases are generated as a result of using natural gas as the common energy source.

The following emission types can occur during **pouring**:

- Thermally degradable components, such as exothermic sleeves, react releasing fumes and/or vapours.
- Chemical compounds from the binder and some blacking systems which can be released as a result of thermal degradation and/or volatilisation, e.g. combustion gases, water vapour, and volatile organic compounds. Some of the degradation products can be odorous.

Experience shows that the maximum emissions (related to total-C) only occur 10 minutes or more after pouring. CO is the main component, with the level of CO being indicative of the release of other compounds. [38, VITO 2001]

During **cooling and shake-out,** the thermal decomposition processes proceed and volatile compounds are generated, mainly controlled by diffusion and evaporation rates.

The removal (shake-out) of the sand moulds and cores from castings is a dust-intensive procedure, as the moulds, at least partially, have to be crushed.

The **second cooling step** releases nothing except water vapour from those plants where water spray is used as a cooling aid. [14, CAEF 1997]

The type of emissions during casting are dependent on the binder type used. Emissions are comparable to those during the mixing stage, with the addition of pyrolysis products occurring upon contact with the hot metal. Table 2.59 gives the results from a qualitative survey of the emissions associated with the various binder types.

Table 2.59: Environmental impact from binder systems upon pouring, shake-out and cooling

System name and binder constituents	Emissions to air during casting	Comments
GREEN SAND Clay Coal dust or substitute Water	Particulate matter- soot from coal burning Carbon monoxide and carbon dioxide Benzene Toluene Xylene	Potential odour (may be associated with the sulphur content of the coal)
SHELL SAND Phenol - Formaldehyde (Novalak) Resin	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Phenol*, cresols* and xylenols* Ammonia Aldehydes Benzene PAH	Odour problems more prevalent – treatment may be necessary although dispersion may suffice
ALKALINE PHENOLIC Resol - Alkaline phenol Formaldehyde resin 1. Gas hardened 2. Self-setting	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Formaldehyde Phenol, cresols and xylenols Aromatics	Odour may be a problem
PHENOLIC URETHANE 1. Gas hardened e.g. Cold-box 2. Self-setting (phenolic urethane no bake)	Particulate matter – soot from the incomplete combustion of the carbon based resins Carbon oxides Nitrogen oxides Monoisocyanates Formaldehyde Phenol, cresols and xylenols Aromatics (inc. polycyclics) Anilines Naphthalenes Ammonia	Odour may be a problem
FURAN Combination resins of:	Particulate matter – soot from the incomplete combustion of the carbon based resins Carbon oxides	Odour may occasionally be a

Phenol Urea Furfuryl alcohol Formaldehyde	Phenol, cresols and xylenols Formaldehyde Aromatics (inc. polycyclics) Sulphur dioxide Ammonia Aniline Isocyanic acid* Methyl isocyanate*	problem
HOT-BOX Combination resins of: Phenol Urea Furfuryl alcohol Formaldehyde	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Nitrogen oxides Formaldehyde Phenol, cresols and xylenols Aromatics (inc. polycyclics) Aniline Ammonia Isocyanic acid* Methyl isocyanate*	
OIL SAND Linseed oil and starch	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Butadiene Ketones Acrolein	Odour may be a problem
CO_2 PROCESS Sodium silicate	Carbon oxides	
SILICATE ESTER Sodium silicate	Carbon oxides Alkanes Acetone Acetic acid Acrolein	
* For resin containing nitrogen (urea). *Source:* [62, UK Environment Agency 2002]		

2.3.2.7.1 Dust emissions

The reported levels of dust emissions to air from casting, cooling and shake-out processes using lost moulds are presented in Figure 2.101 and Figure 2.102.

Some statistical data on the reported dust emission data are presented in the following table.

Table 2.60: Statistical evaluation of the reported dust emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Casting	101	53	25	5.93	2.68	1.99	0.56
Cooling	43	22	16	18.81	6.10	2.67	0.71
Shake-out	81	33	27	11.91	4.22	1.87	0.29
NB: The data above refer to EPs that are associated with only one process: casting, cooling or shake-out. *Source:* [169, TWG 2021]							

2.3.2.7.2 Amines emissions

The reported levels of amines emissions to air from casting, cooling and shake-out processes using lost moulds are presented in Figure 2.103.

Some statistical data on the reported amines emission data are presented in the following table.

Table 2.61: Statistical evaluation of the reported amines emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Casting	2	2	1	-	0	-	-
Cooling	3	3	3	-	0.2	-	-
Shake-out	2	1	1	-	0.43	-	-
NB: The data above refer to EPs that are associated with only one process: casting, cooling or shake-out. *Source:* [169, TWG 2021]							

2.3.2.7.3 Benzene emissions

The reported levels of benzene emissions to air from casting, cooling and shake-out processes using lost moulds are presented in Figure 2.104.

Some statistical data on the reported benzene emission data are presented in the following table.

Table 2.62: Statistical evaluation of the reported benzene emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Casting	18	8	6	1.09	0.59	0.31	0.08
Cooling	16	10	8	7.09	3.18	2.20	0.39
Shake-out	4	2	2	-	2.95	-	-
NB: The data above refer to EPs that are associated with only one process: casting, cooling or shake-out. *Source:* [169, TWG 2021]							

2.3.2.7.4 Formaldehyde emissions

The reported levels of formaldehyde emissions to air from casting, cooling and shake-out processes using lost moulds are presented in Figure 2.105.

Some statistical data on the reported formaldehyde emission data are presented in the following table.

Table 2.63: Statistical evaluation of the reported formaldehyde emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Casting	14	5	4	0.90	0.27	0.15	0.01
Cooling	10	4	2	0.14	0.05	0.03	0.01
Shake-out	7	4	3	-	0.36	0.25	-
NB: The data above refer to EPs that are associated with only one process: casting, cooling or shake-out. *Source:* [169, TWG 2021]							

2.3.2.7.5 Phenol emissions

The reported levels of phenol emissions to air from casting, cooling and shake-out processes using lost moulds are presented in Figure 2.106.

Some statistical data on the reported phenol emission data are presented in the following table.

Table 2.64: Statistical evaluation of the reported formaldehyde emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Casting	9	3	3	-	0.06	0.02	-
Cooling	10	4	2	2.23	1.12	0.92	0.06
Shake-out	2	2	1	-	0.27	-	-
NB: The data above refer to EPs that are associated with only one process: casting, cooling or shake-out. *Source:* [169, TWG 2021]							

2.3.2.7.6 Chromium (Cr) emissions

The reported levels of Cr emissions to air from casting, cooling and shake-out processes using lost moulds are presented in Figure 2.107.

Some statistical data on the reported Cr emission data are presented in the following table.

Table 2.65: Statistical evaluation of the reported Cr emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Casting	5	3	3	-	0.006	-	-
Cooling	1	1	1	-	0.0007	-	-
Shake-out	10	5	4	0.0096	0.006	0.007	0.000057
NB: The data above refer to EPs that are associated with only one process: casting, cooling or shake-out. *Source:* [169, TWG 2021]							

2.3.2.7.7 Lead (Pb) emissions

The reported levels of Pb emissions to air from casting, cooling and shake-out processes using lost moulds are presented in Figure 2.108.

Some statistical data on the reported Pb emission data are presented in the following table.

Table 2.66: Statistical evaluation of the reported Pb emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Casting	13	12	5	0.16	0.078	0.07	0.0034
Cooling	-	-	-	-	-	-	-
Shake-out	12	6	5	0.0048	0.0017	0.0007	0.0
NB: The data above refer to EPs that are associated with only one process: casting, cooling or shake-out. *Source:* [169, TWG 2021]							

2.3.2.7.8 TVOC emissions

The reported levels of TVOC emissions to air from casting, cooling and shake-out processes using lost moulds are presented in Figure 2.109.

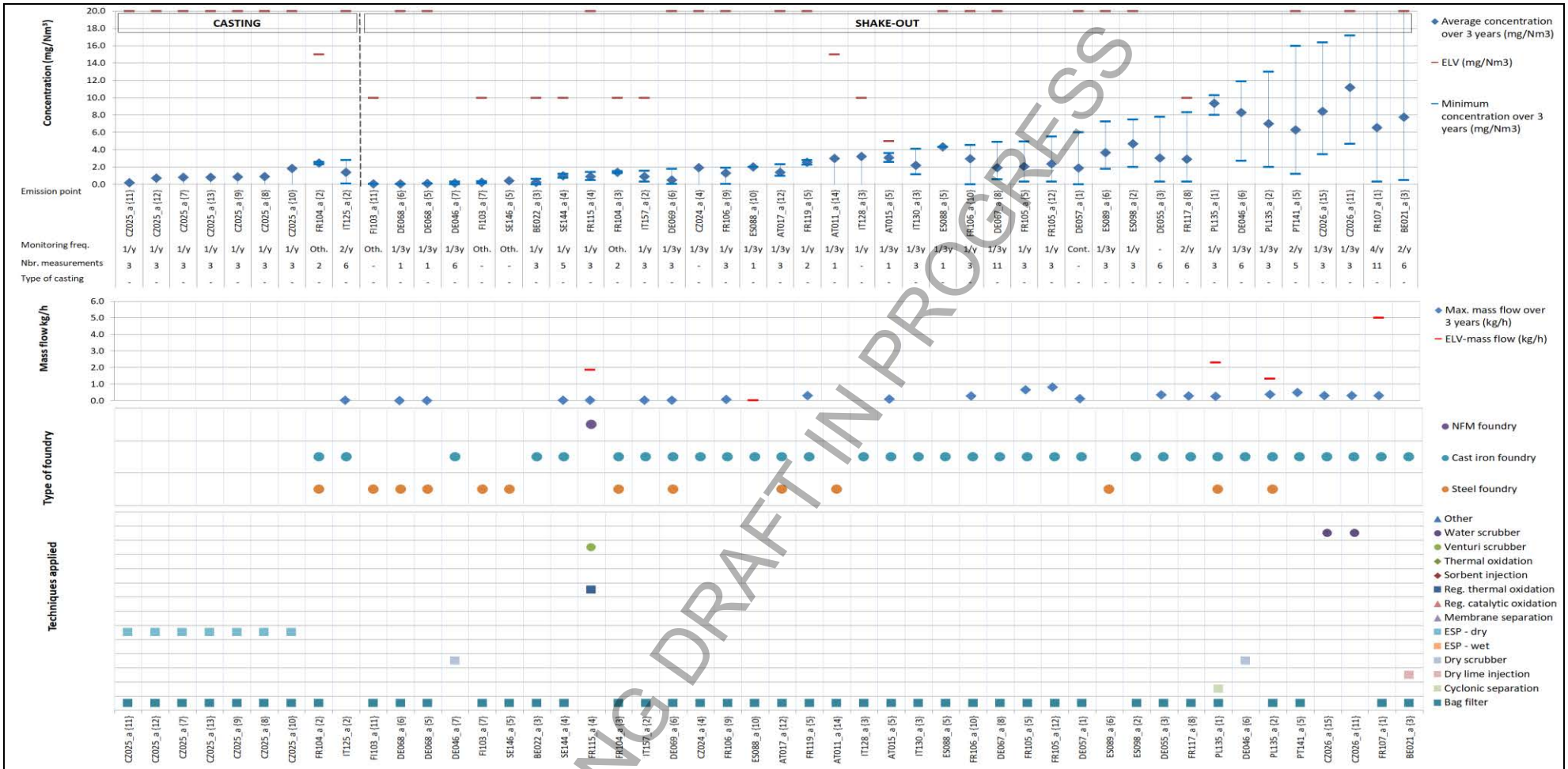
Some statistical data on the reported TVOC emission data are presented in the following table.

Table 2.67: Statistical evaluation of the reported TVOC emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Casting	74	31	15	46.92	16.82	7.75	2.98
Cooling	27	10	5	84.60	36.92	24.50	5.28
Shake-out	21	9	7	60.40	29.46	19.17	6.76
NB: The data above refer to EPs that are associated with only one process, casting, cooling or shake-out. *Source:* [169, TWG 2021]							

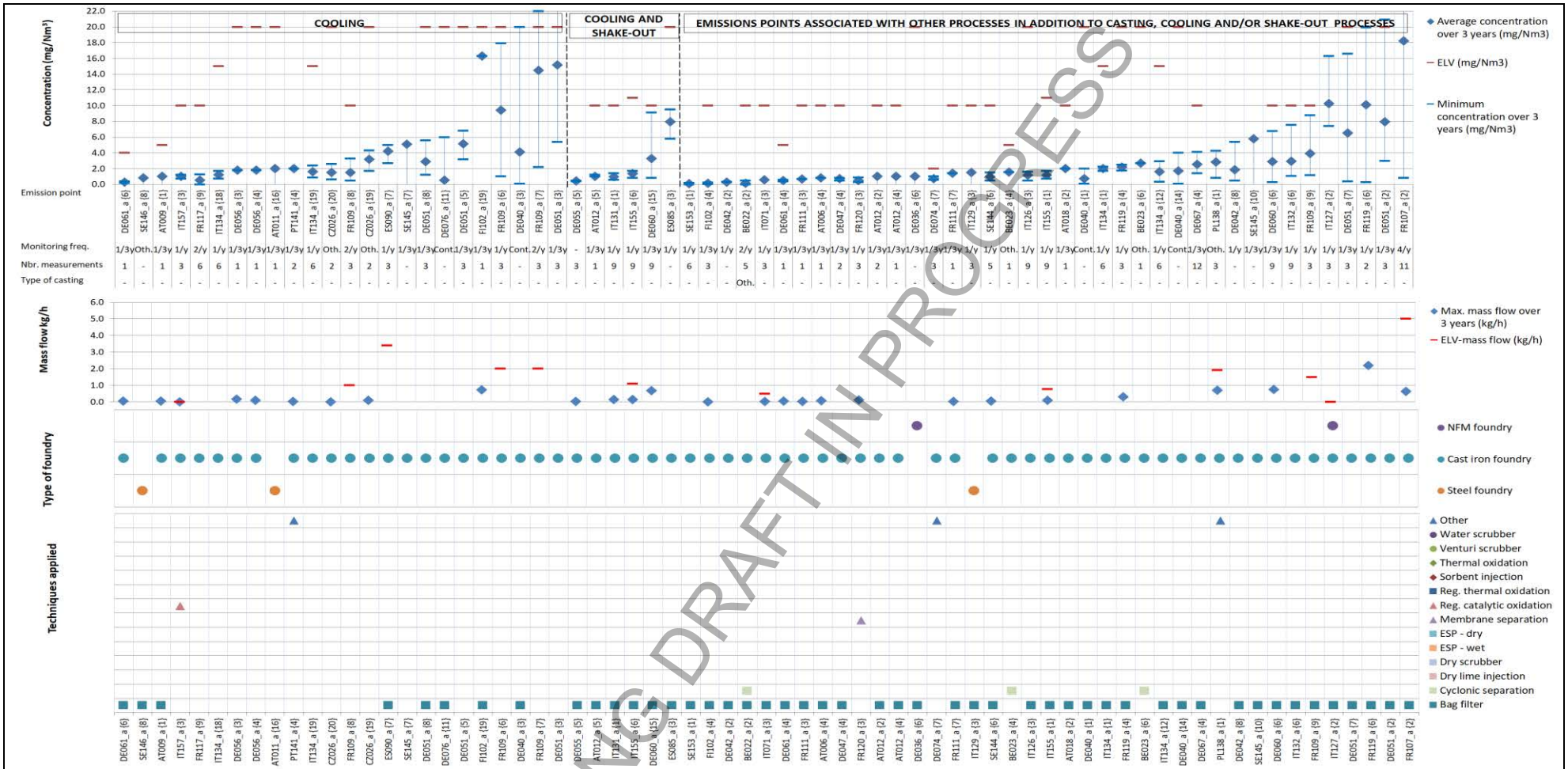
2.3.2.7.9 Figures for emissions to air

The structure of the figures presented in this section is explained in Section 2.3.2.1.10.



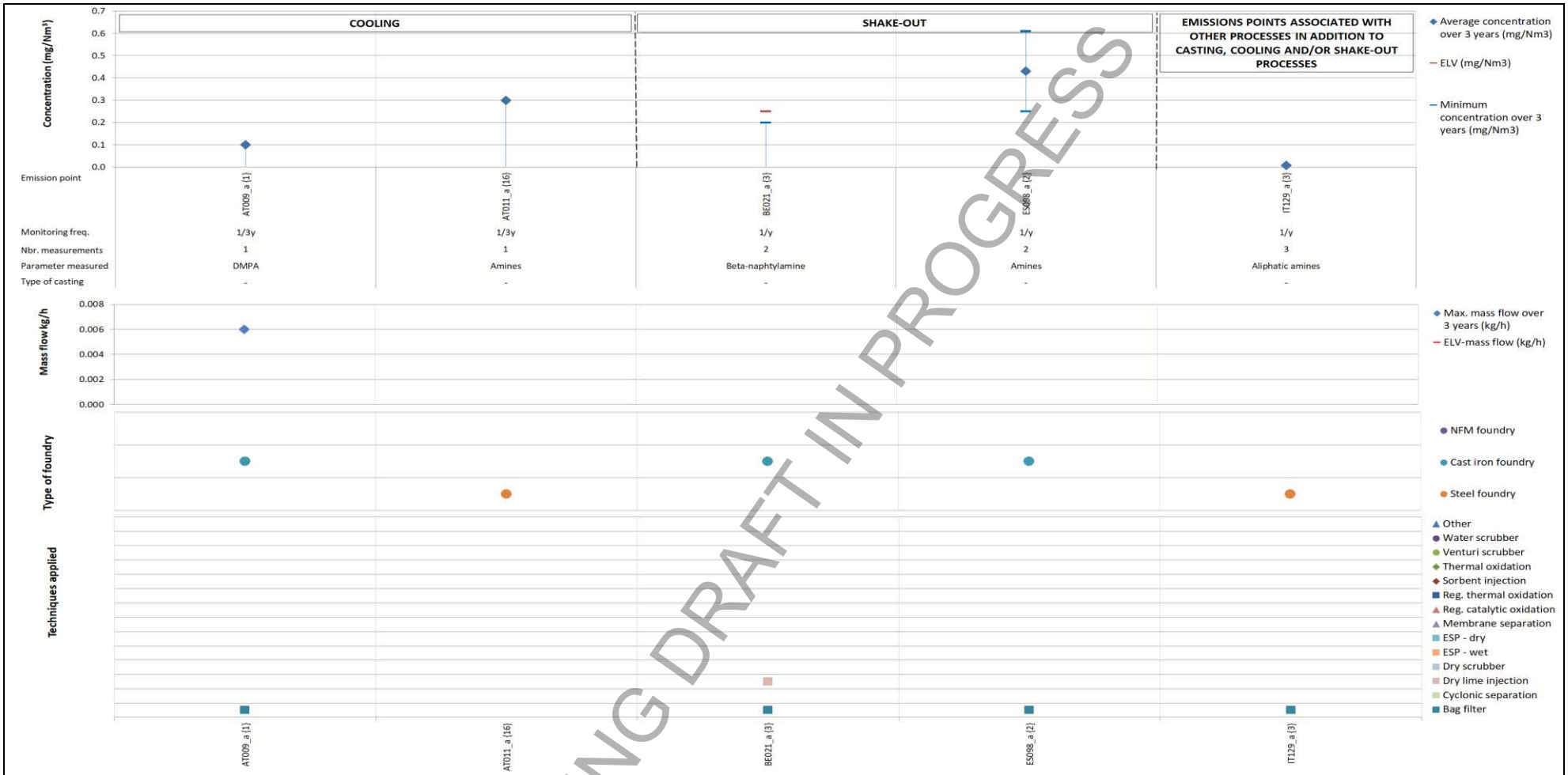
NB: For better visualisation, the ELVs over 20 mg/Nm³ are not shown. The range of ELVs not shown is from 40 mg/Nm³ to 95 mg/Nm³. In addition, the values reported by FR107_a {1} (max. = 30.5 mg/Nm³) and BE021_a {3} (max. = 40.0 mg/Nm³) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.101:Dust emissions from casting, cooling and shake-out processes using lost moulds (sorted by type of process) (1/2)



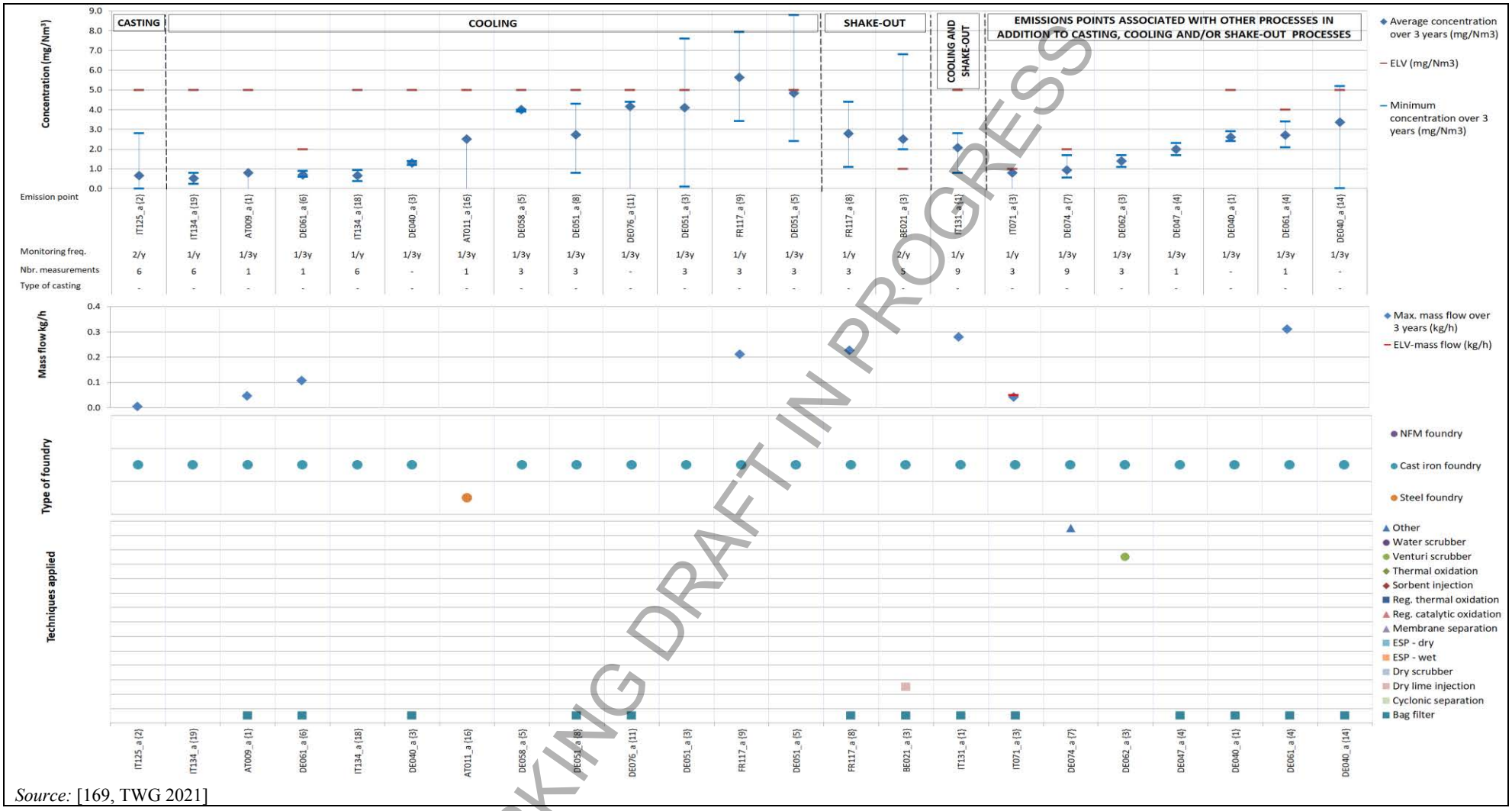
NB: For better visualisation, the ELV reported by PT141_a {4} and ES090_a {7} of 150 mg/Nm^3, and the ELV reported by FR120_a {3} and FR107_a {2} of 40 mg/Nm^3 are not shown. In addition, the values reported by DE051_a {3} (max. = 31.0 mg/Nm^3) and FR107_a {2} (max. = 96.6 mg/Nm^3) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.102:Dust emissions from casting, cooling and shake-out processes using lost moulds (sorted by type of process) (2/2)



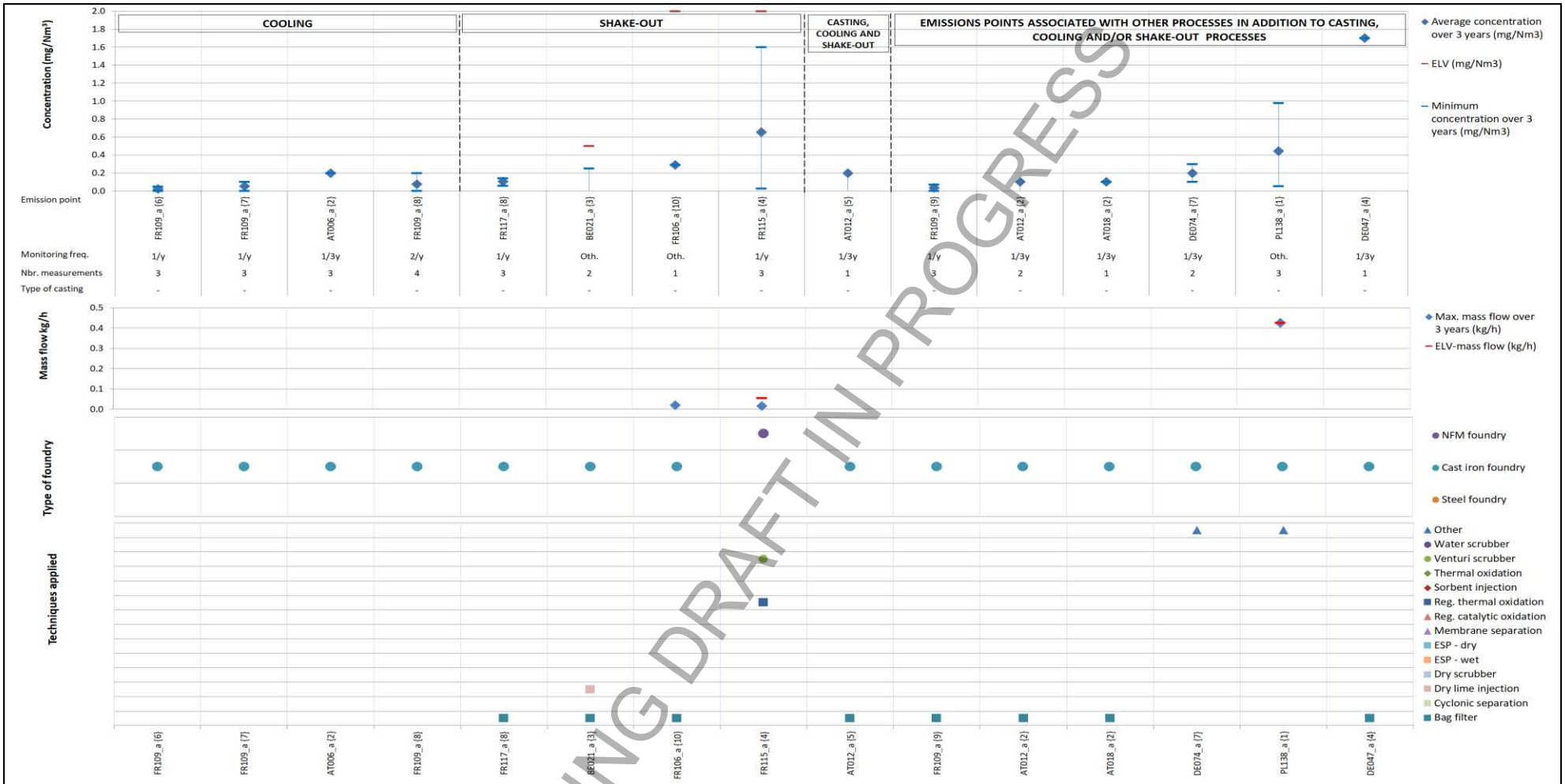
NB: For better visualisation, the ELVs over 0.7 mg/Nm^3 are not shown. The range of ELVs not shown is from 0.25 mg/Nm^3 to 5 mg/Nm^3.
Source: [169, TWG 2021]

Figure 2.103:Amines emissions from casting, cooling and shake-out processes using lost moulds (sorted by type of process)



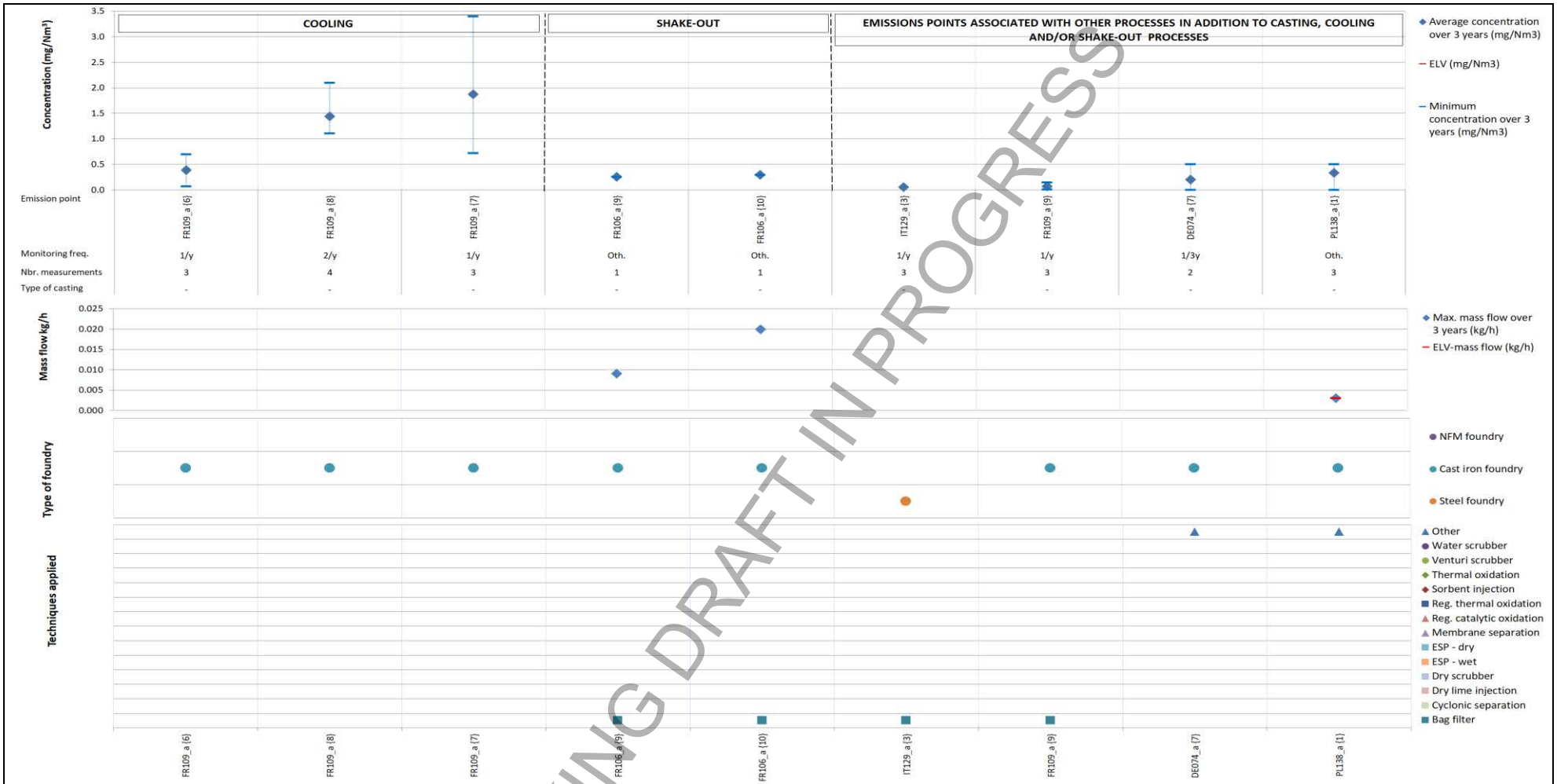
Source: [169, TWG 2021]

Figure 2.104:Benzene emissions from casting, cooling and shake-out processes using lost moulds (sorted by type of process)



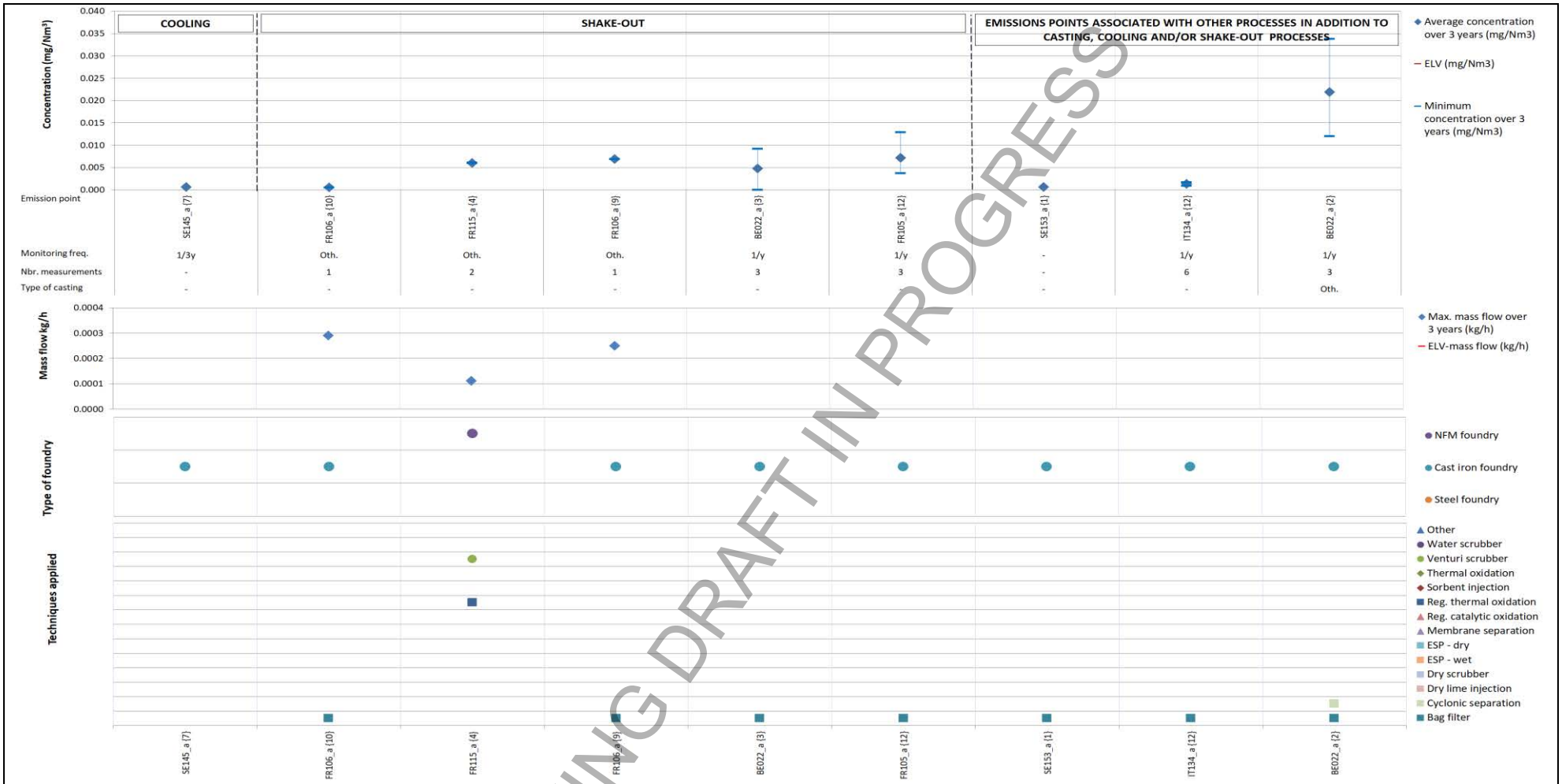
NB: For better visualisation, the ELVs over 2 mg/Nm³ are not shown. The range of ELVs not shown is from 5 mg/Nm³ to 20 mg/Nm³.
Source: [169, TWG 2021]

Figure 2.105:Formaldehyde emissions from casting, cooling and shake-out processes using lost moulds (sorted by type of process)



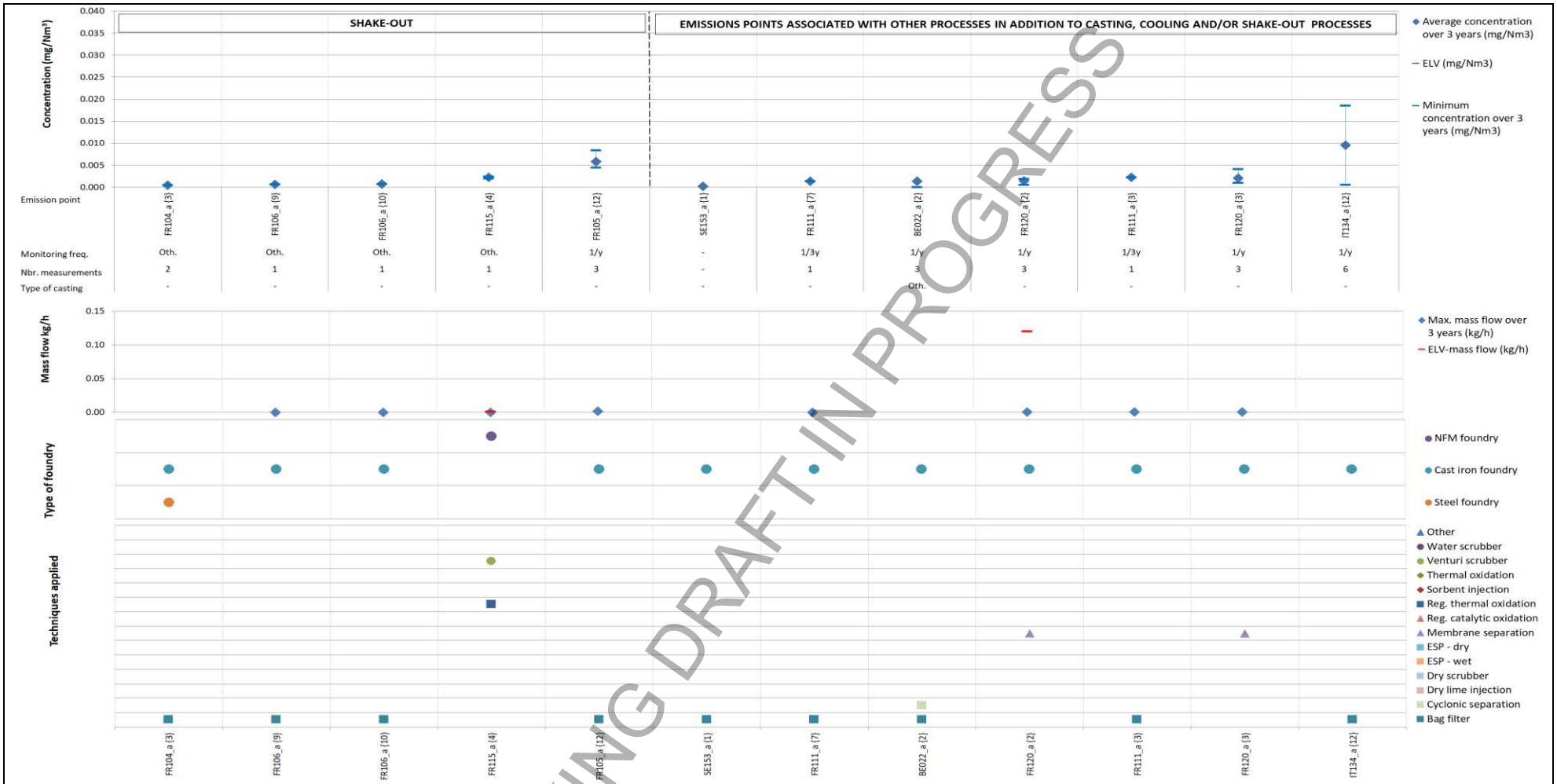
NB: For better visualisation, the ELVs over 3.5 mg/Nm^3 are not shown. The range of ELVs not shown is from 5 mg/Nm^3 to 20 mg/Nm^3.
Source: [169, TWG 2021]

Figure 2.106:Phenol emissions from casting, cooling and shake-out processes using lost moulds (sorted by type of process)



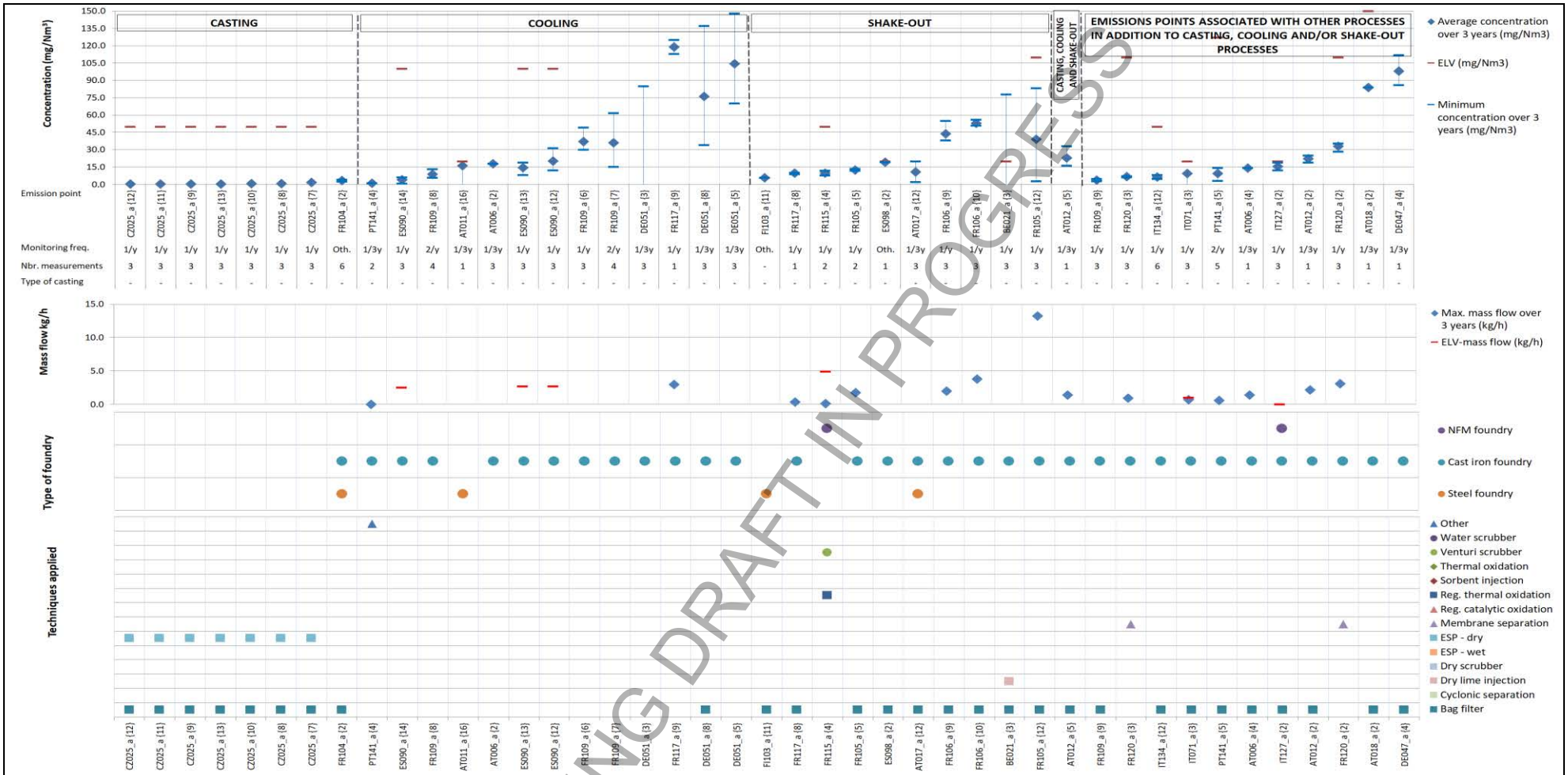
NB: For better visualisation, the ELVs of 5 mg/Nm³ reported by BE022_a {3}, IT134_a {12} and BE022_a {2} are not shown.
Source: [169, TWG 2021]

Figure 2.107:Chromium emissions from casting, cooling and shake-out processes using lost moulds (sorted by type of process)



NB: For better visualisation, the ELVs over 0.04 mg/Nm³ are not shown. The range of ELVs not shown is from 1 mg/Nm³ to 5 mg/Nm³.
Source: [169, TWG 2021]

Figure 2.108:Lead emissions from casting, cooling and shake-out processes using lost moulds (sorted by type of process)



NB: For better visualisation, the ELV reported by PT141_a {4} of 2 000 mg/Nm³ is not shown.
Source: [169, TWG 2021]

Figure 2.109:TVOC emissions from casting, cooling and shake-out processes using lost moulds (sorted by type of process)

2.3.2.8 Alternative casting processes (i.e. lost foam, ceramic shell casting)

2.3.2.8.1 Unbonded sand – lost foam

The inputs/outputs for the lost-foam process using unbonded sand are presented in the following table.

Input	Output
– EPS granulate	– Sand moulds
– EPS glue	– EPS residues
– Refractory coating	– Products of pyrolysis and combustion
– Sand	– Dust

Emission data for organic compounds are given in Table 2.68. These apply to an aluminium lost foam foundry producing 1.5 t/h compared to a green sand foundry producing 1.2 t/h and using 1.9 t/h cold-box cores. The lost foam foundry was equipped with a bag house and a post-combustion unit. The green sand data apply to a unit with bag house filtration. The data show that the lost foam foundry, with the application of more intense flue-gas cleaning, emits higher levels of BTEX and formaldehyde, but a clearly lower level of organic carbon. Post-combustion of the casting off-gases is needed to decompose the products from EPS pyrolysis upon pouring.

Table 2.68: Stack emission data for lost foam and green sand aluminium foundries

Compound	Lost foam foundry	Green sand foundry
Benzene	35.33	8.5
Toluene, xylene, ethylbenzene, styrene	354.67	18.58
Unknown organic compounds	96.67	655.0
Total organic carbon	857.33	1283.33
PAH	1.45	1.43
Formaldehyde	18.00	2.08
Phenol	18.00	69.83
NB: All values in g/tonne molten aluminium. *Source:* [35, Spillner, A. 1997]		

In the SF data collection, three plants (DE078, IT129 and IT130) reported the use of the lost foam process but without specific data on the emission levels from this process. [169, TWG 2021]

[TWG, please provide – if available - additional information and detailed data on the emission levels associated with the Lost Foam process]

A recent study associates the use of the lost foam process with elevated emissions of BTEX, due to the thermal decomposition of expanded polystyrene resulting in benzene-toluene-styrene emissions. [181, Basque Government 2019]. As BTEX compounds are aromatic in nature and, therefore, have a characteristic odour, they are likely to result in odour nuisance in the surrounding area. The reported ambient benzene concentrations were in the range from 1 µg/m^3 to 2.8 µg/m^3 while the reported emission levels were of the order:

- benzene: 290-4 140 µg/m^3;
- toluene: 280-7 600 µg/m^3;
- styrene: 560-3 730 µg/m^3;
- isopropanol: 350-2 330 µg/m^3.

It is noted that the above emission levels are associated with no application of any abatement technique.

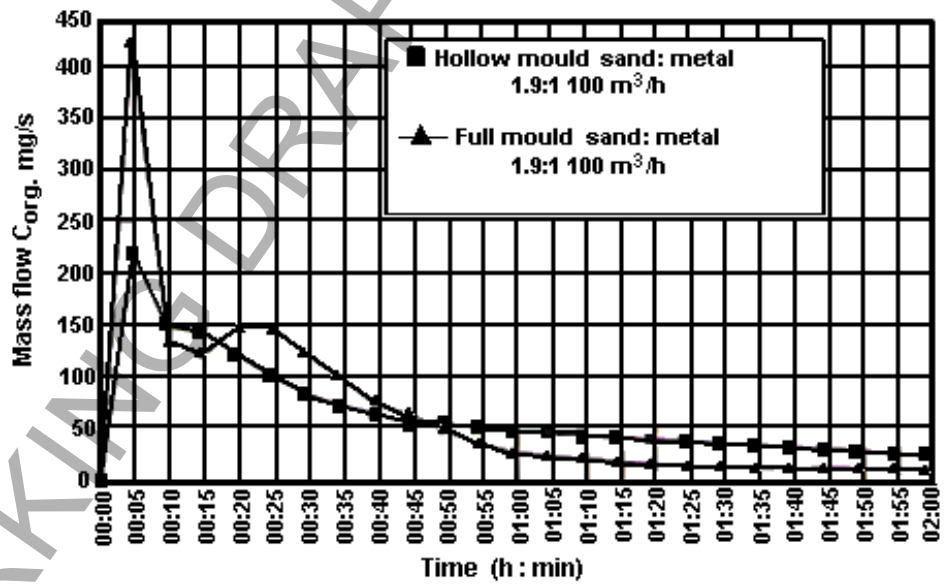
2.3.2.8.2 Chemically bonded sand – full mould

The inputs/outputs for the full mould casting processes are presented in the following table.

Input	Output
– EPS granulate	– Sand moulds
– EPS glue	– EPS residues
– Refractory coating	– Products of pyrolysis and combustion
– Sand	– Dust
– Binders	

The mass flow of emissions from full mould and hollow mould casting processes are to be considered as similar. This can be seen from Figure 2.110 which shows the mass flow of organic carbon as a function of time upon pouring. Time '0:00' corresponds to the starting of the pouring. The data were collected using furan-bonded sands, both for full and hollow mould making.

The full mould process shows a high emission upon pouring and an initial peak emission immediately after pouring which levels off within 1 hour. The hollow mould process shows a lower initial emission, but the levelling off goes slower and takes up to 2 hours. Therefore, the total organic carbon emission over the whole cooling step is equal for both processes. Additional measurements showed that the same profile applies for benzene, ethylbenzene, phenol and furfuryl alcohol. The maximum emission for styrene and toluene occurs after 15-30 minutes. This is due to an initial condensation of the molecules on the colder parts of the mould. [113, Müller, G. 1996]



Source: [113, Müller, G. 1996]

Figure 2.110: Waste gas load upon pouring in full and hollow moulds (cast alloy: lamellar iron; mould: furan-bonded sand; 1.9 tonne sand: 1 tonne Fe)

2.3.2.8.3 Ceramic shell casting

No plants in the SF data collection reported the use of the ceramic shell casting technique.
[TWG please provide any available information-data for plants applying this technique]

2.3.2.9 Casting in permanent moulds

The inputs/outputs for the casting process in permanent moulds are presented in the following table.

Input	Output
- Water-based release agent - Cooling water - Molten metal - Cores	– Casting – Oily mist from release agent spraying – Organic pollutants from thermal degradation of core binder – Metal oxide containing dusts from holding furnace – Dust from shake-out of cores – Waste water

Mass balance data for three different foundries using pressure die-casting of molten aluminium are given in Table 2.69.

Table 2.69: Mass balance data including inputs, exhaust gas and effluent compositions for three aluminium pressure die-casting foundries

	Foundry A	Foundry B	Foundry C
Input			
Water	802 l/tonne	935 l/tonne	1709 l/tonne
Release agent	16 l/tonne	8.26 l/tonne	1.12 l/tonne
Electricity	1 103 kWh/tonne	1 380 kWh/tonne	652 kWh/tonne
Output			
Waste water[1] COD pH SS Oil and grease BOD_5 Al	 18 000 mg/l 7.5 1 300 mg/l 3 000 mg/l 2 000 mg/l 5 mg/l	122 l/tonne	 126 mg/l 7.5 1 mg/l 1 mg/l (total hydrocarbons) 78 mg/l 0.6 mg/l
Exhaust gas NOx VOC Dust		 0.006 kg/tonne 0.28 kg/tonne 1.8 kg/tonne	 0.14 – 0.27 kg/tonne 0.030 – 0.16 kg/tonne

All values are expressed per tonne of good casting or in mg/l effluent.
[1] For foundry C, waste water quality after treatment consists in a distilling plant and cooling-evaporation towers.
Source: [76, Silva Ribeiro, C. A. 2002], [100, TWG 2002]

In ~~current~~ die-casting ~~practice~~, water-based release agents are sprayed on the open die, after dilution to a 1:50 – 1:200 ratio. Besides die coating, this spraying is used for die cooling. This explains the difference in water use displayed in the table. This practice causes a loss and spillage of water, and an up to 40 % water/agent leakage into the foundry waste water system.

Emission and consumption levels for permanent moulding processes depend on the type of alloy used, the surface area of the melt, the quantity of the sand cores which are inserted in the mould, and the surface/volume rate of the casting. The sand cores are the main sources of emissions. There is no important difference between the different casting techniques. Due to the wide variety of processes and applications, it is not possible to give average data. [100, TWG 2002]

Electricity consumption depends on process aspects, such as the closing force of the die, which are chosen on technical grounds.

Emission factors for the casting of bronze, brass and zamac as used in Belgium are given in Table 2.70.

Table 2.70: Indicative emission factors for casting of bronze, brass and zamac

Alloy	CuO	SnO	PbO	ZnO	Al_2O_3	MnO
Bronze	0.06	0.04	2 – 20	625 – 6 250	n.a	n.a
Brass	0.01	n.a	0.007 – 1	125 – 21 500	n.a	n.a
Zamac	n.a	n.a	n.a	0.004	0.2	0.01
All data are expressed in g/tonne molten metal. *Source:* [38, VITO 2001]						

2.3.2.9.1 Dust emissions

The reported levels of dust emissions to air from casting in permanent moulds are presented in Figure 2.111 and Figure 2.112.

Some statistical data on the reported dust emission data are presented in the following table.

Table 2.71: Statistical evaluation of the reported dust emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Dust	120	50	27	6.65	2.80	1.45	0.29
NB: The data above refer to EPs that are associated with the casting process in permanent moulds only. *Source:* [169, TWG 2021]							

2.3.2.9.2 Benzene emissions

The reported levels of benzene emissions to air from casting in permanent moulds are presented in Figure 2.113.

Some statistical data on the reported benzene emission data are presented in the following table.

Table 2.72: Statistical evaluation of the reported benzene emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Benzene	64	23	20	3.48	1.53	1.1	0.236
NB: The data above refer to EPs that are associated with the casting process in permanent moulds only. *Source:* [169, TWG 2021]							

2.3.2.9.3 TVOC emissions

Reported levels of TVOC emissions to air from casting in permanent moulds are presented in Figure 2.114.

Some statistical data of reported TVOC emission data are presented in the following table.

Table 2.73: Statistical evaluation of the reported TVOC emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
TVOC	97	35	25	54.48	25.08	17.10	3.07
NB: The data above refer to EPs that are associated with the casting process in permanent moulds only. *Source:* [169, TWG 2021]							

2.3.2.9.4 Lead (Pb) emissions

Reported levels of Pb emissions to air from casting in permanent moulds are presented in Figure 2.115.

Some statistical data on the reported Pb emission data are presented in the following table.

Table 2.74: Statistical evaluation of the reported Pb emission data

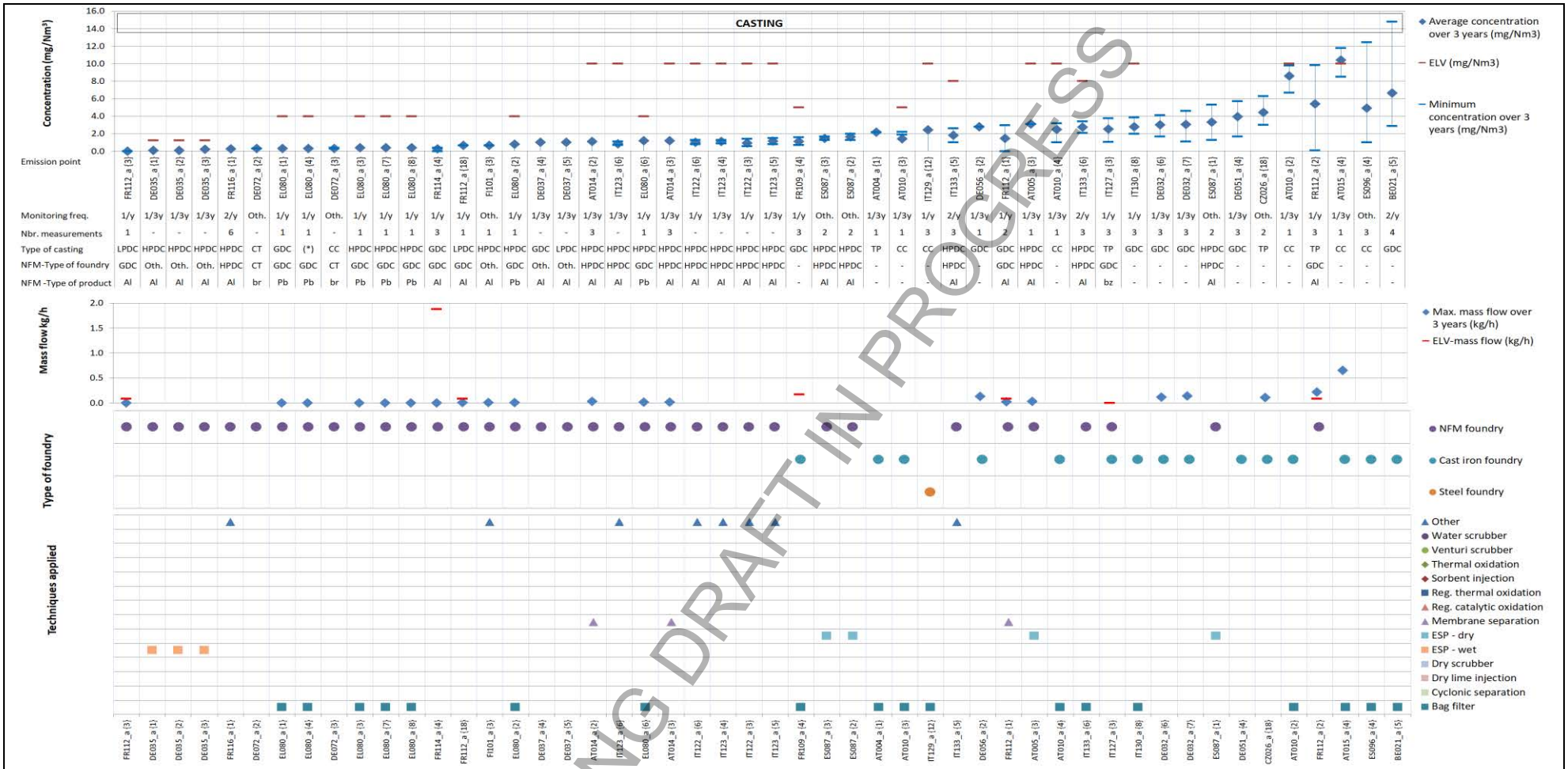
Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Lead (Pb)	37	21	11	0.189	0.065	0.0104	0.00015
NB: The data above refer to EPs that are associated with the casting process in permanent moulds only. *Source:* [169, TWG 2021]							

2.3.2.9.5 Phenol emissions

Reported levels of phenol emissions to air from casting in permanent moulds are presented in Figure 2.116.

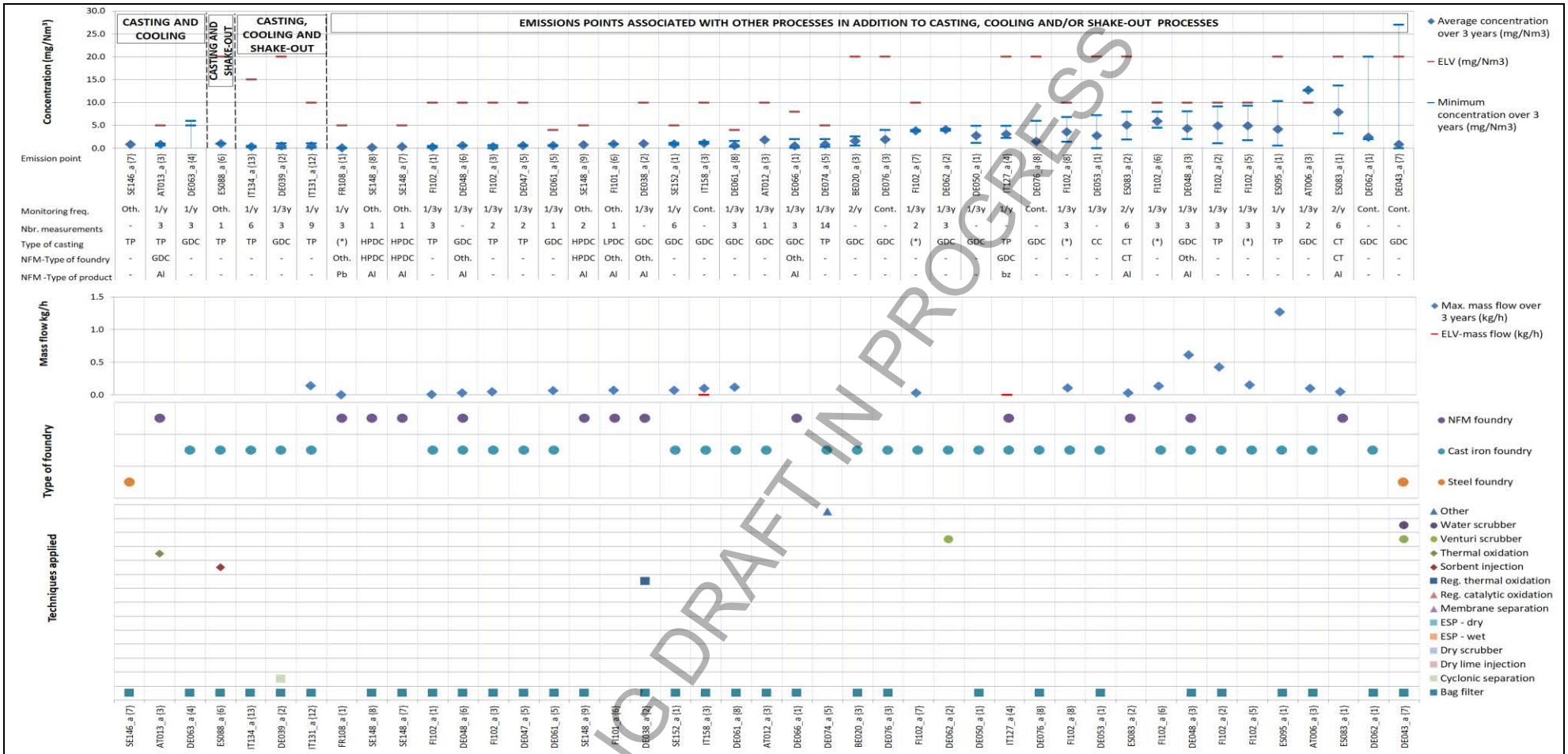
2.3.2.9.6 Figures for emissions to air

The structure of figures presented in this section is explained in Section 2.3.2.1.10.



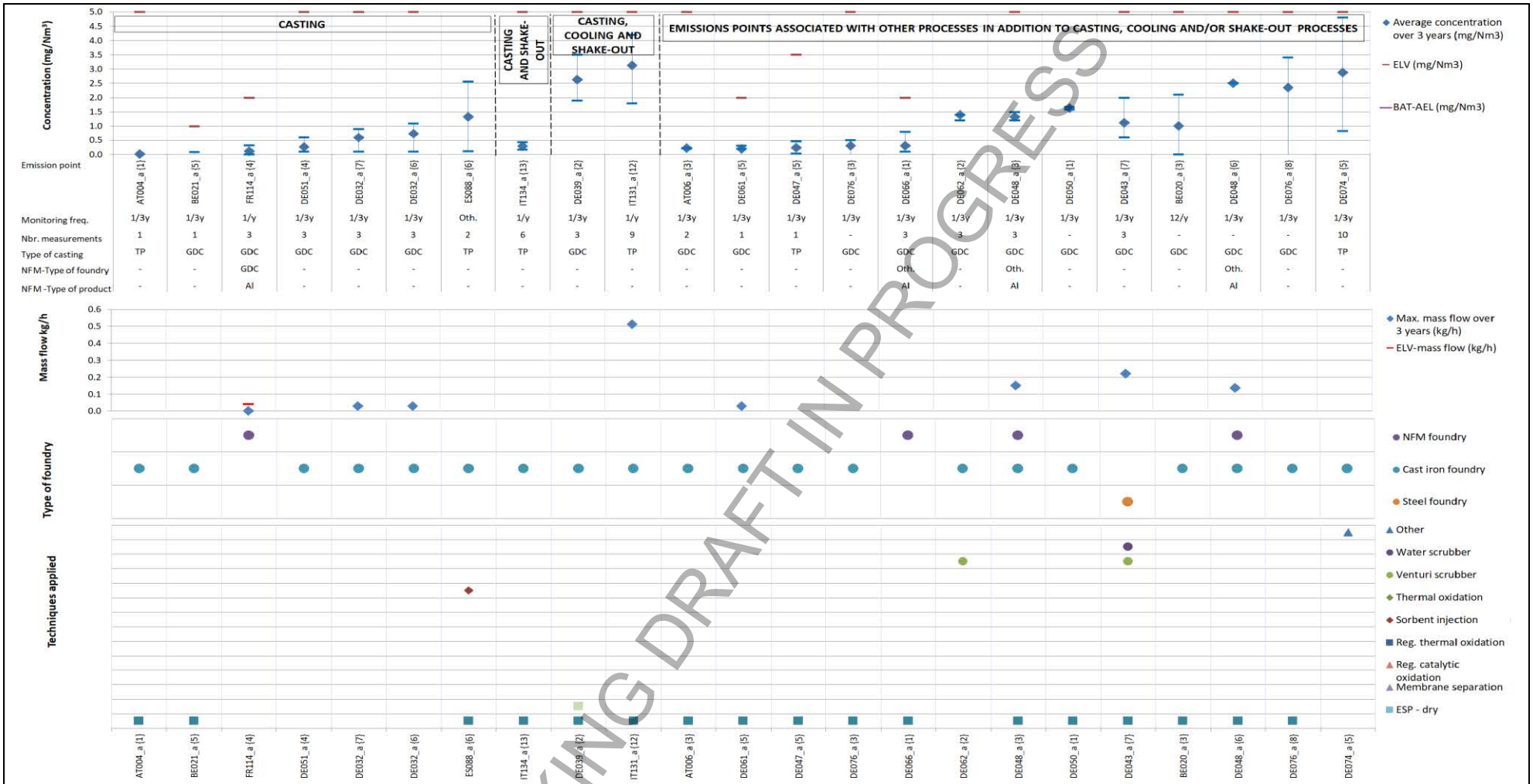
NB: For better visualisation, the ELVs of 20 mg/Nm³ are not shown.
Source: [169, TWG 2021]

Figure 2.111:Dust emissions from the casting process in permanent moulds (1/2)



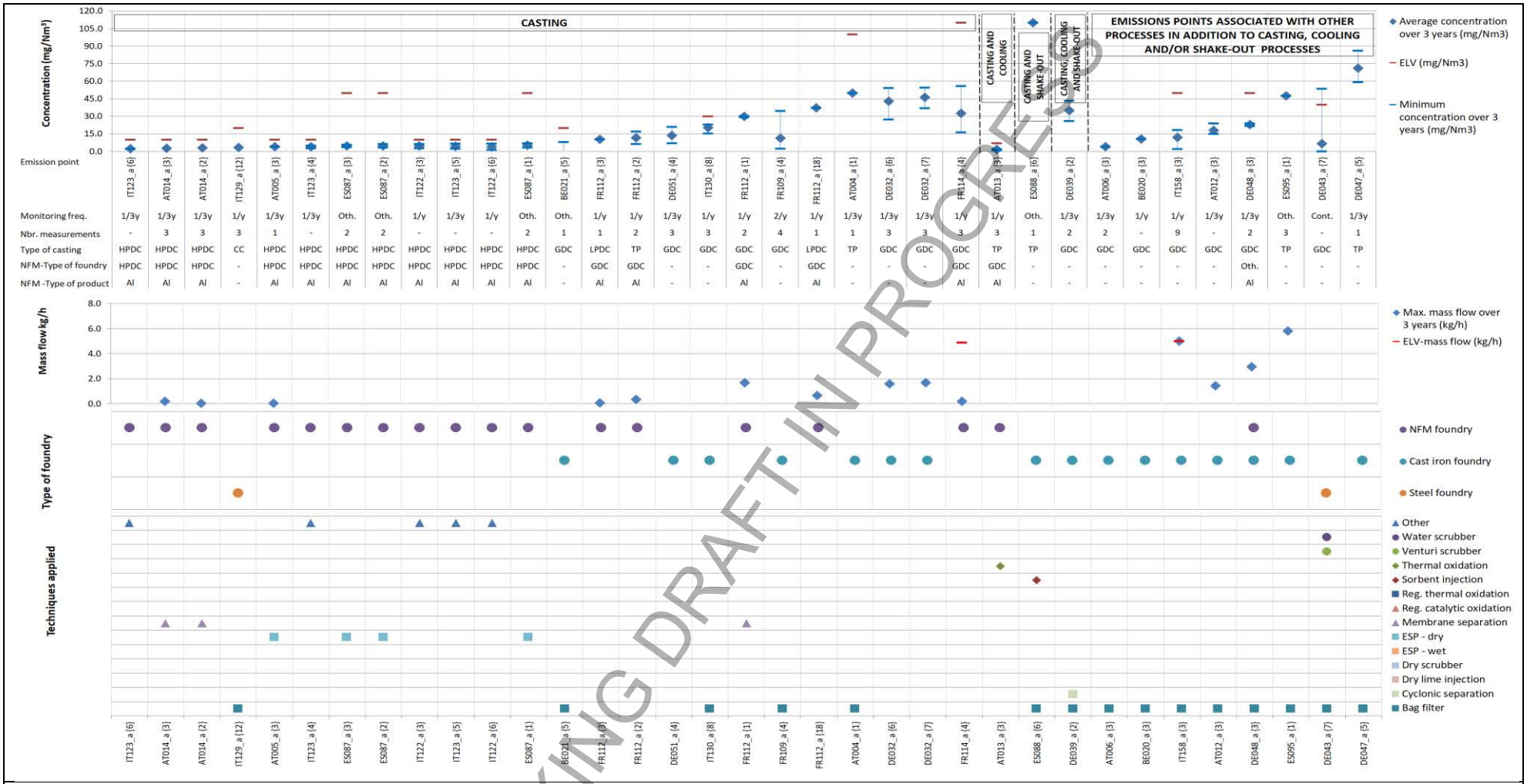
NB: (*) FR108_a {1} reported the following types of casting: Gravity casting - Low-pressure die-casting - Centrifugal casting.
(*) FI102_a {7}, FI102_a {8}, FI102_a {6} and FI102_a {5} reported the following types of casting: Tilt pouring - Gravity casting.
Source: [169, TWG 2021]

Figure 2.112:Dust emissions from the casting process in permanent moulds (2/2)



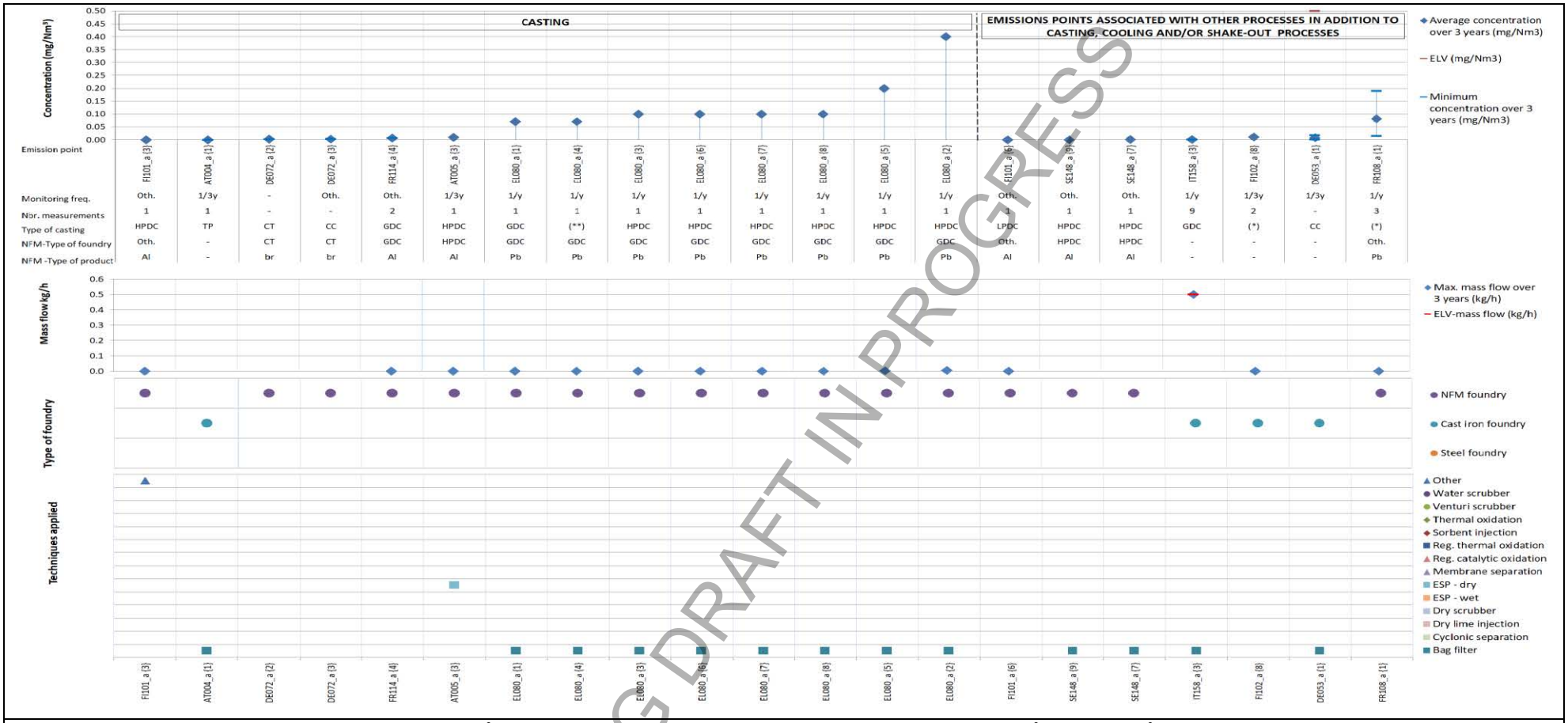
Source: [169, TWG 2021]

Figure 2.113:Benzene emissions from the casting process in permanent moulds



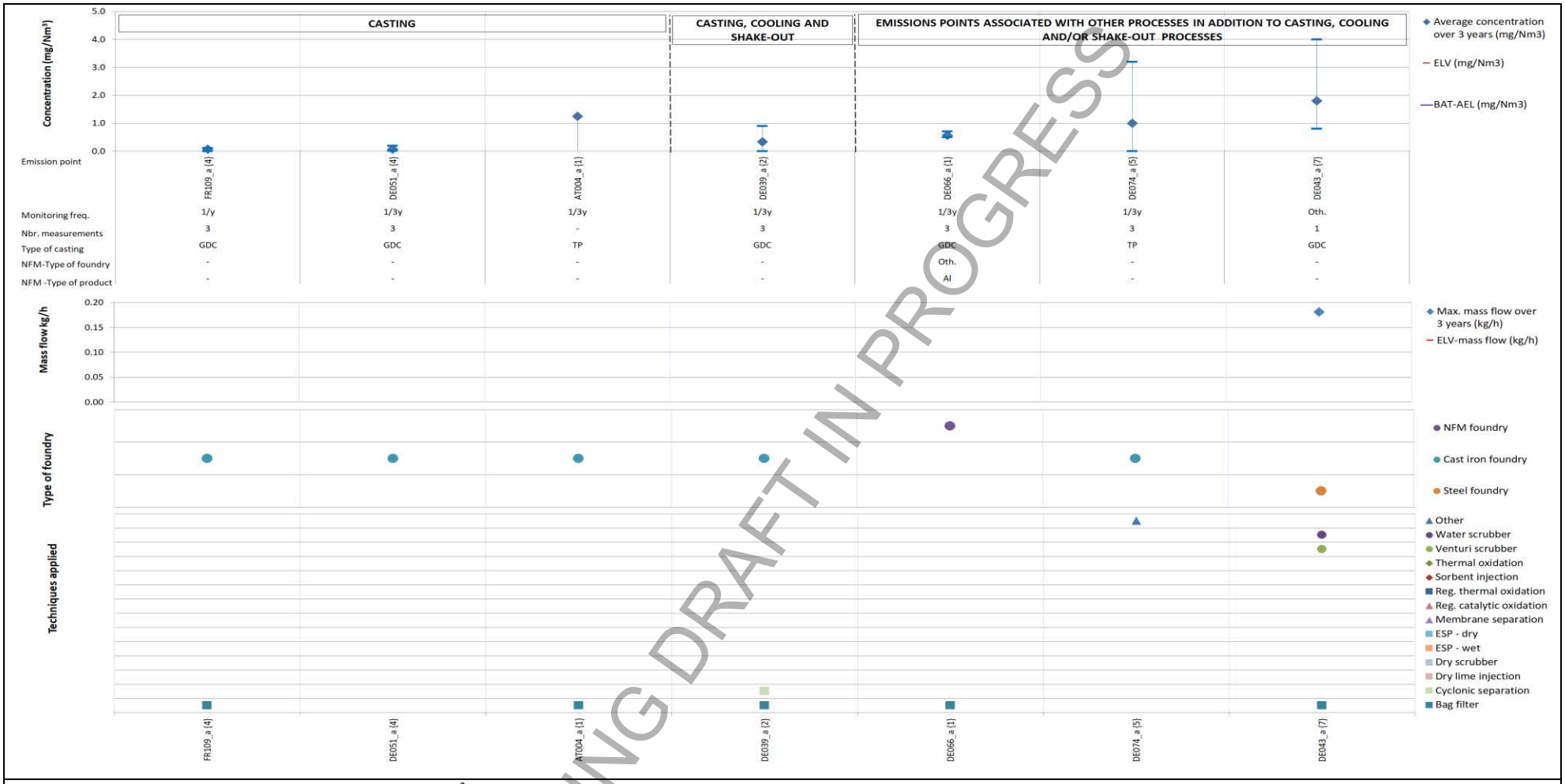
Source: [169, TWG 2021]

Figure 2.114:TVOC emissions from the casting process in permanent moulds



NB: For better visualisation, the ELVs over 0.5 mg/Nm³ are not shown. The range of ELVs not shown is from 1 mg/Nm³ to 5 mg/Nm³.
(*) FR108_a {1} reported the following types of casting: Gravity casting - Low-pressure die-casting - Centrifugal casting.
(*) FI102_a {8} reported the following types of casting: Tilt pouring - Gravity casting.
(**) Pending to confirm by the MS the type of casting.
Source: [169, TWG 2021]

Figure 2.115:Pb emissions from the casting process in permanent moulds



NB: For better visualisation, the ELVs of 20 mg/Nm^3 are not shown.
Source: [169, TWG 2021]

Figure 2.116:Phenol emissions from the casting process in permanent moulds

2.3.2.10 Finishing

In foundries, finishing includes a number of mechanical operations carried out after the casting process including deburring, abrasive cutting, chiselling, needling, fettling, slide grinding, shot blasting and welding.

The inputs/outputs for the finishing process are presented in the following table.

Input	Output
- Unfinished castings - Abrasives - Water, soap - Electricity	– Finished castings – Dust (*sand, metal particles*) from mechanical operations – Volatised metals, combustion products from thermal operations – Waste water

2.3.2.10.1 Dust emissions

The reported levels of dust emissions to air from finishing are presented in Figure 2.117, Figure 2.118, Figure 2.119 and Figure 2.120.

Some statistical data on the reported dust emission data are presented in the following table.

Table 2.75: Statistical evaluation of the reported dust emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Dust	427	199	78	10.75	2.77	1.22	0.20
NB: The data above refer to EPs that are associated with finishing only. *Source:* [169, TWG 2021]							

2.3.2.10.2 TVOC emissions

The reported levels of TVOC emissions to air from finishing are presented in Figure 2.121.

Some statistical data on the reported TVOC emission data are presented in the following table.

Table 2.76: Statistical evaluation of the reported TVOC emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
TVOC	18	12	6	5.08	3.62	3.80	2.16
NB: The data above refer to EPs that are associated with finishing only. *Source:* [169, TWG 2021]							

2.3.2.10.3 Lead (Pb) emissions

The reported levels of Pb emissions to air from finishing are presented in Figure 2.122.

Some statistical data on the reported Pb emission data are presented in the following table.

Table 2.77: Statistical evaluation of the reported Pb emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Lead (Pb)	29	18	7	0.009	0.0041	0.0018	0.00036
NB: The data above refer to EPs that are associated with finishing only. *Source:* [169, TWG 2021]							

2.3.2.10.4 Nickel (Ni) emissions

The reported levels of Ni emissions to air from finishing are presented in Figure 2.123.

Some statistical data on the reported Ni emission data are presented in the following table.

Table 2.78: Statistical evaluation of the reported Ni emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Nickel (Ni)	44	23	10	0.01225	0.0047	0.0025	0.000643
NB: The data above refer to EPs that are associated with finishing only. *Source:* [169, TWG 2021]							

2.3.2.10.5 Cadmium (Cd) emissions

The reported levels of Cd emissions to air from finishing are presented in Figure 2.124.

Some statistical data on the reported Cd emission data are presented in the following table.

Table 2.79: Statistical evaluation of the reported Cd emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Cadmium (Cd)	29	18	7	0.00134	0.0005	0.0002	0
NB: The data above refer to EPs that are associated with finishing only. *Source:* [169, TWG 2021]							

2.3.2.10.6 Chromium (Cr) emissions

The reported levels of Cr emissions to air from finishing are presented in Figure 2.125.

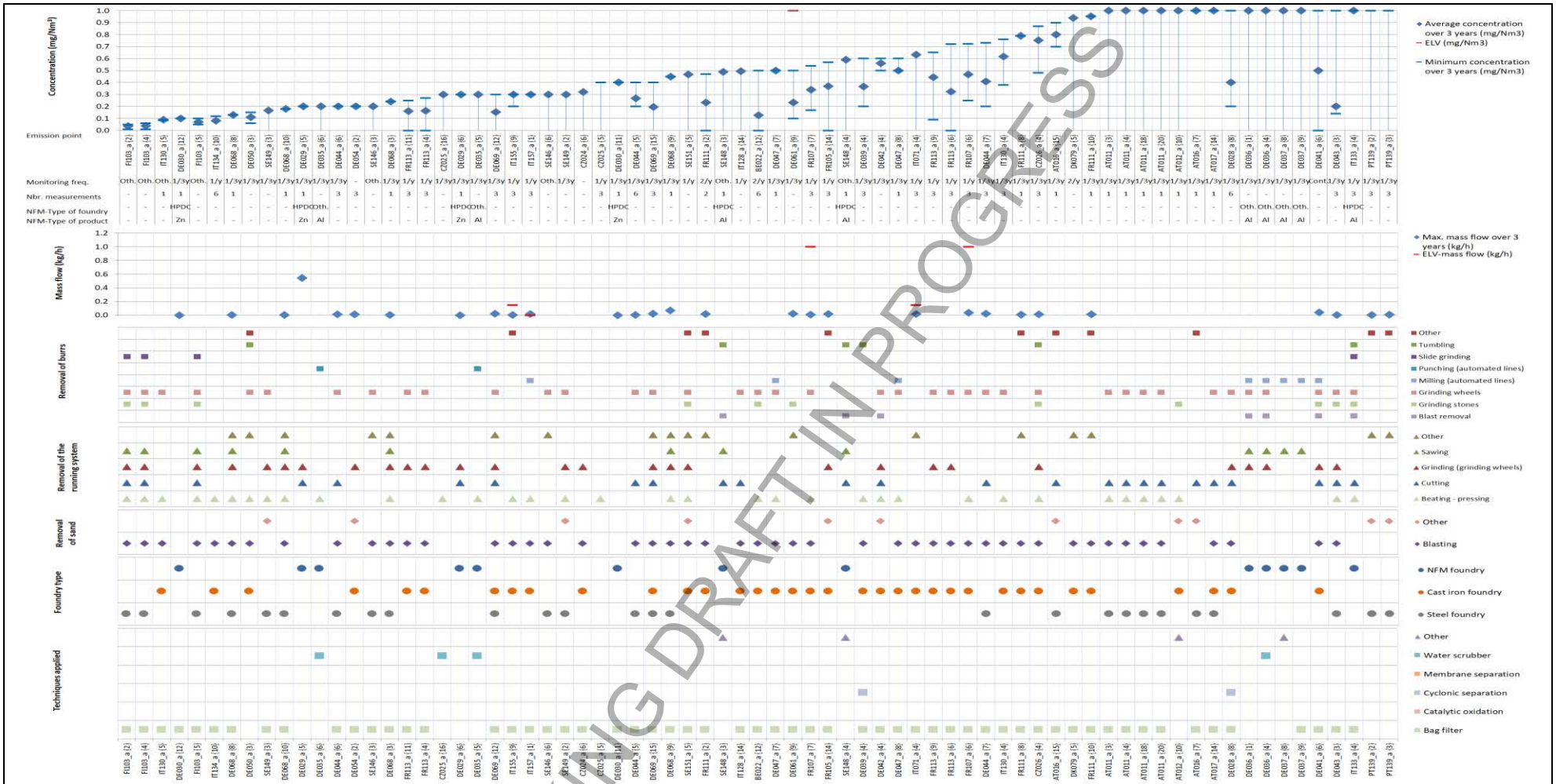
Some statistical data on the reported Cr emission data are presented in the following table.

Table 2.80: Statistical evaluation of the reported Cr emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Chromium (Cr)	41	21	9	0.0743	0.0283	0.0134	0.001
NB: The data above refer to EPs that are associated with finishing only. *Source:* [169, TWG 2021]							

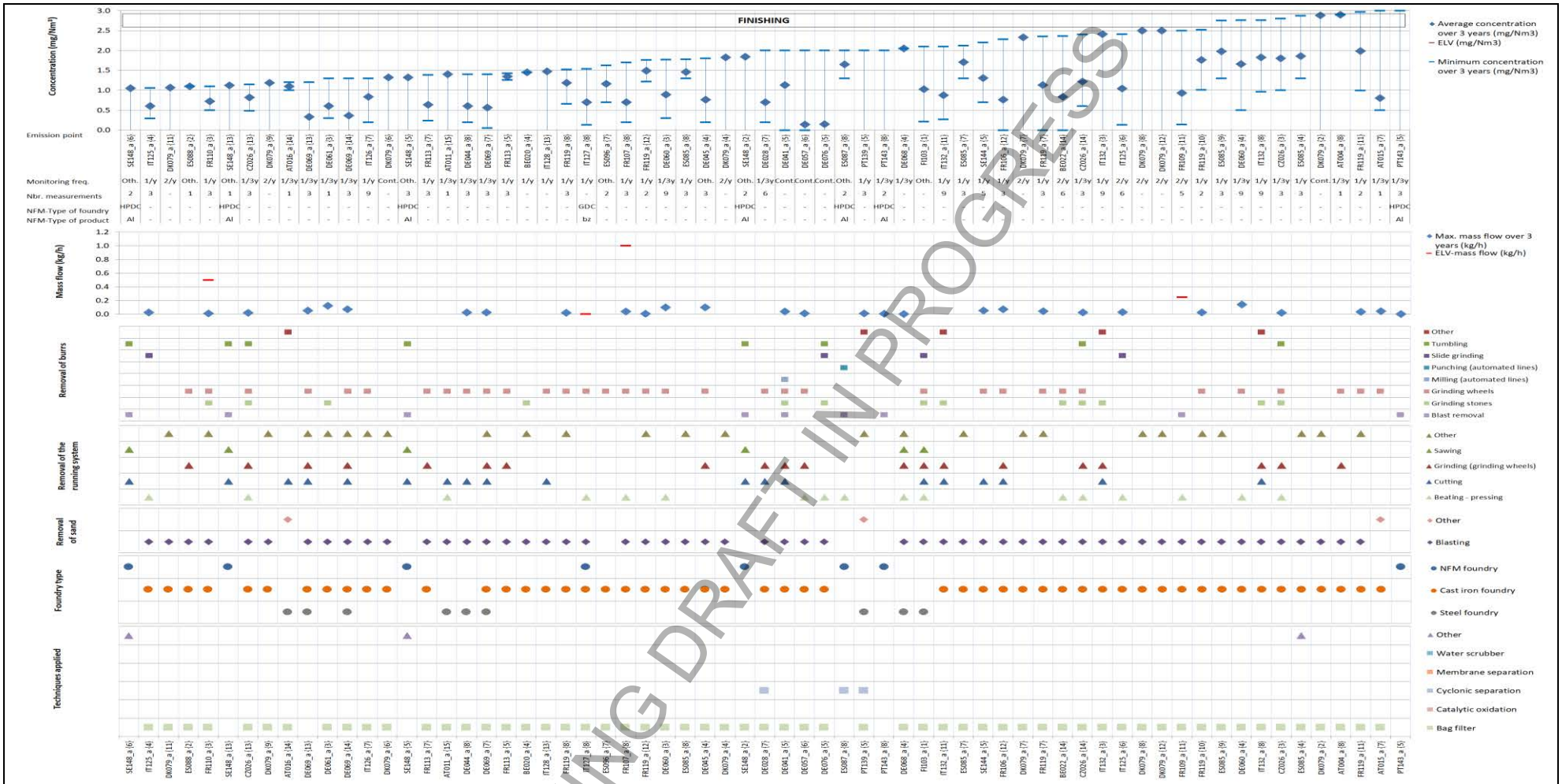
2.3.2.10.7 Figures for emissions to air

The structure of figures presented in this section is explained in Section 2.3.2.1.10.



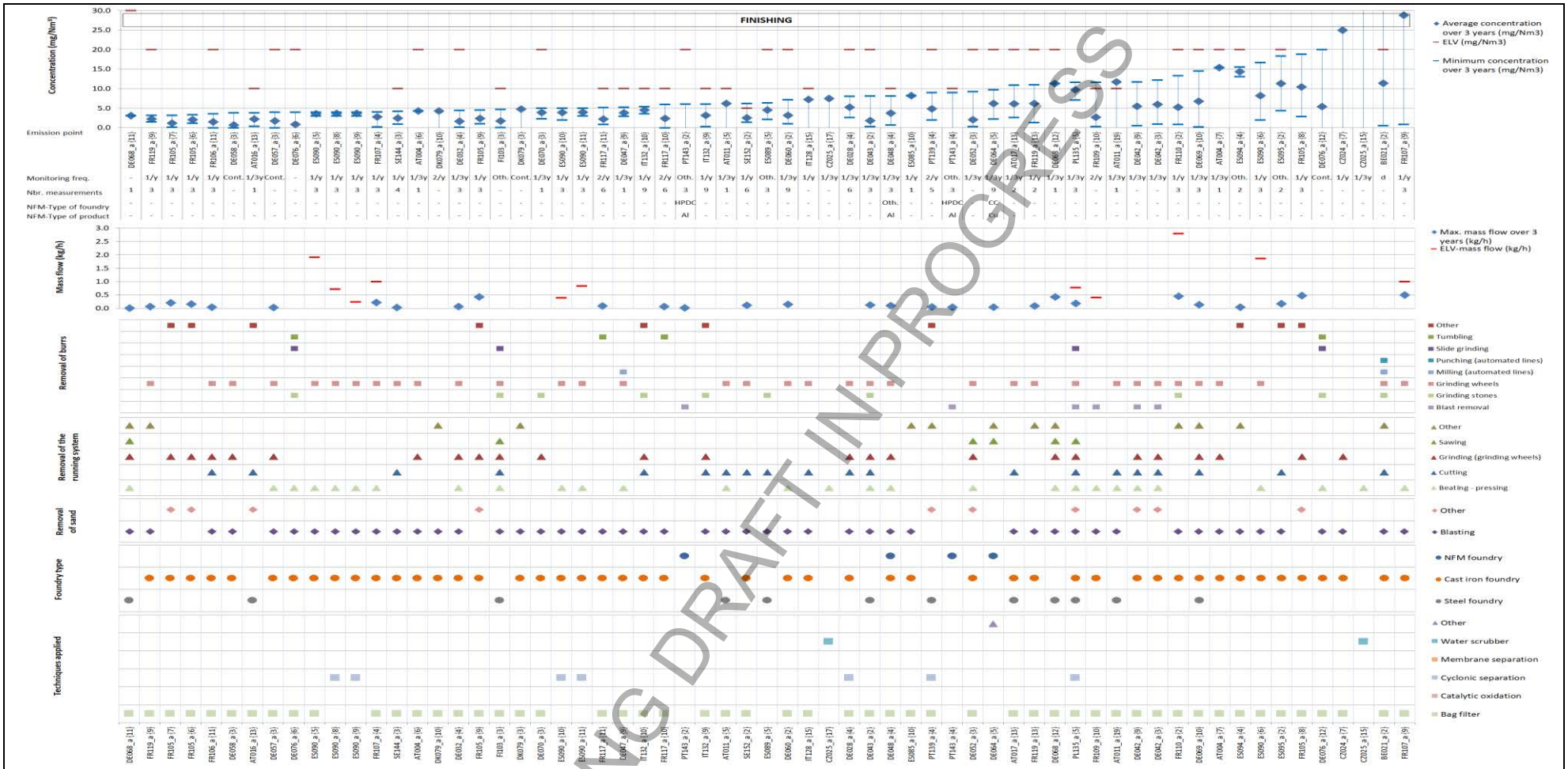
NB: For better visualisation, the ELVs over 1 mg/Nm³ are not shown. The range of ELVs not shown is from 5 mg/Nm³ to 100 mg/Nm³.
Source: [169, TWG 2021]

Figure 2.117:Dust emissions from finishing (sorted by type of process) (1/4)



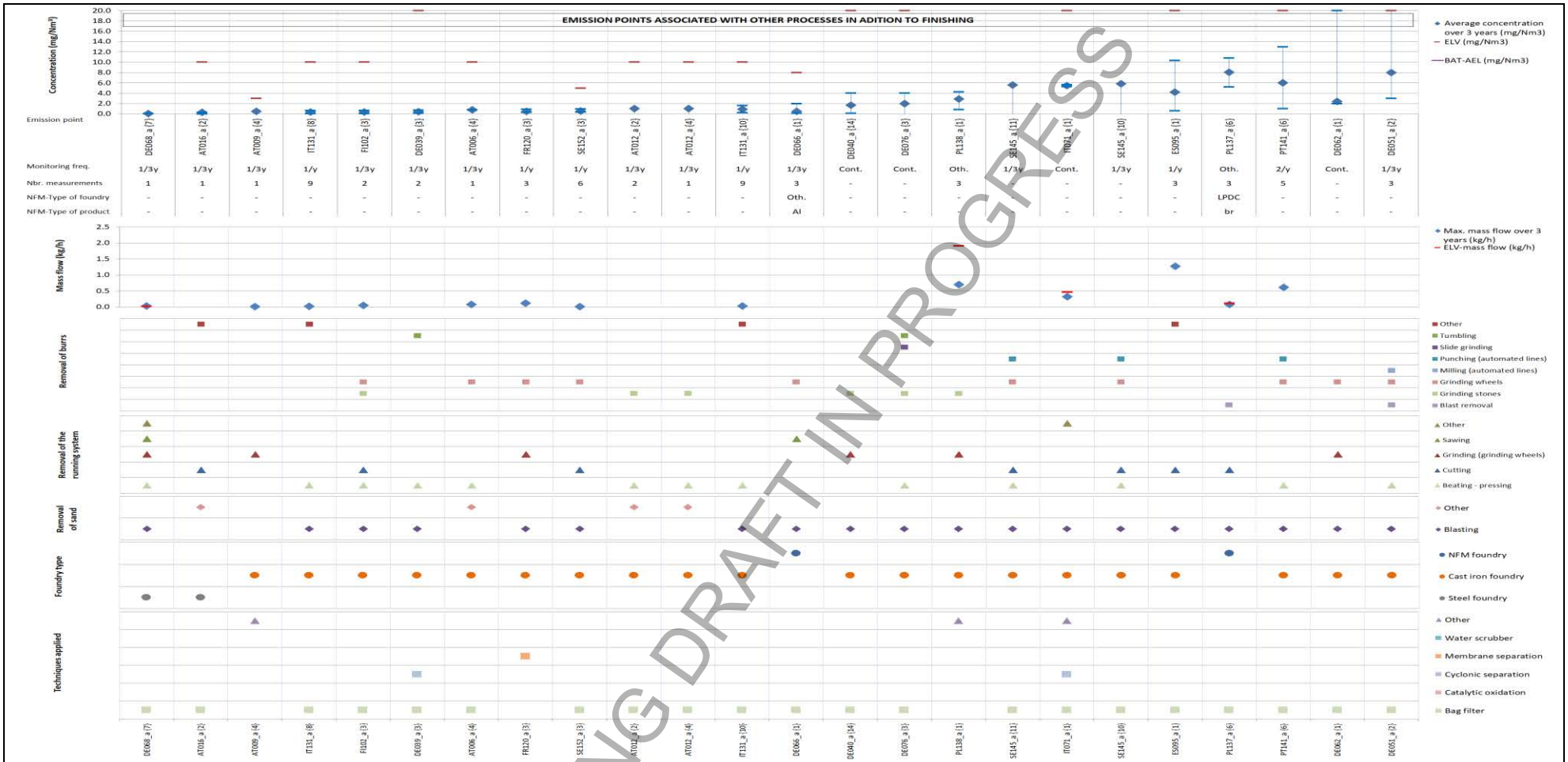
NB: For better visualisation, the ELVs over 3 mg/Nm³ are not shown. The range of ELVs not shown is from 4 mg/Nm³ to 100 mg/Nm³.
Source: [169, TWG 2021]

Figure 2.118:Dust emissions from finishing (sorted by type of process) (2/4)



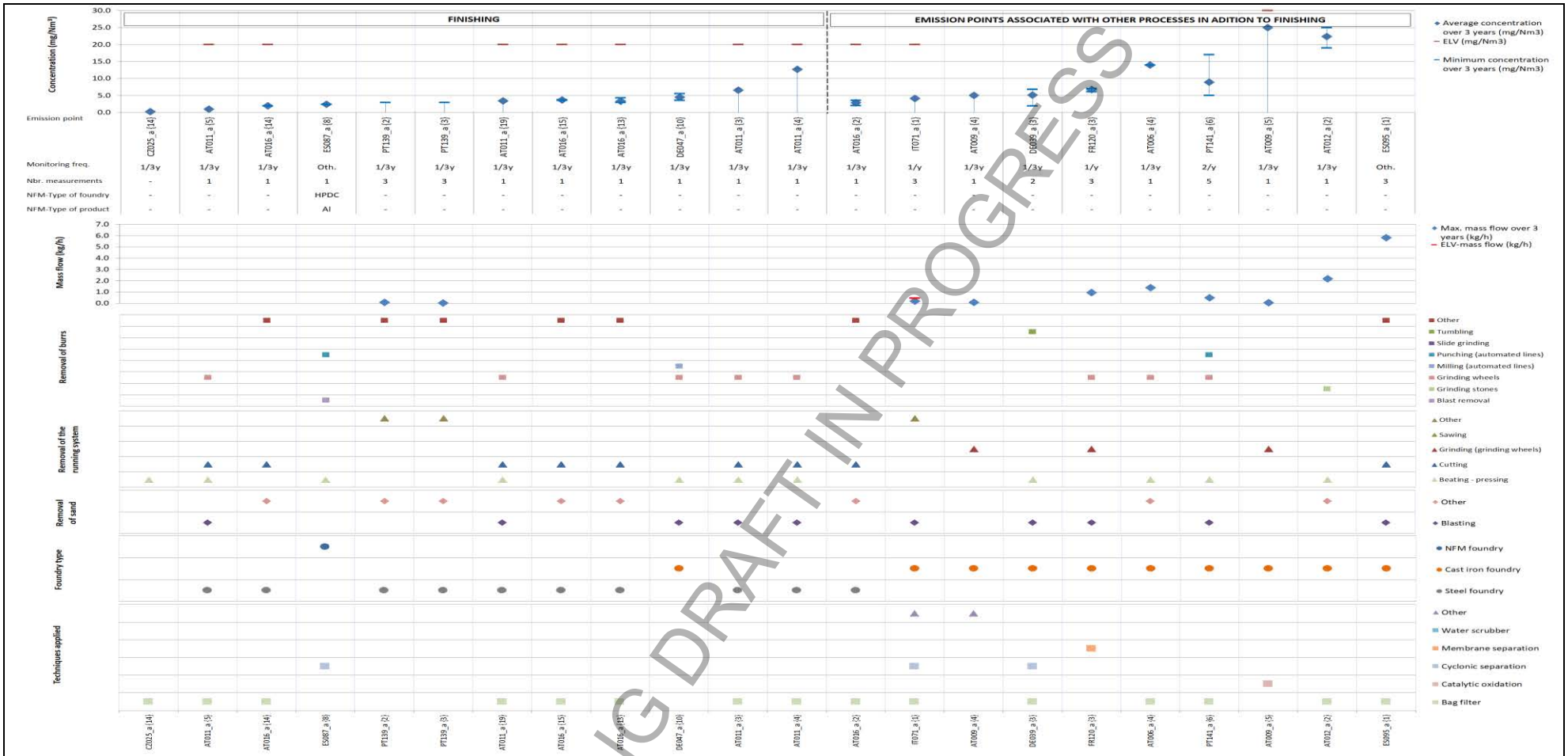
NB: For better visualisation, the ELVs over 3 mg/Nm³ are not shown. The range of ELVs not shown is from 4 mg/Nm³ to 100 mg/Nm³. In addition, the values reported by CZ025_a {15} (avg. = 35.6 mg/Nm³), BE021_a {2} (max. = 41.5 mg/Nm³) and FR107_a {9} (max. = 62.3 mg/Nm³) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.119:Dust emissions from finishing (sorted by type of process) (3/4)



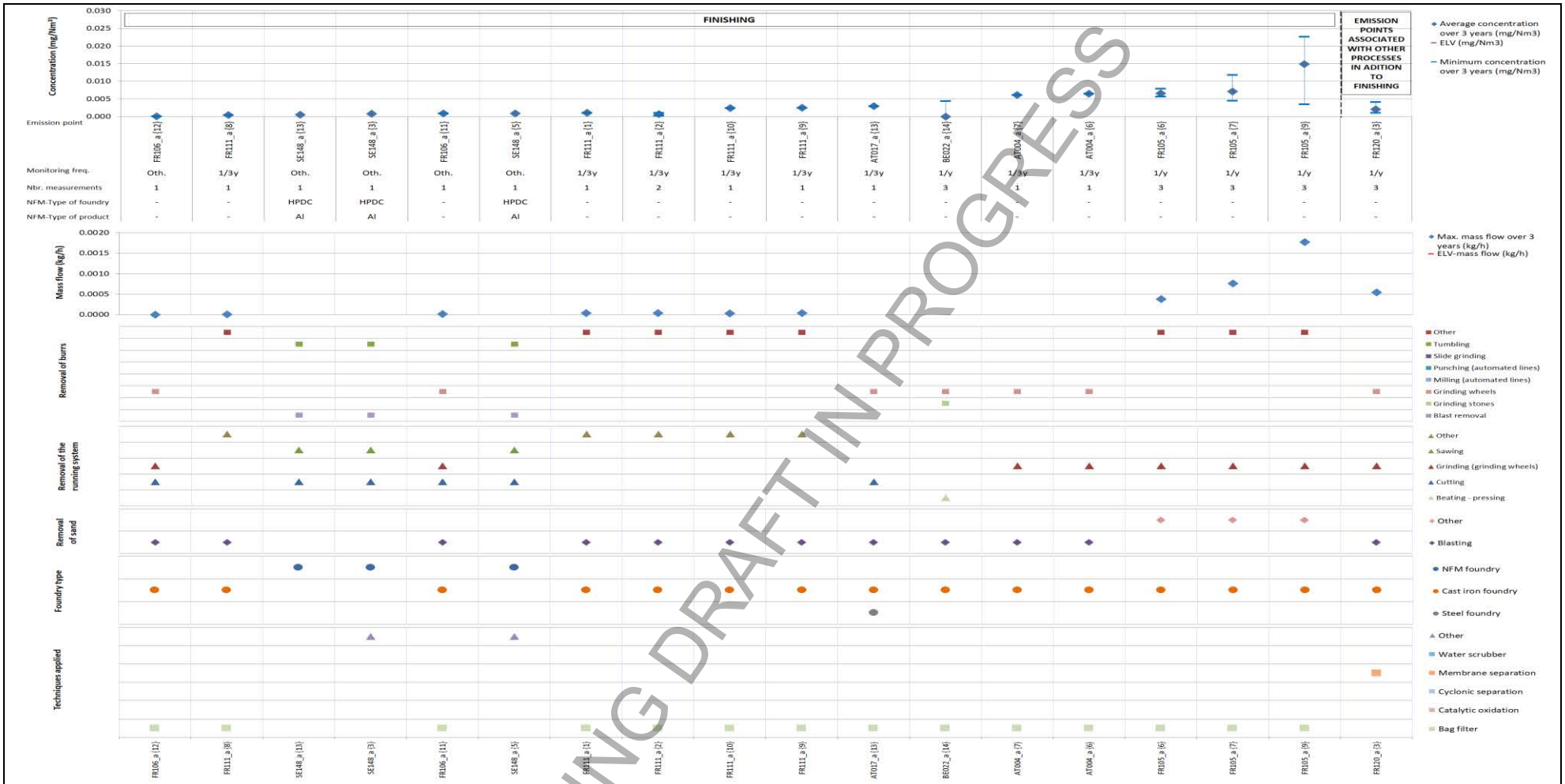
NB: For better visualisation, the ELVs (20 mg/Nm^3) reported by FR120_a {3} is not shown.
For better visualisation, the value reported by DE051_a {2} (max. = 20.9 mg/Nm^3) is not shown in the figure.
Source: [169, TWG 2021]

Figure 2.120:Dust emissions from finishing (sorted by type of process) (4/4)



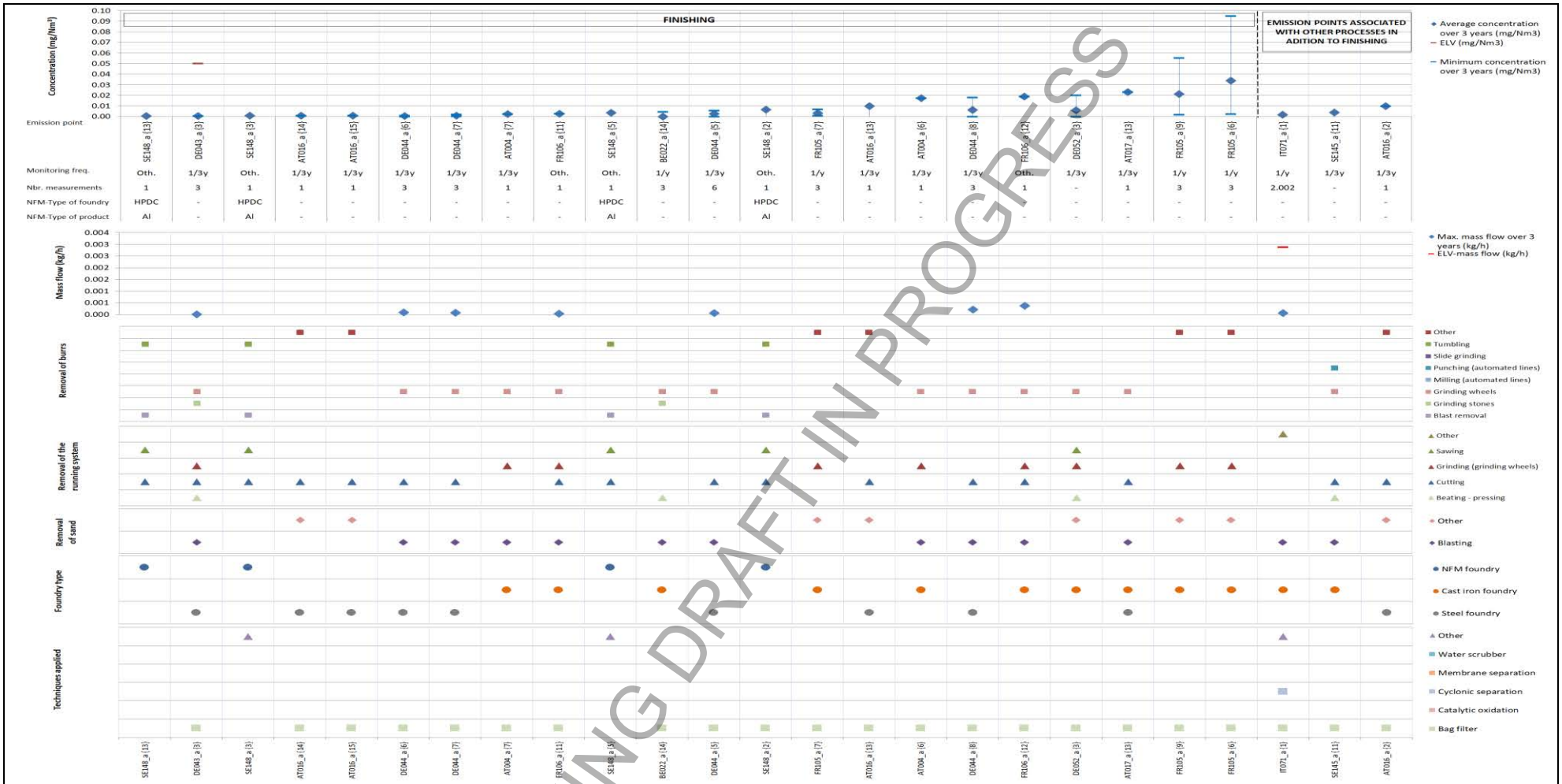
NB: For better visualisation, the ELVs over 30 mg/Nm³ are not shown. The range of ELVs not shown is from 50 mg/Nm³ to 200 mg/Nm³.
For better visualisation, the values reported by ES095_a {1} (min. = 47.7 mg/Nm³, avg. = 47.7 mg/Nm3, max. = 47.7 mg/Nm³) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.121:TVOC emissions from finishing (sorted by type of process)



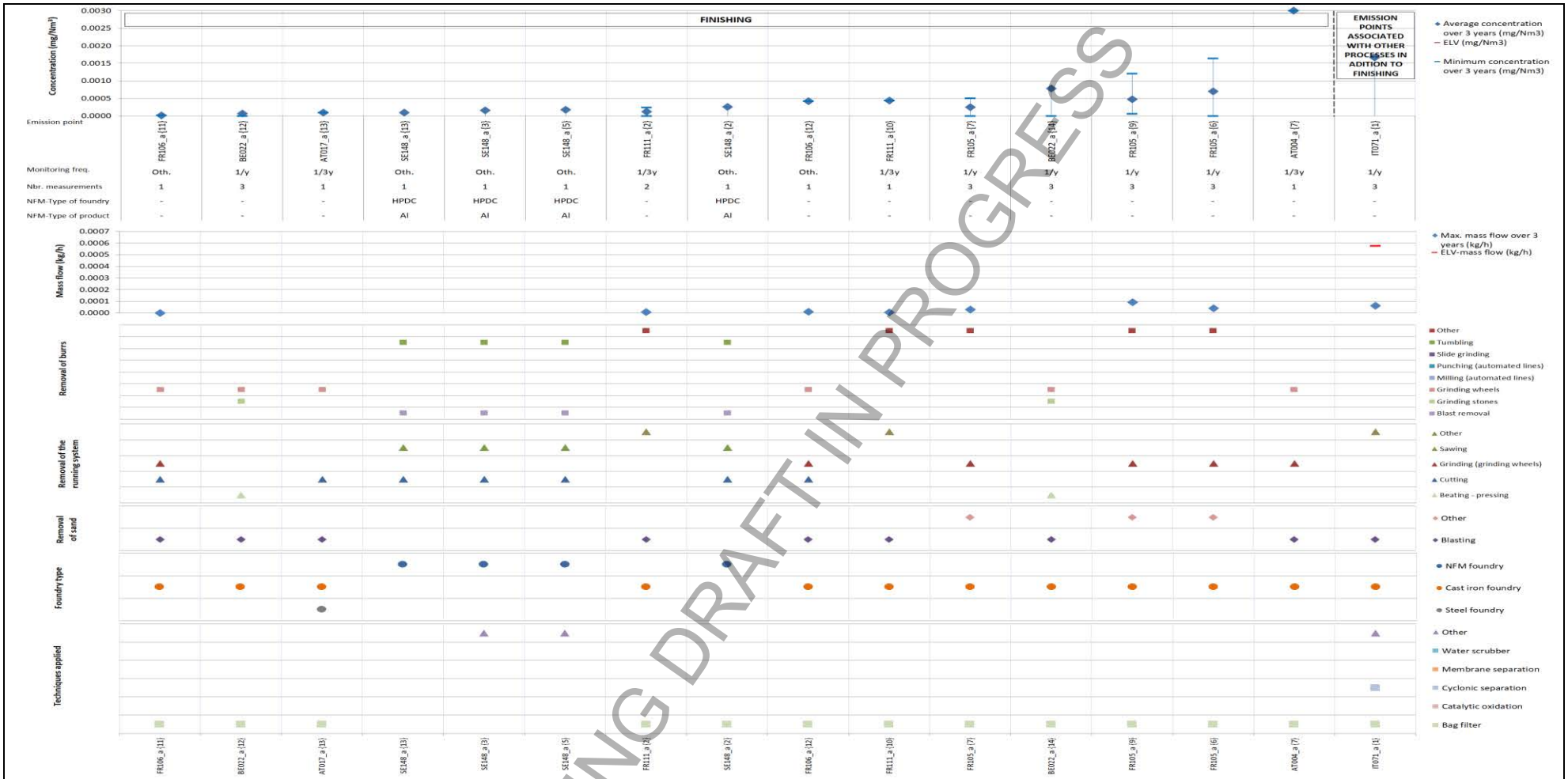
NB: For better visualisation, the ELVs over 0.03 mg/Nm³ are not shown. The range of ELVs not shown is from 1 mg/Nm³ to 5 mg/Nm³.
Source: [169, TWG 2021]

Figure 2.122:Pb emissions from finishing (sorted by type of process)



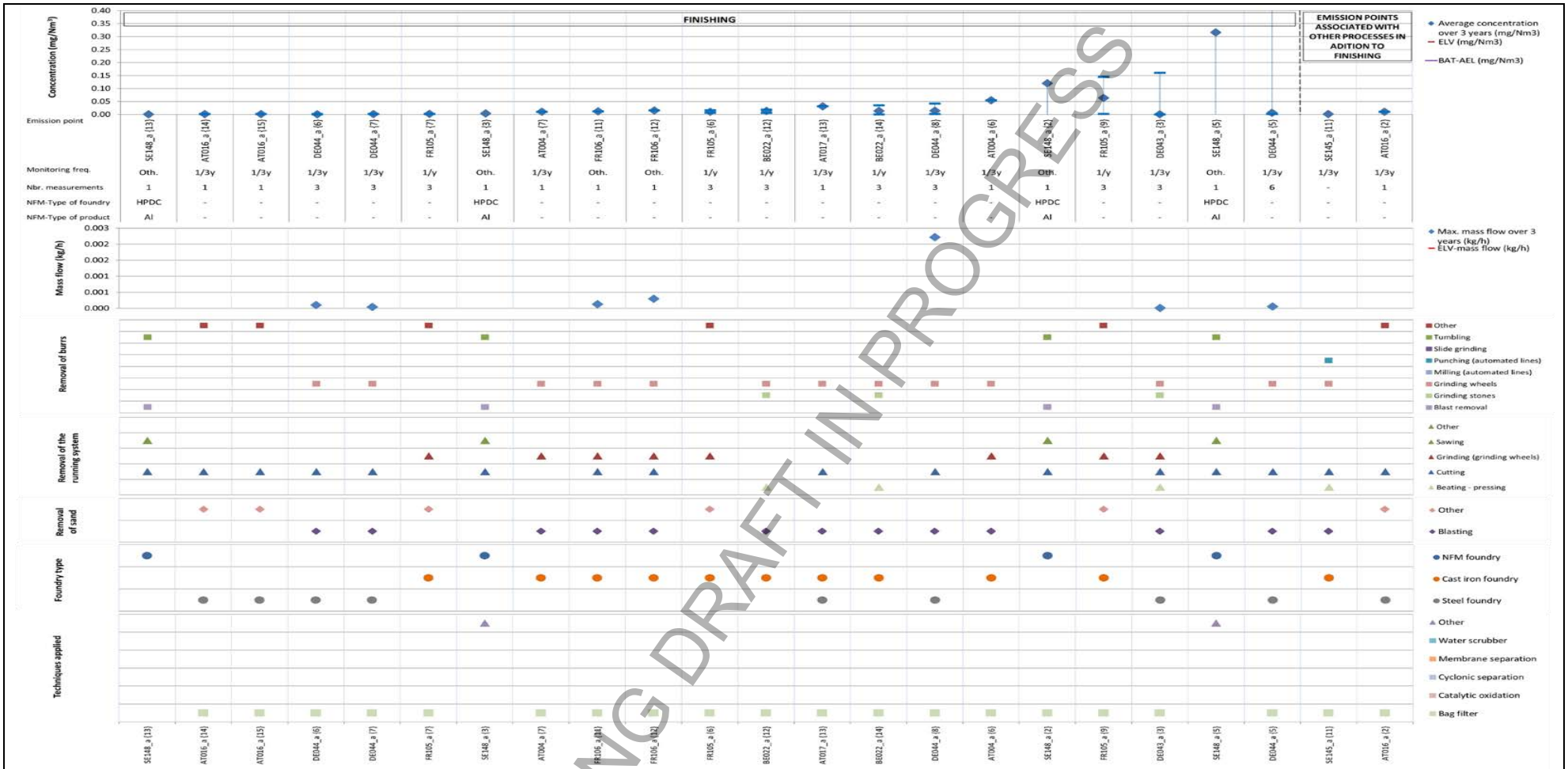
NB: For better visualisation, the ELVs over 0.1 mg/Nm^3 are not shown. The range of ELVs not shown is from 0.125 mg/Nm^3 to 1 mg/Nm^3.
Source: [169, TWG 2021]

Figure 2.123:Ni emissions from finishing (sorted by type of process)



NB: For better visualisation, the ELVs over 0.003 mg/Nm^3 are not shown. The range of ELVs not shown is from 0.05 mg/Nm^3 to 0.2 mg/Nm^3.
Source: [169, TWG 2021]

Figure 2.124:Cd emissions from finishing (sorted by type of process)



NB: For better visualisation, the ELVs over 0.4 mg/Nm^3 are not shown. The range of ELVs not shown is from 1 mg/Nm^3 to 5 mg/Nm^3.
For better visualisation, the value reported by DE044_a {5} (max. = 2 mg/Nm^3) is not shown in the figure.
Source: [169, TWG 2021]

Figure 2.125: Cr emissions from finishing (sorted by type of process)

2.3.2.11 Sand reconditioning and regeneration

In the following sections, emission data for the sand reconditioning (preparation) and regeneration processes are presented.

In this document, sand reconditioning refers to any mechanical operation associated with the preparation and reconditioning of green and/or natural sand. This includes screening, removing tramp metal, separating and removing fines and oversized agglomerates. The sand is then cooled and sent to storage/reuse.

On the other hand, sand regeneration refers to any mechanical and/or thermal operation associated with the regeneration of chemically bonded sand in order to remove the residual binders. This includes an initial mechanical step (e.g. crushing, screening) followed by mechanical (e.g. grinding wheel, impact drum) and/or thermal (e.g. fluidised bed or rotary furnaces) processes.

2.3.2.11.1 Dust emissions

The reported levels of dust emissions to air from sand reconditioning and regeneration are presented in Figure 2.126 and Figure 2.127.

Some statistical data on the reported dust emission data are presented in the following table.

Table 2.81: Statistical evaluation of the reported dust emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Dust	214	89	58	11.93	4.26	1.83	0.29
NB: The data above refer to EPs that are associated with the sand reconditioning and regeneration processes only. *Source:* [169, TWG 2021]							

2.3.2.11.2 Benzene emissions

The reported levels of benzene emissions to air from sand reconditioning and regeneration are presented in Figure 2.128.

Some statistical data on the reported benzene emission data are presented in the following table.

Table 2.82: Statistical evaluation of the reported benzene emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Benzene	25	10	8	1.53	0.51	0.15	0.10
NB: The data above refer to EPs that are associated with the sand reconditioning and regeneration processes only. *Source:* [169, TWG 2021]							

2.3.2.11.3 Formaldehyde emissions

The reported levels of formaldehyde emissions to air from sand reconditioning and regeneration are presented in Figure 2.129.

Some statistical data on the reported formaldehyde emission data are presented in the following table.

Table 2.83: Statistical evaluation of the reported formaldehyde emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
Formaldehyde	23	10	10	1.11	0.50	0.11	0.03
NB: The data above refer to EPs that are associated with the sand reconditioning and regeneration processes only. *Source:* [169, TWG 2021]							

2.3.2.11.4 NO_X emissions

The reported levels of NO_X emissions to air from sand reconditioning and regeneration are presented in Figure 2.130.

Some statistical data on the reported NO_X emission data are presented in the following table.

Table 2.84: Statistical parameters of the reported NOX emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
NO_X	29	13	10	125	29	11.5	1.7
NB: The data above refer to EPs that are associated with the sand reconditioning and regeneration processes only. *Source:* [169, TWG 2021]							

2.3.2.11.5 SO_2 emissions

The reported levels of SO_2 emissions to air from sand reconditioning and regeneration are presented in Figure 2.131.

Some statistical data on the reported SO_2 emission data are presented in the following table.

Table 2.85: Statistical evaluation of the reported SO2 emission data

Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm³			
SO_2	19	7	6	335	100	1.7	0.1
NB: The data above refer to EPs that are associated with the sand reconditioning and regeneration processes only. *Source:* [169, TWG 2021]							

2.3.2.11.6 TVOC emissions

The reported levels of TVOC emissions to air from sand reconditioning and regeneration are presented in Figure 2.132.

Some statistical data on the reported TVOC emission data are presented in the following table.

Table 2.86: Statistical evaluation of the reported TVOC emission data

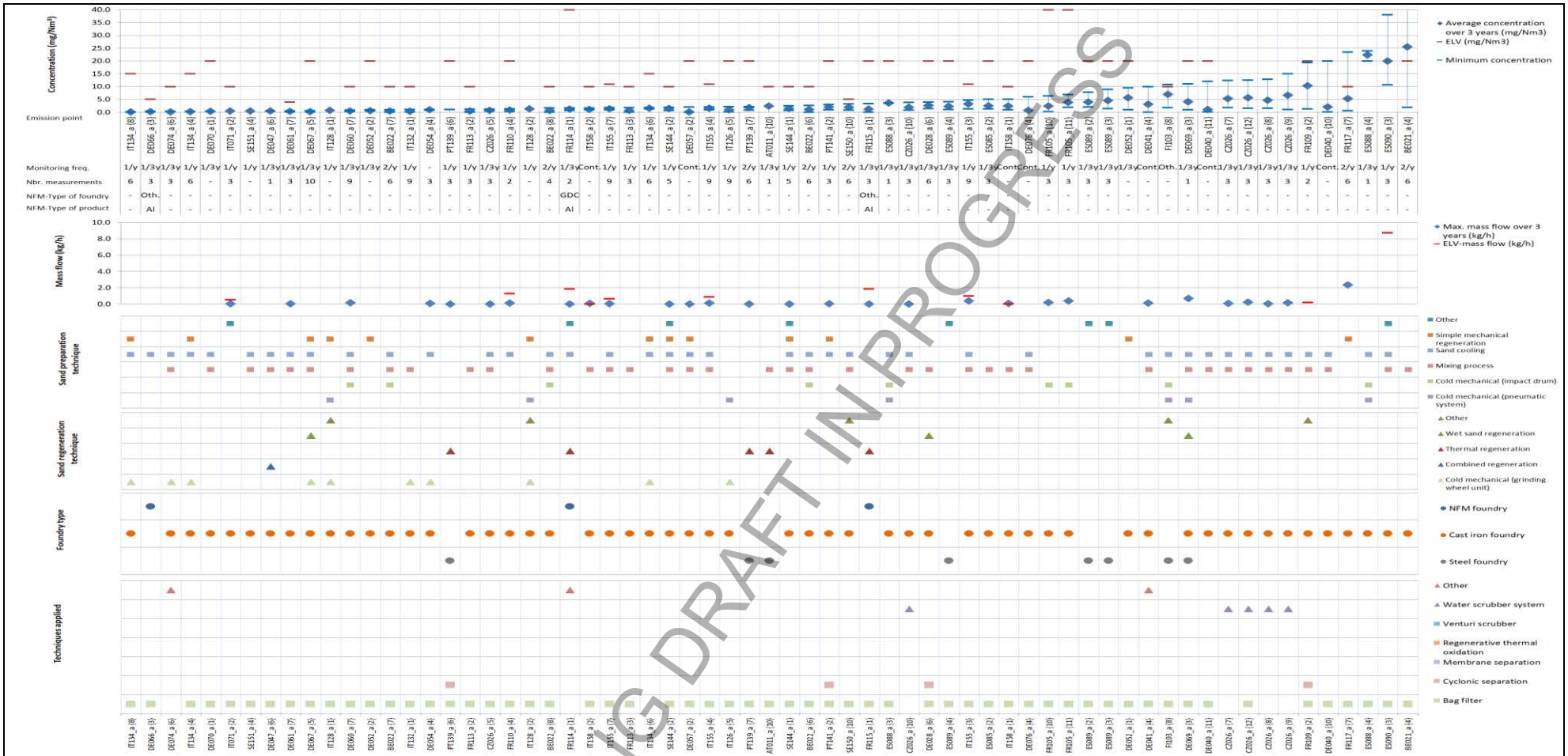
Parameter	Number of data	Number of EPs	Number of plants	90th percentile	Average	Median	10th percentile
				mg/Nm^3			
TVOC	32	16	13	61.73	31.79	7.90	1.06
NB: The data above refer to EPs that are associated with the sand reconditioning and regeneration processes only. *Source:* [169, TWG 2021]							

2.3.2.11.7 Metal emissions

The reported levels of metal (lead, nickel and cadmium) emissions to air from sand reconditioning and regeneration are presented in Figure 2.133 (for Pb), Figure 2.134 (for Ni) and Figure 2.135 (for Cd).

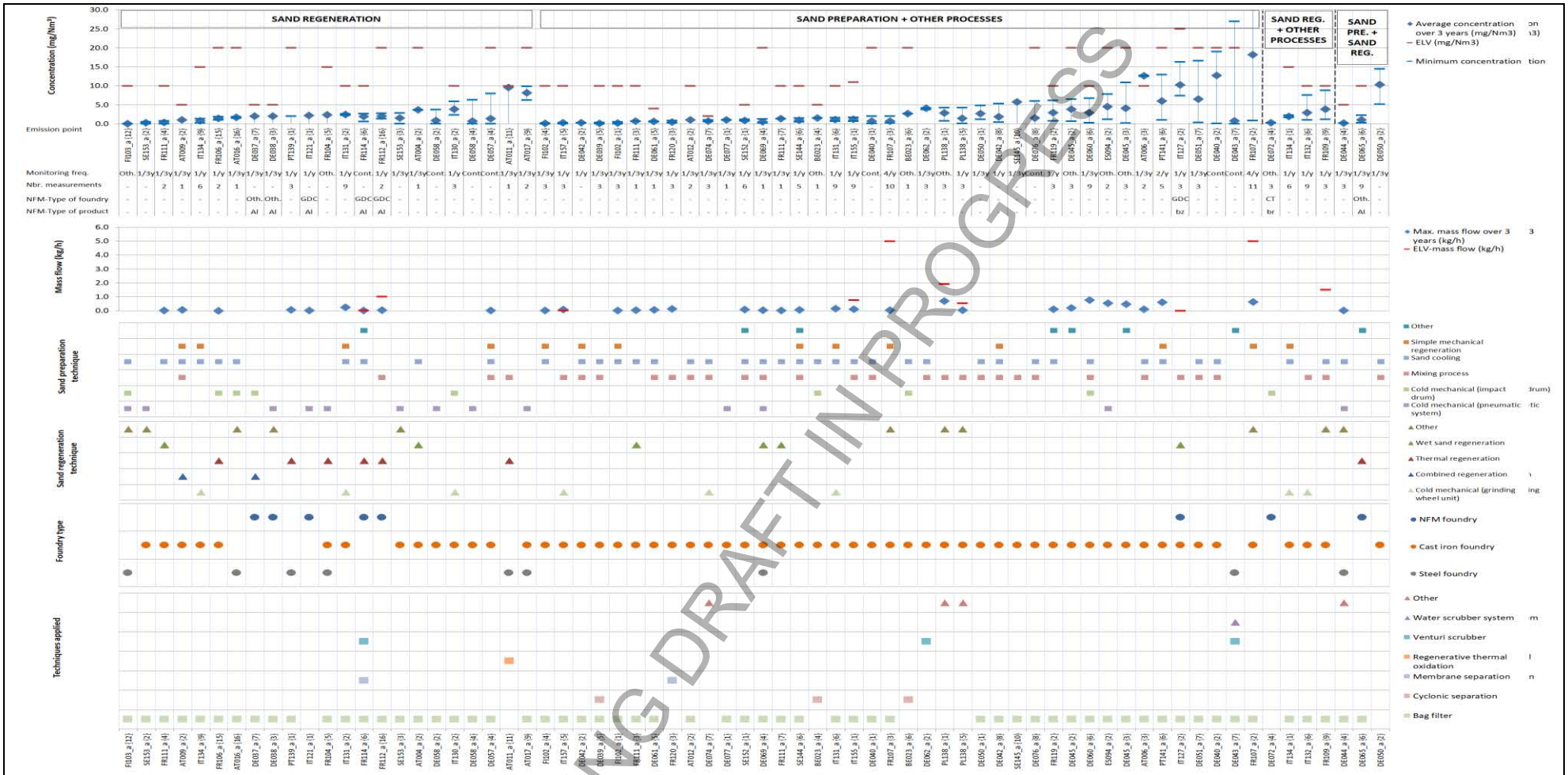
2.3.2.11.8 Figures for emissions to air

The structure of figures presented in this section is explained in Section 2.3.2.1.10.



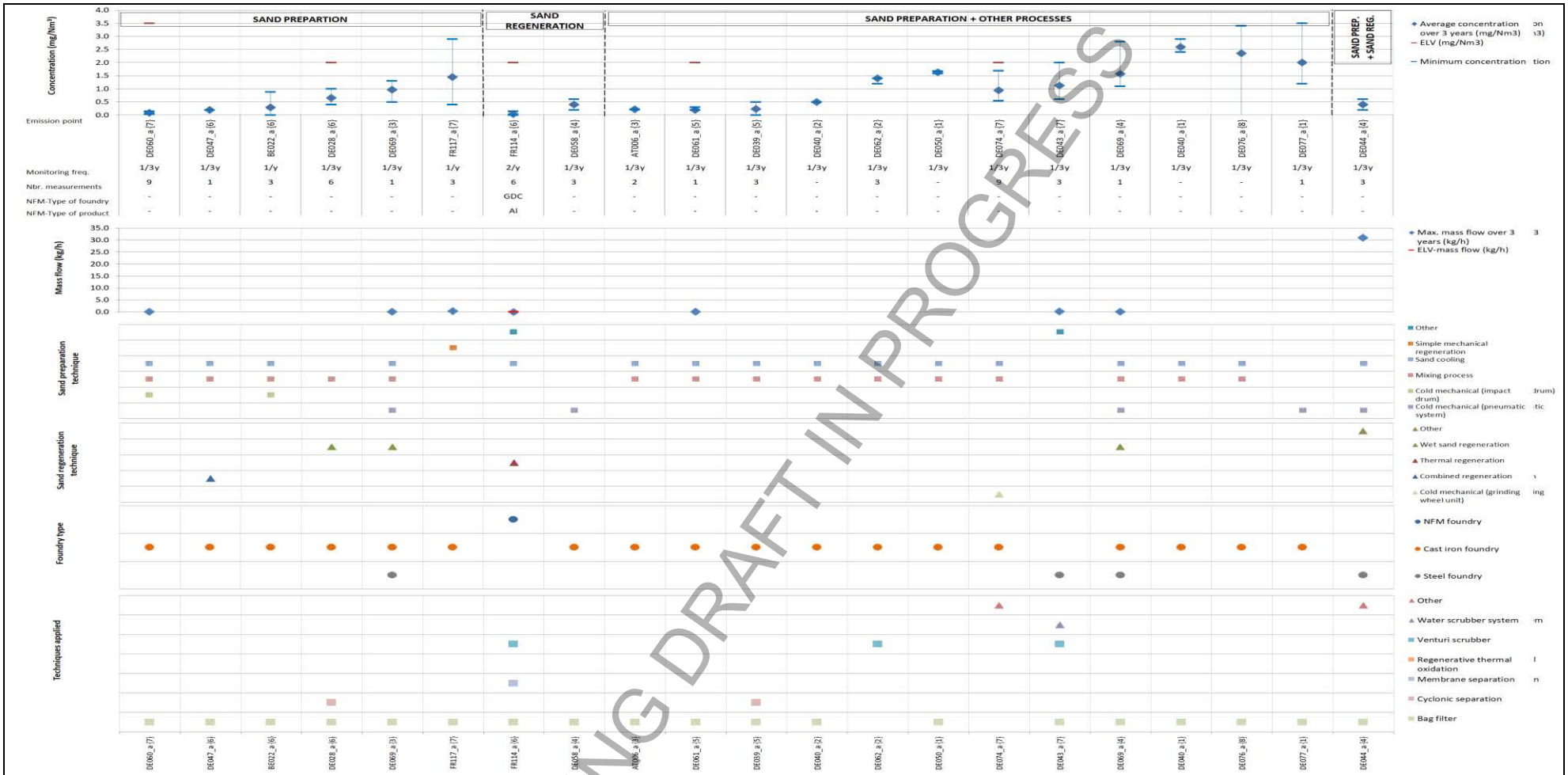
NB: For better visualisation, the ELVs over 40 mg/Nm³ are not shown. The range of ELVs not shown is from 50 mg/Nm³ to 150 mg/Nm³.
For better visualisation, the value reported by BE021_a {4} (max. = 103.3 mg/Nm³) is not shown in the figure.
Source: [169, TWG 2021]

Figure 2.126:Dust emissions from sand preparation and regeneration (sorted by type of process) (1/2)



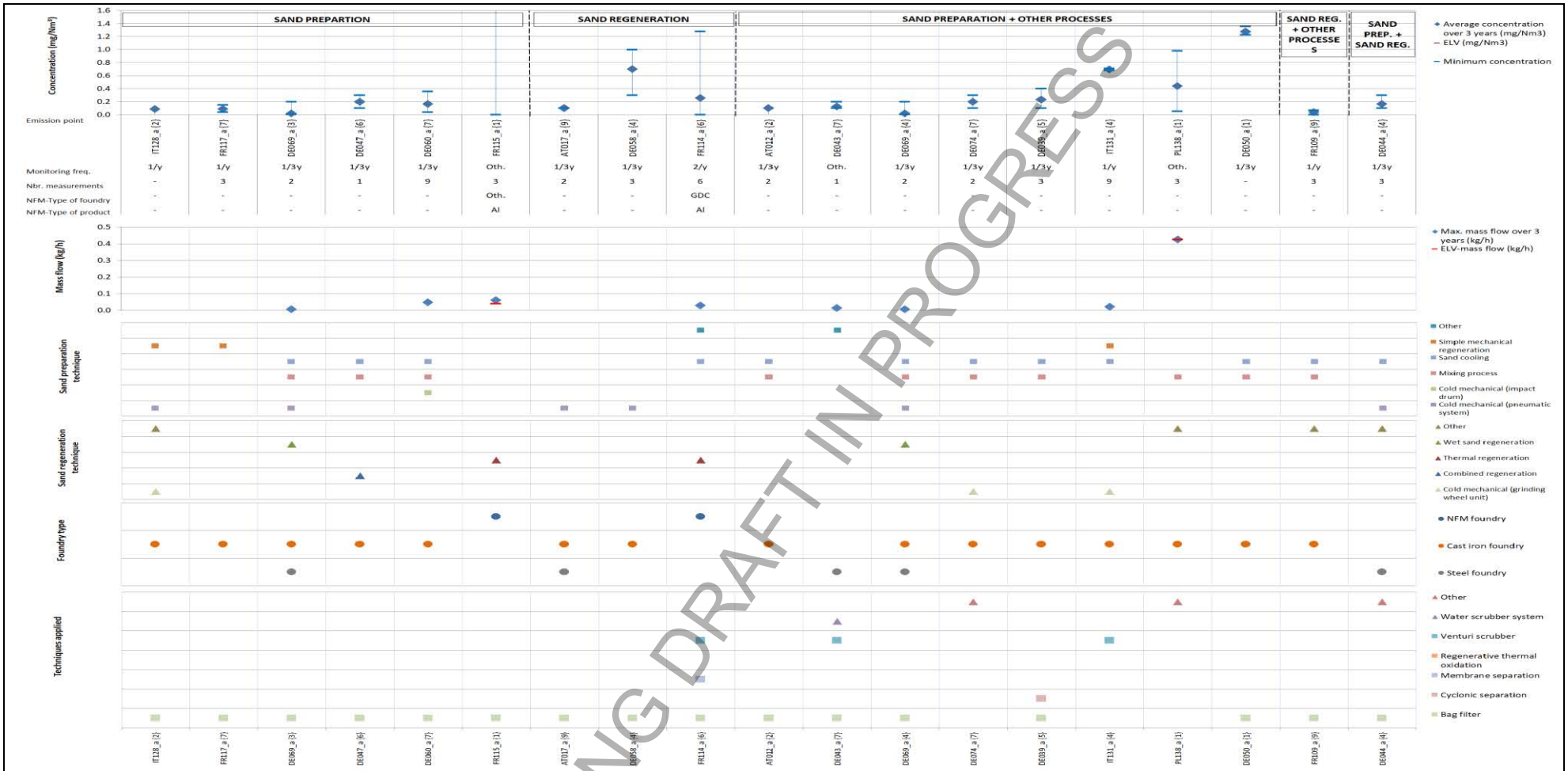
NB: For better visualisation, the ELVs of 40 mg/Nm³ reported by FR120_a {3}, FR107_a {3} and FR107_a {2} are not shown.
For better visualisation, the value reported by FR107_a {2} (max. = 96.6 mg/Nm³) is not shown in the figure.
Source: [169, TWG 2021]

Figure 2.127:Dust emissions from sand preparation and regeneration (sorted by type of process) (2/2)



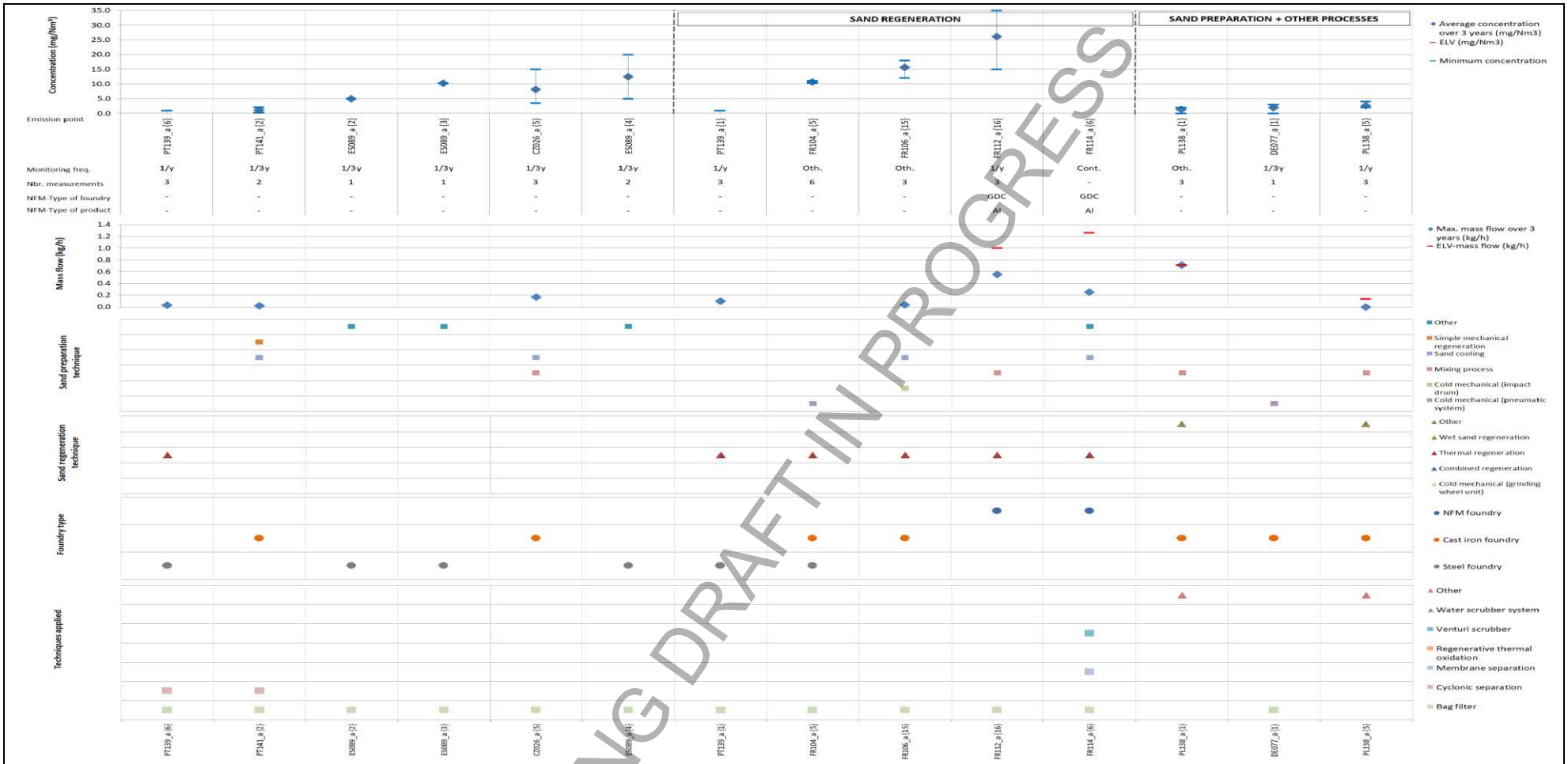
NB: For better visualisation, the ELVs of 5 mg/Nm^3 are not shown.
Source: [169, TWG 2021]

Figure 2.128:Benzene emissions from sand preparation and regeneration (sorted by type of process)



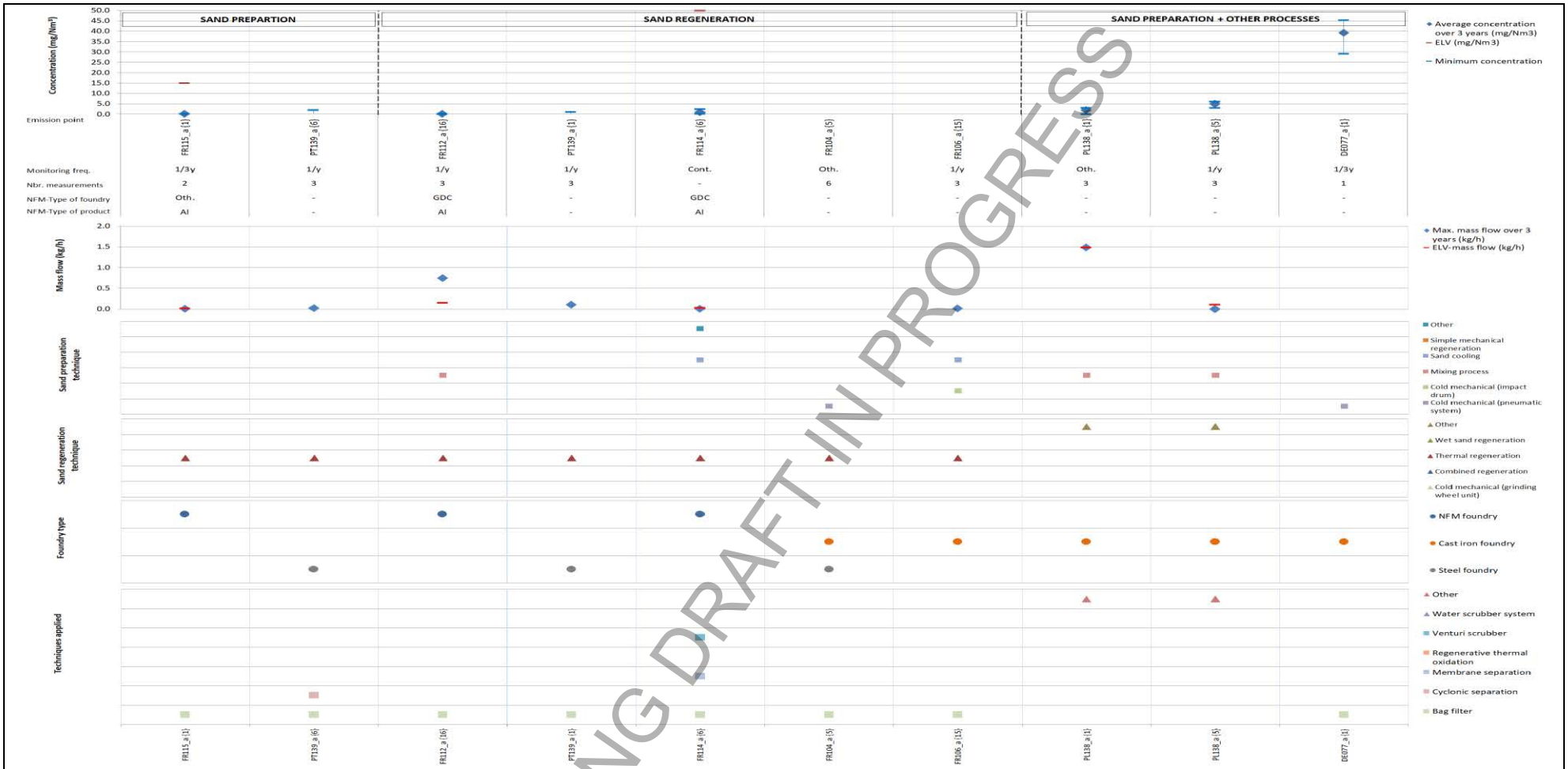
NB: For better visualisation, the ELVs over 1.6 mg/Nm^3 are not shown. The range of ELVs not shown is from 2 mg/Nm^3 to 20 mg/Nm^3.
For better visualisation, the values reported by FR115_a {1} (avg. = 2.0 mg/Nm^3, max. = 5.9 mg/Nm^3) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.129:Formaldehyde emissions from sand preparation and regeneration (sorted by type of process)



NB: For better visualisation, the ELVs over 35 mg/Nm³ are not shown. The range of ELVs not shown is from 100 mg/Nm³ to 615 mg/Nm³.
For better visualisation, the values reported by FR114_a {6} (min. = 96 mg/Nm³, avg. = 126.8 mg/Nm³, max. = 166 mg/Nm³) are not shown in the figure.
Source: [169, TWG 2021]

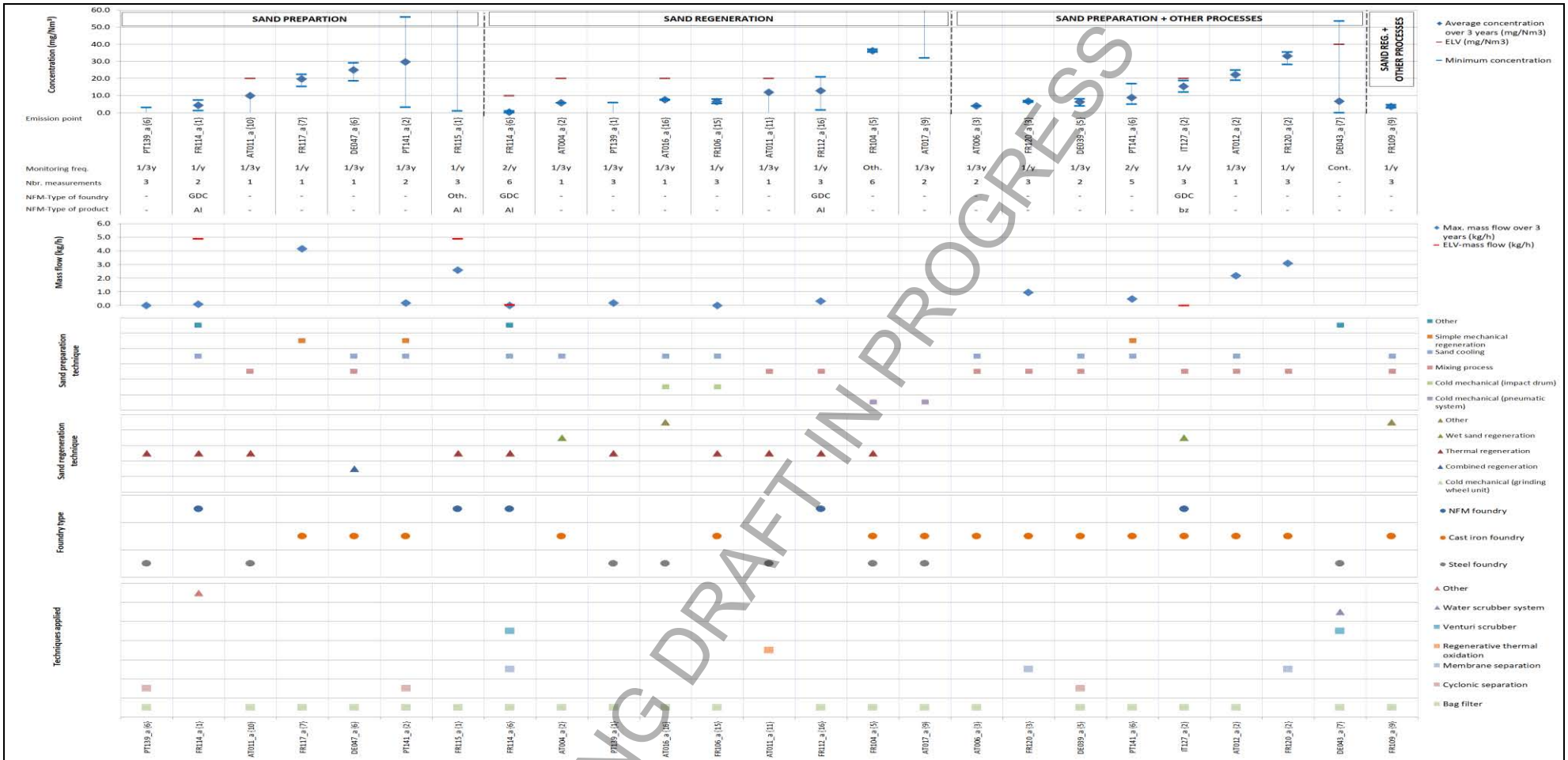
Figure 2.130:NO_X emissions from sand preparation and regeneration (sorted by type of process)



NB: For better visualisation, the ELVs over 50 mg/Nm³ are not shown. The range of ELVs range shown is from 100 mg/Nm³ to 300 mg/Nm³. In addition, the values reported by FR104_a{5} (min. = 95 mg/Nm³, avg. = 100 mg/Nm³, max. = 105 mg/Nm³) and FR106_a {15} (min. = 310 mg/Nm³, avg. = 364 mg/Nm³, max. = 440 mg/Nm³) are not shown in the figure.

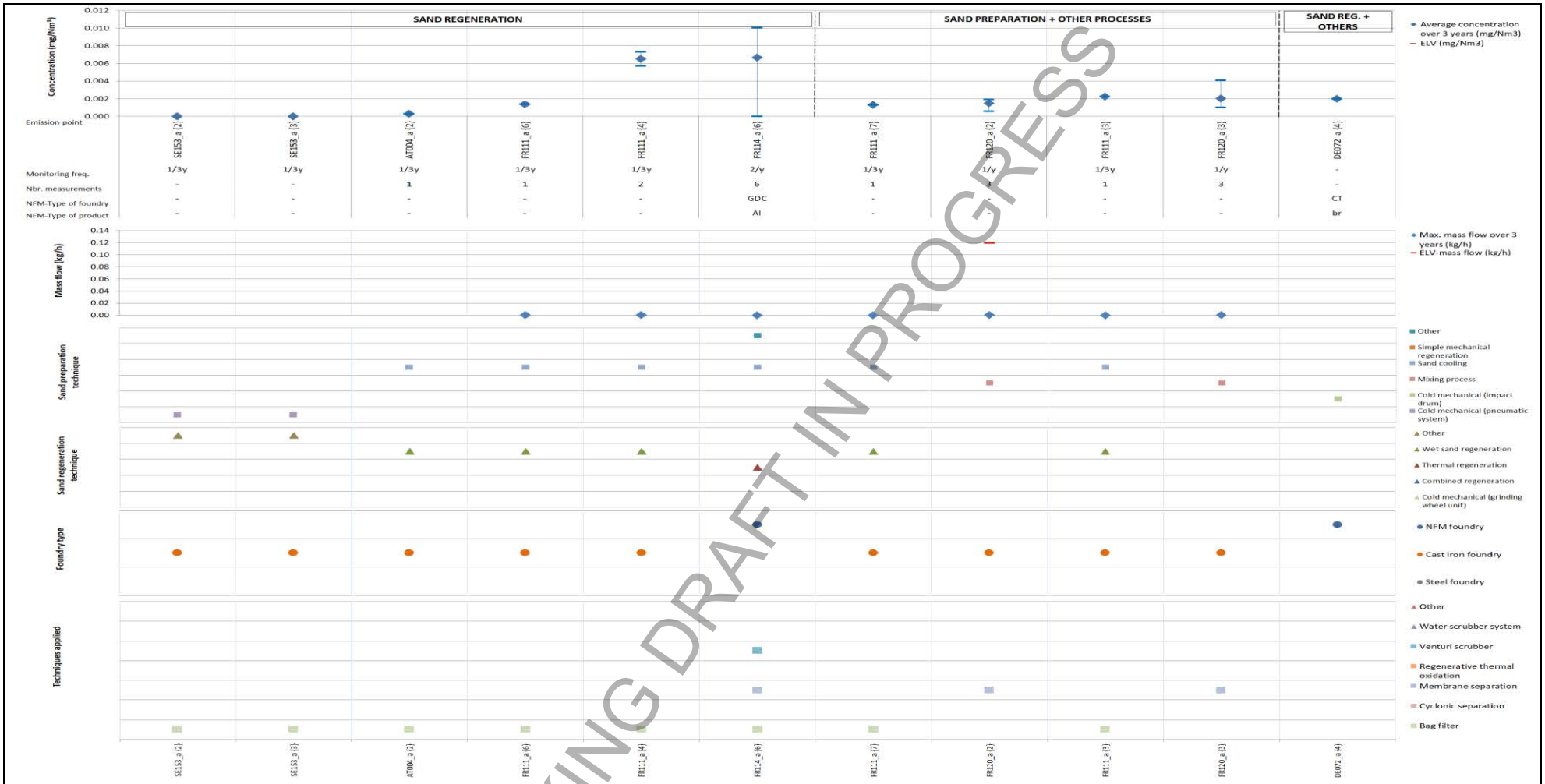
Source: [169, TWG 2021]

Figure 2.131: SO_2 emissions from sand preparation and regeneration (sorted by type of process)



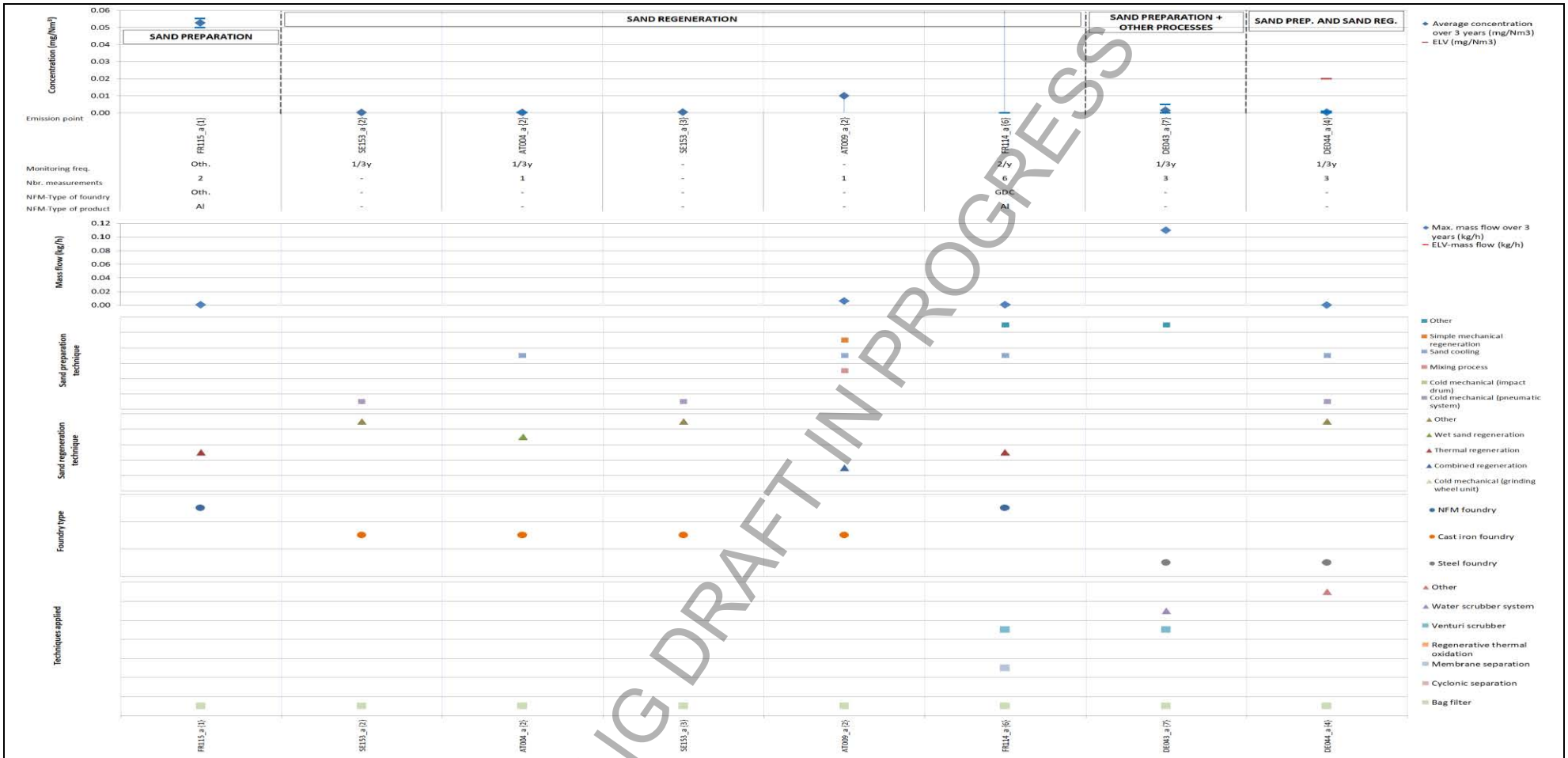
NB: For better visualisation, the ELVs over 60 mg/Nm^3 are not shown. The range of ELVs not shown is from 73 mg/Nm^3 to 200 mg/Nm^3. In addition, the values reported by FR115_a {1} (avg. = 103.9 mg/Nm^3, max. = 250 mg/Nm^3) and AT017_a {9} (avg. = 70 mg/Nm^3, max. = 123 mg/Nm^3) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.132:TVOC emissions from sand preparation and regeneration (sorted by type of process)



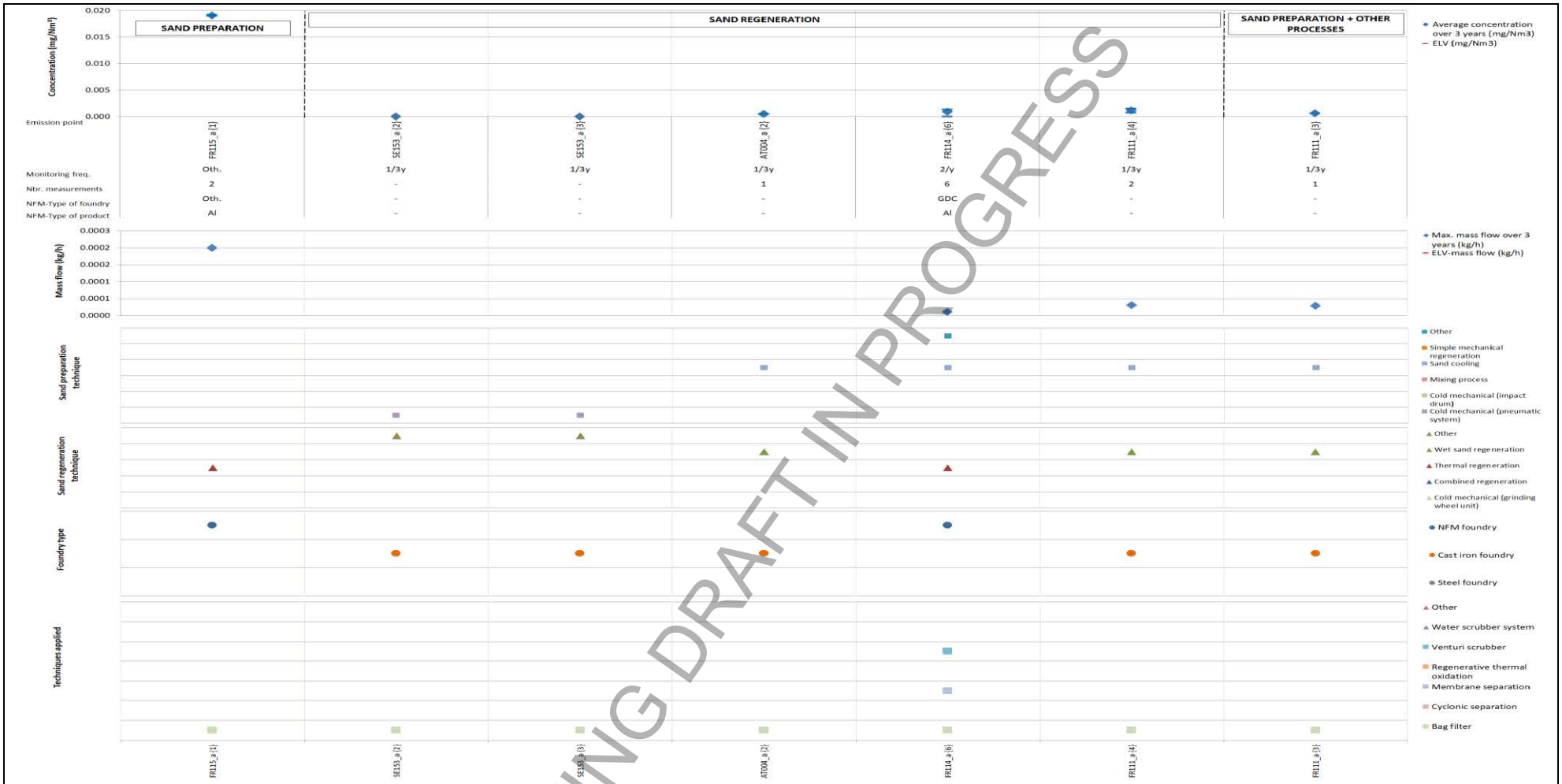
NB: For better visualisation, the ELVs of 1 mg/Nm³ are not shown.
Source: [169, TWG 2021]

Figure 2.133:Pb emissions from sand preparation and regeneration (sorted by type of process)



NB: For better visualisation, the ELVs over 0.06 mg/Nm³ are not shown. The range of ELVs not shown is from 0.5 mg/Nm³ to 1 mg/Nm³.
For better visualisation, the values reported by FR114_a {6} (avg. = 0.07 mg/Nm³, max. = 0.2 mg/Nm³) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.134:Ni emissions from sand preparation and regeneration (sorted by type of process)



NB: For better visualisation, the ELVs of 0.05 mg/Nm^3 reported by FR115_a {1} and AT004_a {2} are not shown.
Source: [169, TWG 2021]

Figure 2.135:Cd emissions from sand preparation and regeneration (sorted by type of process)

2.3.3 Emissions to water

This section contains information on emissions to water from foundries (direct and indirect discharge to a receiving water body).

Figures for emissions to water consist of four sections:

- The upper part (section) shows the maximum concentration and the minimum of each of the 3 reporting years, and the average value obtained over the reporting period. Below the x-axis, information is included such as the point of release, the monitoring frequency and the number of measurements reported.
- The second part (section) shows the average mass flow values, either for the maximum concentration obtained over the reporting period or the average for the year when the maximum concentration was obtained.
- The third part (section) of the graph provides information on the processes associated with the generation of waste water.
- The fourth part (section) of the graph provides the information on the BAT candidates applied. All the figures are sorted in ascending order of the maximum concentration values for the 3 reporting years.

The following tables contain an overview of the reported data for emissions to water (direct and inditrect disharges).

Table 2.87: Statistical evaluation of the reported emission data for direct discharge

Substance/ parameter	Number of emission points	Max. concentration	80th percentile	Average	Median	20th percentile
COD	12	120	49	38.1	30	12
TSS	10	120	28.2	27.3	17.4	9.6
Zn	8	0.8	-	0.2	0.1	-
Fe	7	5.5	-	1.6	1.1	-
Ni	6	0.12	-	0.02	0.01	-
Total N	6	25.4	-	12.1	8.9	-
As	5	0.06	-	0.01	-	-
Cr	5	0.01	-	0.0033	0.0003	-
Cu	5	0.6	-	0.062	0.003	-
HOI	5	1.29	-	0.39	0.10	-
Cd	4	0.01	-	0.0011	0.004	-
Oils/total hydrocarbons	4	1.0	-	0.29	0.10	-
Pb	4	0.02	-	0.006	0.00004	-
Total P	4	1.0	-	0.39	0.3	-
Al	3	0.8	-	0.3	0.34	-
AOX	2	0.14	-	0.12	-	-
BOD5	2	14	-	12	-	-

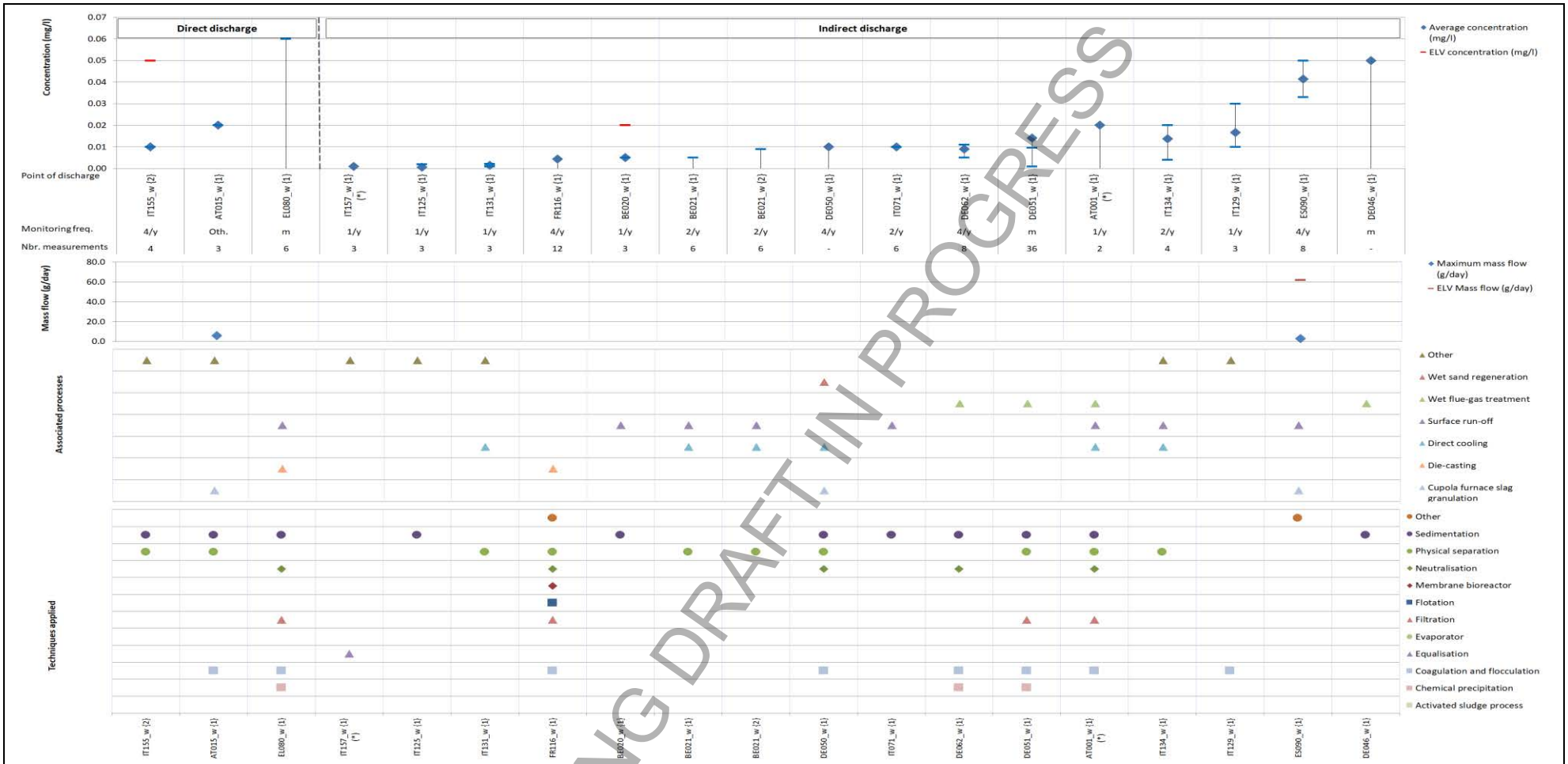
Table 2.88: Statistical evaluation of the reported emission data for indirect discharge

Substance/ parameter	Number of emission points	Max. concentration	80th percentile	Average	Median	20th percentile
COD	38	43 800	1 340	2 222	67	27.8
TSS	33	408	160	85.6	56.3	16
Zn	50	4.9	0.82	0.43	0.13	0.04
Fe	11	35	4.52	4.17	1.1	0.19
Ni	33	2.5	0.08	0.09	0.01	0.004
Total N	24	120	42.4	23.2	10.4	2.77
As	17	0.05	0.026	0.0086	0.005	0.0021
Cr	34	1.3	0.04	0.05	0.01	0.004
Cu	41	0.7	0.13	0.08	0.04	0.02
HOI	18	2 410	15	162.32	1.2	0.7
Cd	20	0.02	0.0047	0.0022	0.0008	0.0001
Oils/total hydrocarbons	24	25.30	9.33	4.42	10.4	0.16
Pb	38	0.35	0.05	0.034	0.01	0.003
Total P	9	1.3	0.04	0.05	0.01	0.002
Al	11					
AOX	23	4.8	1.6	0.72	0.22	0.05
Hg	11	0.0019	0.0012	0.0003	0.0002	0.0001
Phenols (Phenol index)	10	2.6	0.4	0.27	0.059	0.0058
Mn	6	0.51	-	0.13	0.05	-

2.3.3.1 Figures for emissions to water

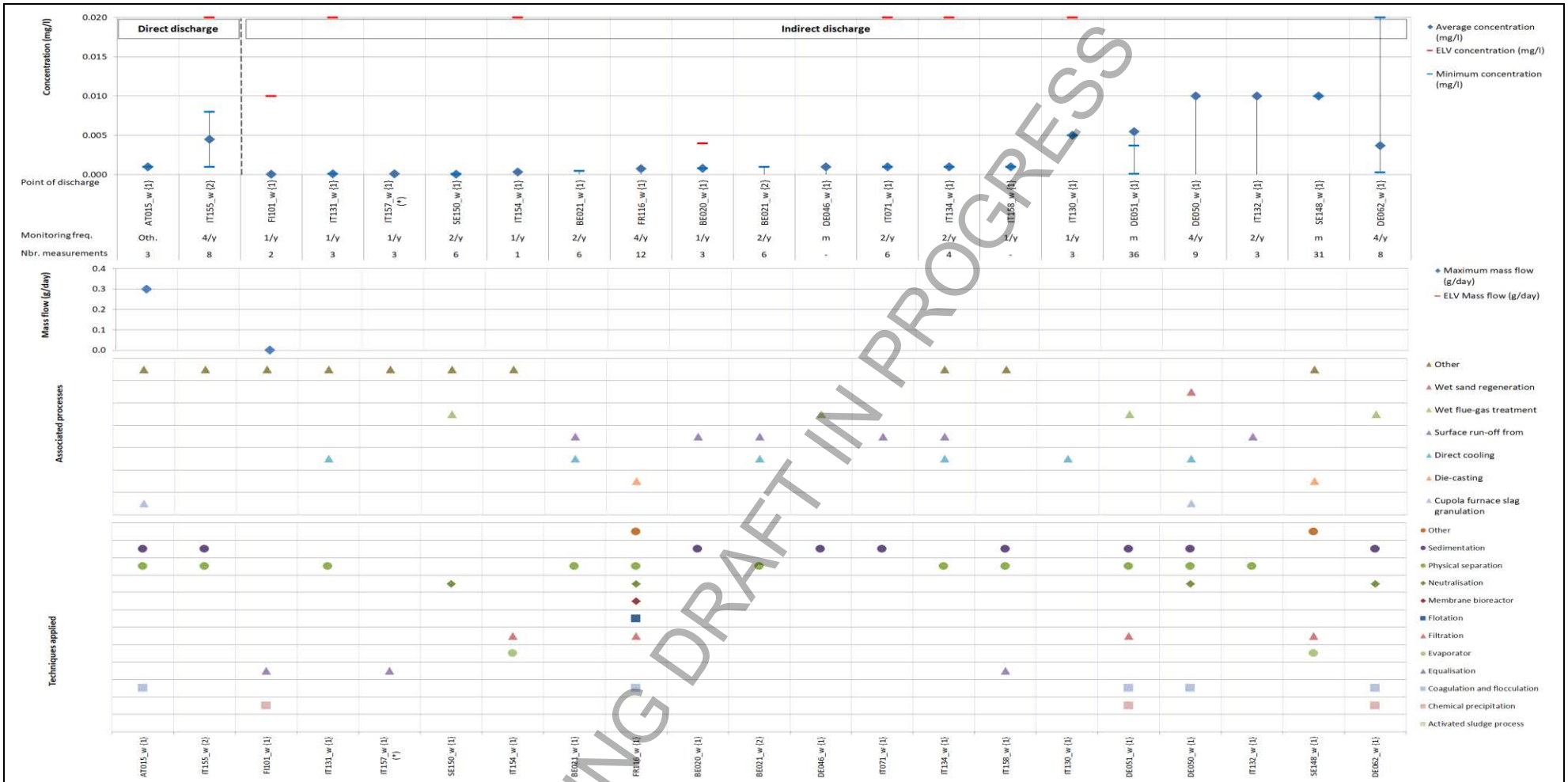
NB: For better visualisation, the ELV reported by FR119_w {1} of 5 mg/l is not shown. In addition, the values reported by FR113_w {2} (avg. = 1.5 mg/l, max. = 1.8 mg/l), DE062_w {1} (avg. = 1.7 mg/l, max. = 2.3 mg/l), DE051_w {1} (avg. = 1.1 mg/l, max. = 4.8 mg/l) and FR116_w {1} (avg. = 9.5 mg/l) are not shown in the figure.
(*) AT001_w {1} reported a % of waste water discharged from foundry below 50 %.
Source: [169, TWG 2021]

Figure 2.136:Adsorbable organically bound halogens (AOX) emissions for direct and indirect discharges



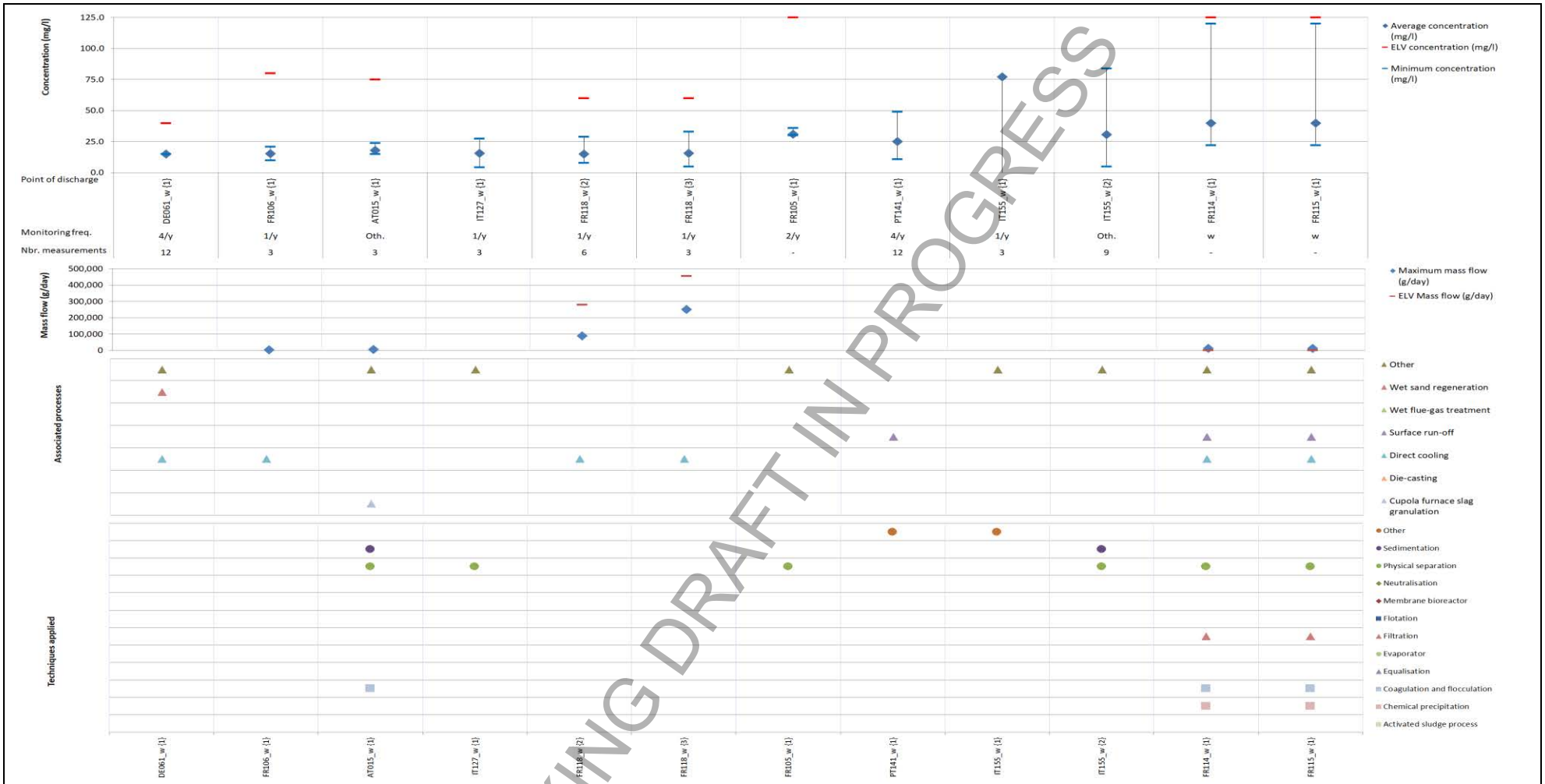
NB: For better visualisation, the ELVs over 0.07 mg/l are not shown. The range of ELVs not shown is from 0.1 mg/l to 1mg/l.
(*) IT157_w {1} and AT001_w {1} reported a % of waste water discharged from foundry below 50 %.
Source: [169, TWG 2021]

Figure 2.137:Arsenic (As) emissions for direct and indirect discharges



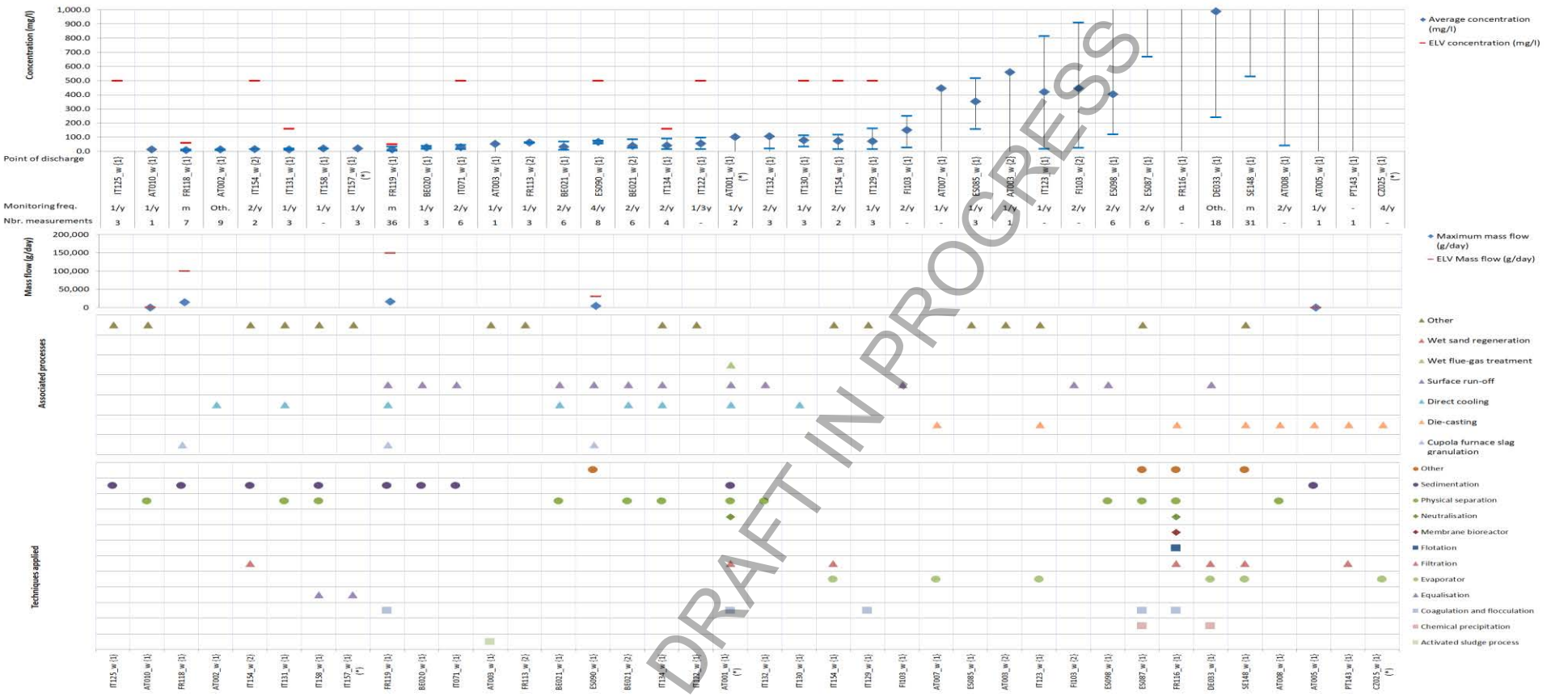
NB: For better visualisation, the ELV reported by AT015_w {1} of 0.1 mg/l is not shown.
(*) IT157_w {1} reported a % of waste water discharged from foundry below 50 %.
Source: [169, TWG 2021]

Figure 2.138:Cadmium (Cd) emissions for direct and indirect discharges



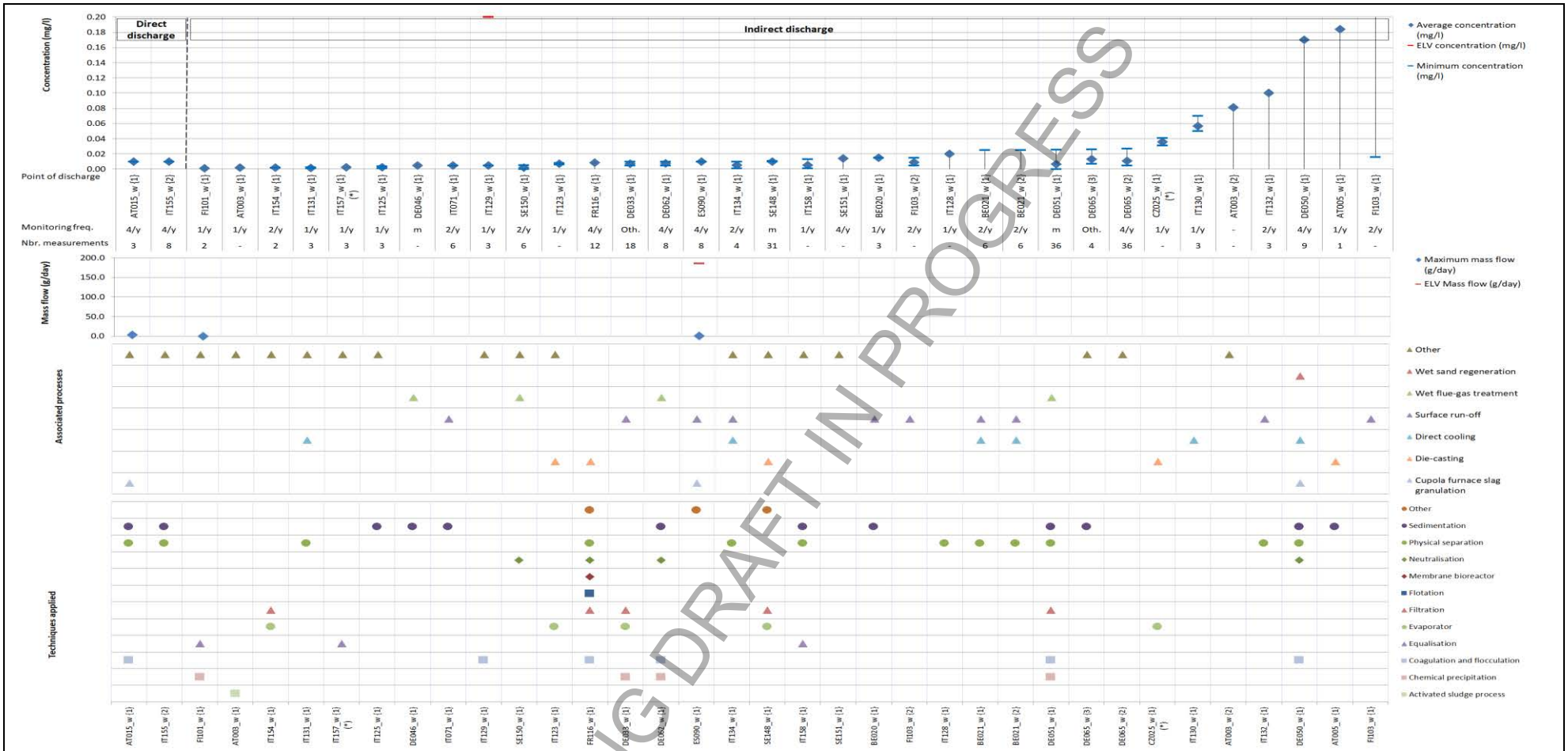
NB: For better visualisation, the ELVs over 125 mg/l are not shown. The range of ELVs not shown is from 150 mg/l to 160 mg/l.
Source: [169, TWG 2021]

Figure 2.139:COD emissions for direct discharges



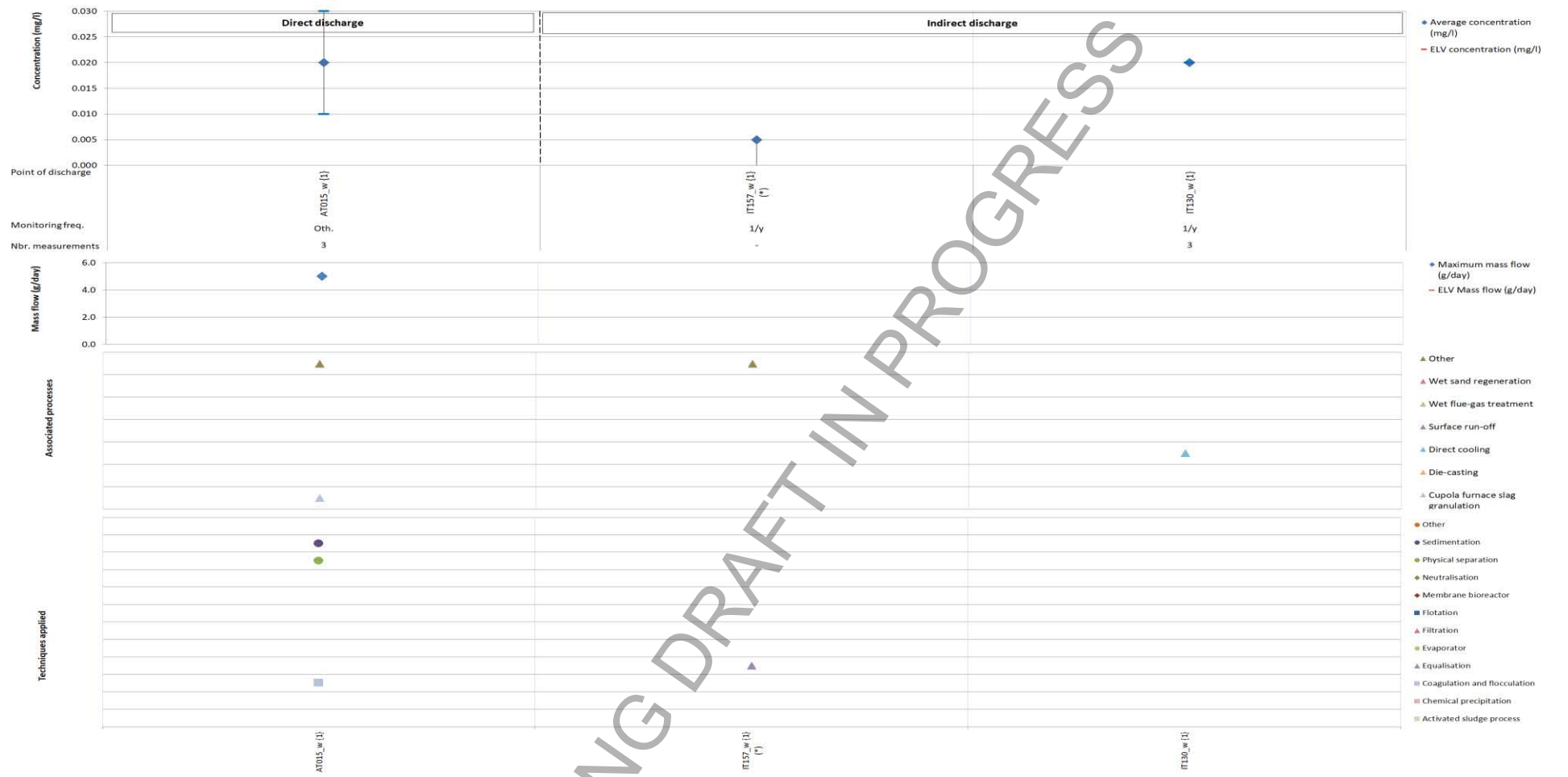
NB: For better visualisation, the ELVs over 1 000mg/l are not shown. The range of ELVs not shown is from 12 000 mg/l to 20 700 mg/l.
For better visualisation, the values reported by ES098_w {1} (max. = 1 200 mg/l), ES087_w {1} (avg. = 1 170 mg/l, max. = 1 900 mg/l), FR116_w {1} (avg. = 2 179 mg/l), DE033_w {1} (max. = 2 900 mg/l), SE148_w {1} (avg. = 1 595 mg/l, max. = 4 100 mg/l), AT008_w {1} (avg. = 1 755 mg/l, max. = 7 550 mg/l), AT005_w {1} (avg. = 8 700 mg/l), PT143_w {1} (max. = 12 000 mg/l) and CZ025_w {1} (min. = 23 300 mg/l, avg. = 32 260 mg/l, max. = 43 800 mg/l) are not shown in the figure.
(*) IT157_w {1}, AT001_w {1} and CZ025_w {1} reported a % of waste water discharged from foundry below 50 %.
Source: [169, TWG 2021]

Figure 2.140:COD emissions for indirect discharges



NB: For better visualisation, the ELVs over 0.2 mg/l are not shown. The range of ELVs not shown is from 0.5 mg/l to 0.4 mg/l. In addition, the values reported by FI103_w {1} (avg. = 0.5 mg/l, max. = 1.3 mg/l) are not shown in the figure.
(*) IT157_w {1} and CZ025_w {1} reported a % of waste water discharged from foundry below 50 %.
Source: [169, TWG 2021]

Figure 2.141:Chromium (Cr) emissions for direct and indirect discharges

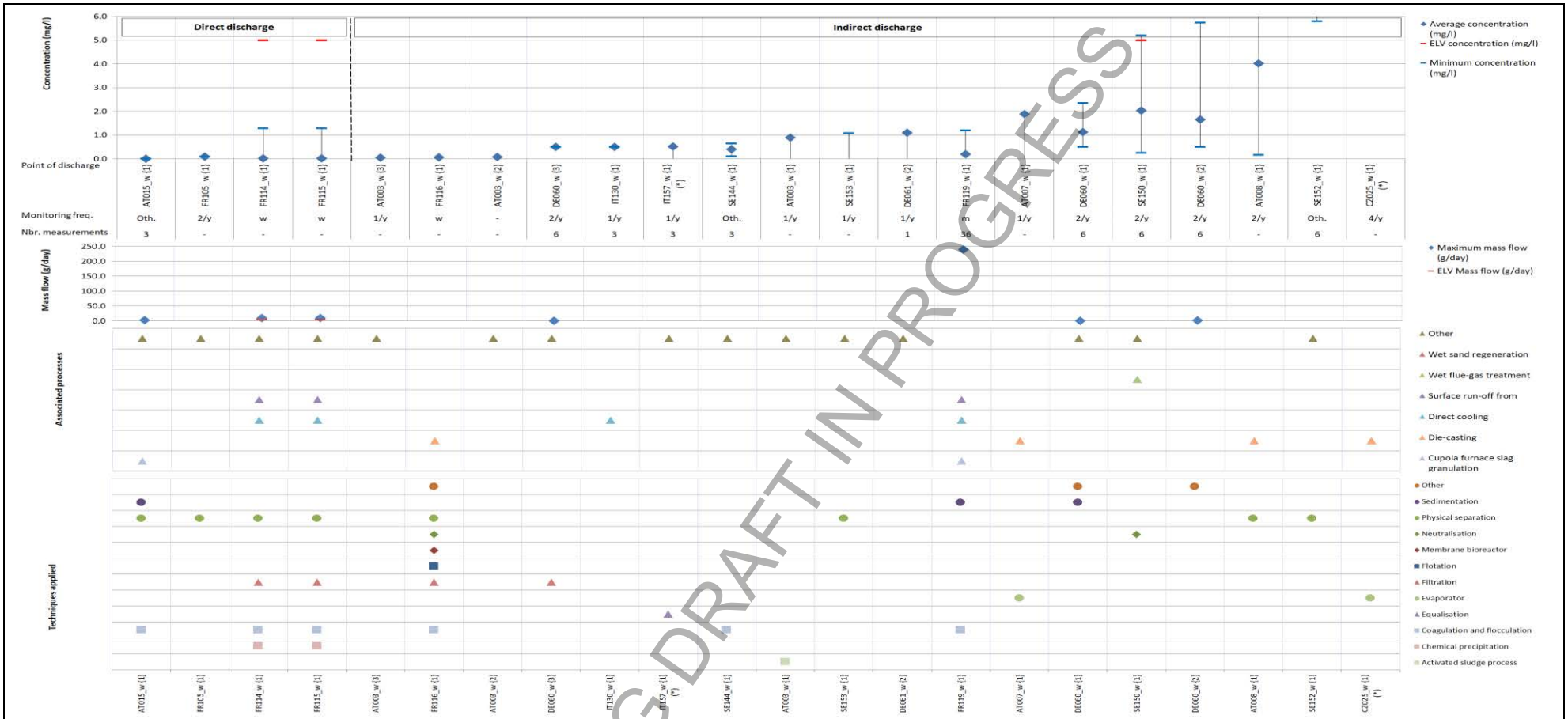


NB: For better visualisation, the ELV reported by AT015_w {1} of 0.1 mg/l and the ELV reported by IT130_w {1} of 2.0 mg/l are not shown.
(*) IT157_w {1} reported a % of waste water discharged from foundry below 50 %.
Source: [169, TWG 2021]

Figure 2.142:Cyanide emissions for direct and indirect discharges

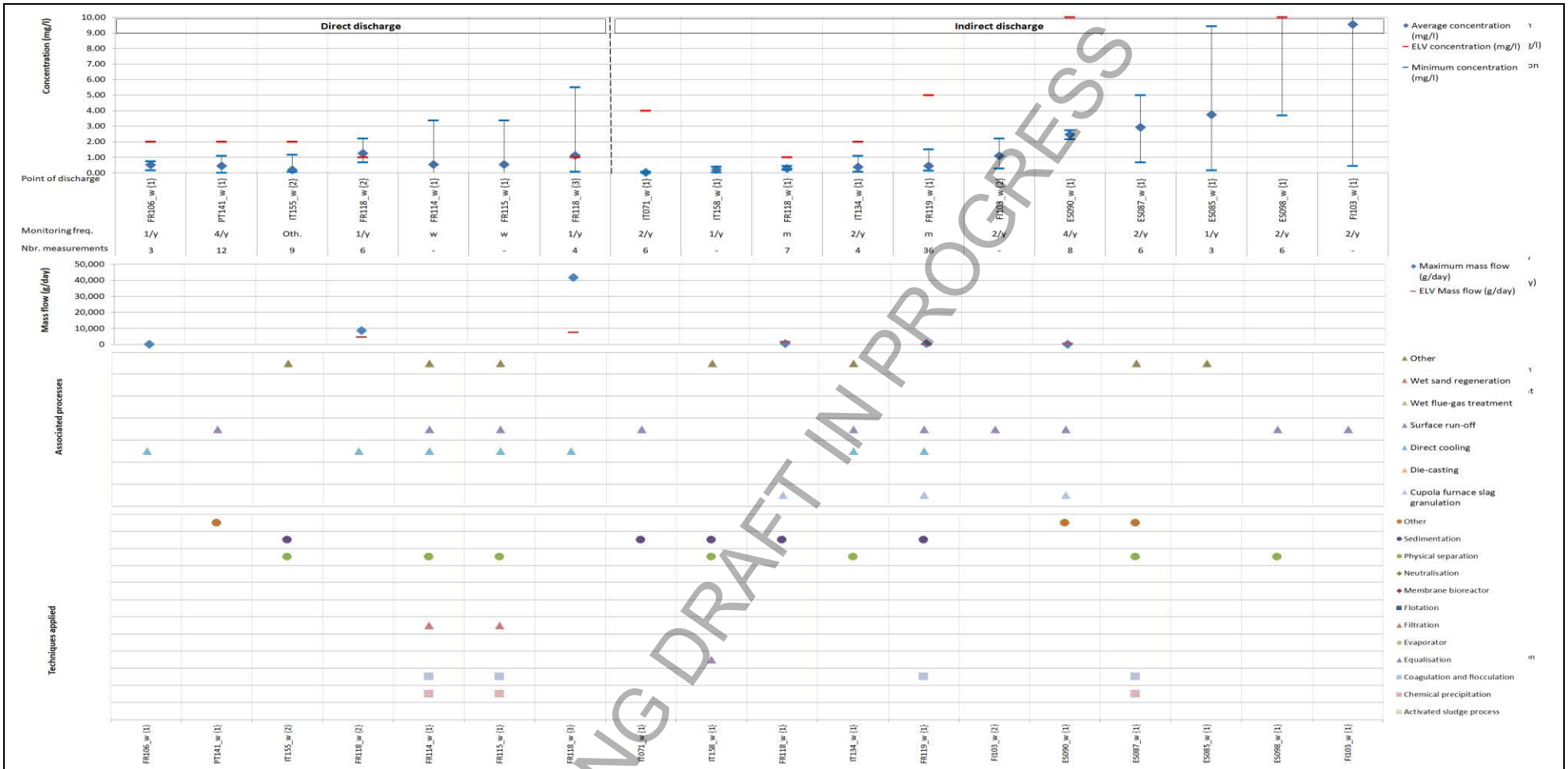
NB: For better visualisation, the ELV reported by AT007_w {1} of 20 mg/l is not shown.
Source: [169, TWG 2021]

Figure 2.143:Fluoride emissions for indirect discharges



NB: For better visualisation, the ELVs over 6 mg/l are not shown. The range of ELVs not shown is from 10 mg/l to 2 700 mg/l. In addition, the values reported by AT008_w {1} (max. = 17 mg/l), SE152_w {1} (avg. = 18.6 mg/l, max. = 48 mg/l) and CZ025_w {1} (min. = 126 mg/l, avg. = 1 136 mg/l, max. = 2 410 mg/l) are not shown in the figure.
(*) IT157_w {1} and CZ025_w {1} reported a % of waste water discharged from foundry below 50 %.
Source: [169, TWG 2021]

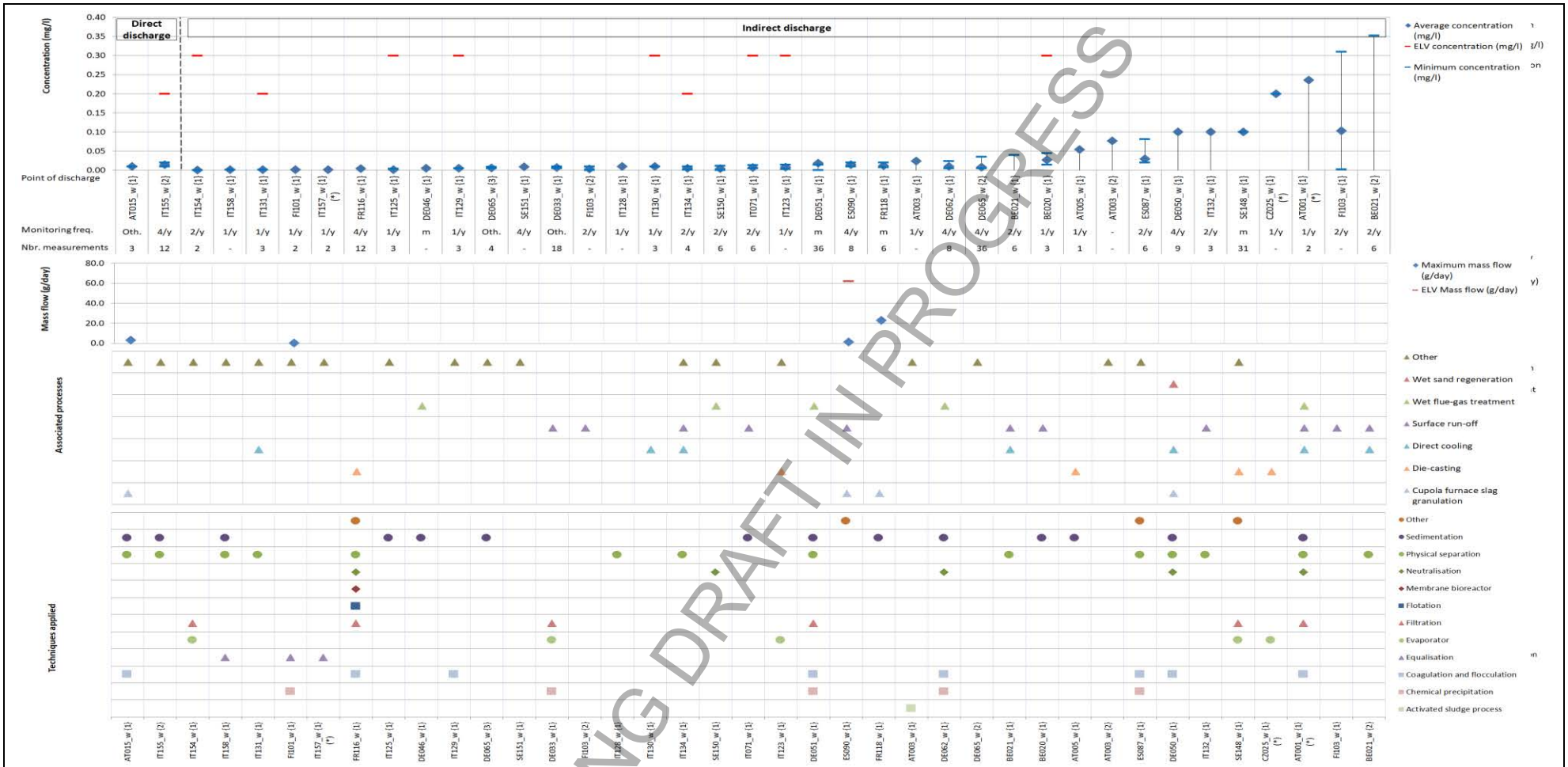
Figure 2.144:Hydrocarbon oil index (HOI) emissions for direct and indirect discharges



NB: For better visualisation, the ELV reported by ES087_w {1} and ES085_w {1} of 20 mg/l is not shown in the figure. In addition, the values reported by ES098_w {1} (avg. = 10.7 mg/l, max. = 33 mg/l) and FI103_w {1} (max. = 35 mg/l) are not shown in the figure.

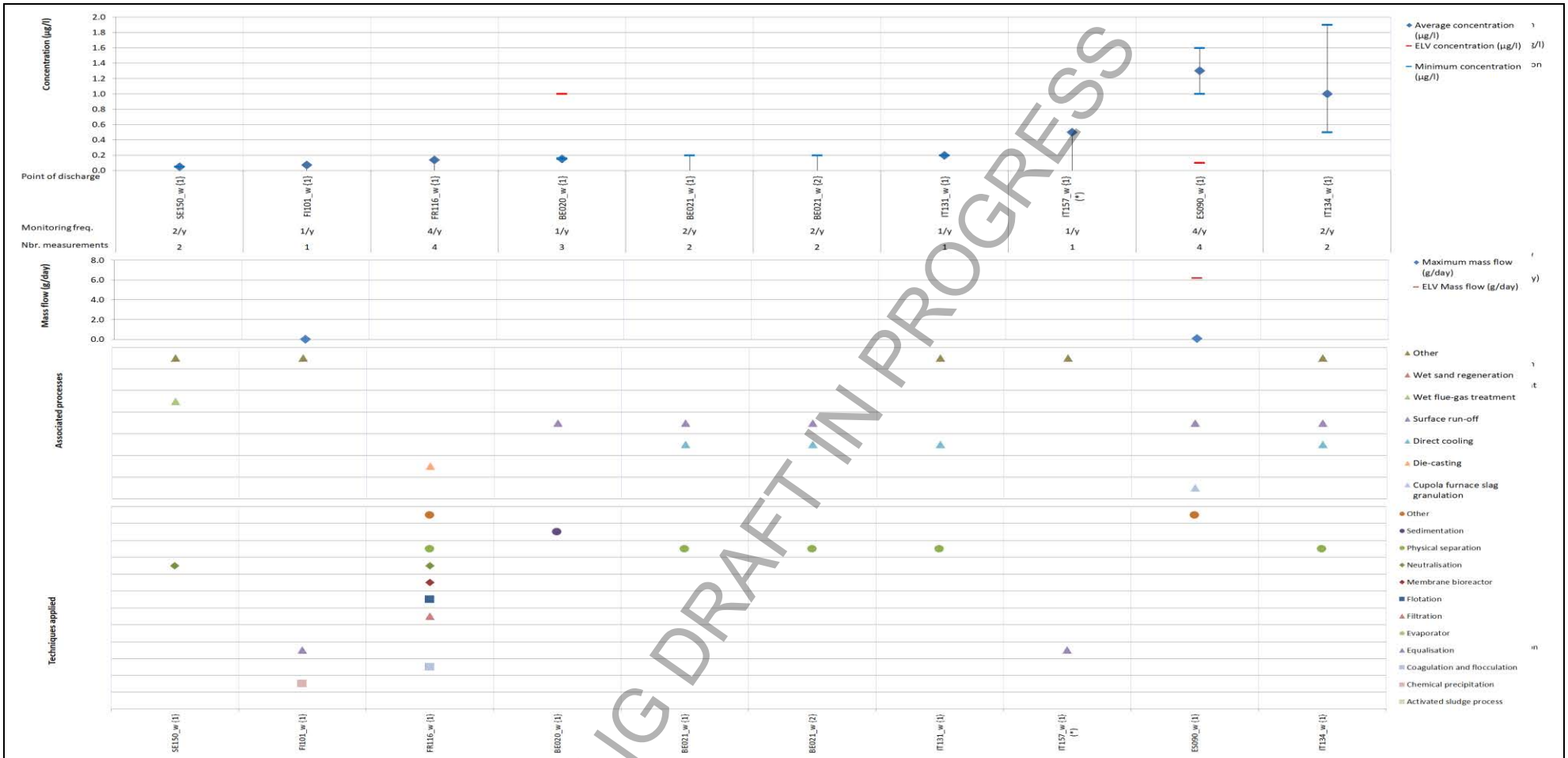
Source: [169, TWG 2021]

Figure 2.145:Iron (Fe) emissions for direct and indirect discharges



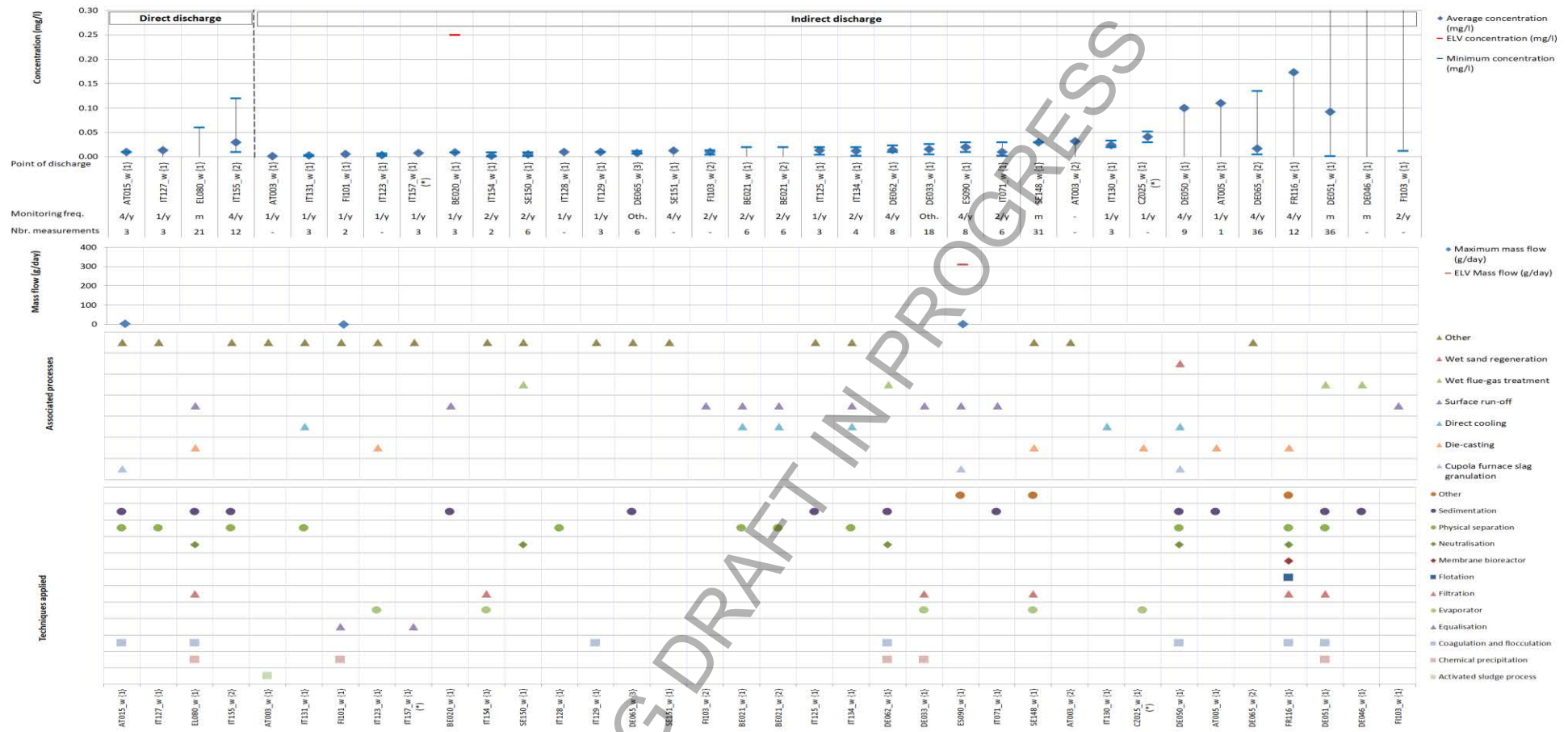
NB: For better visualisation, the ELVs over 0.4 mg/l are not shown. The range the ELVs not shown is from 0.5 mg/l to 1 mg/l.
(*) IT157_w {1}, AT001_w {1} and CZ025_w {1} reported a % of waste water discharged from foundry below 50 %.
Source: [169, TWG 2021]

Figure 2.146:Lead (Pb) emissions for direct and indirect discharges



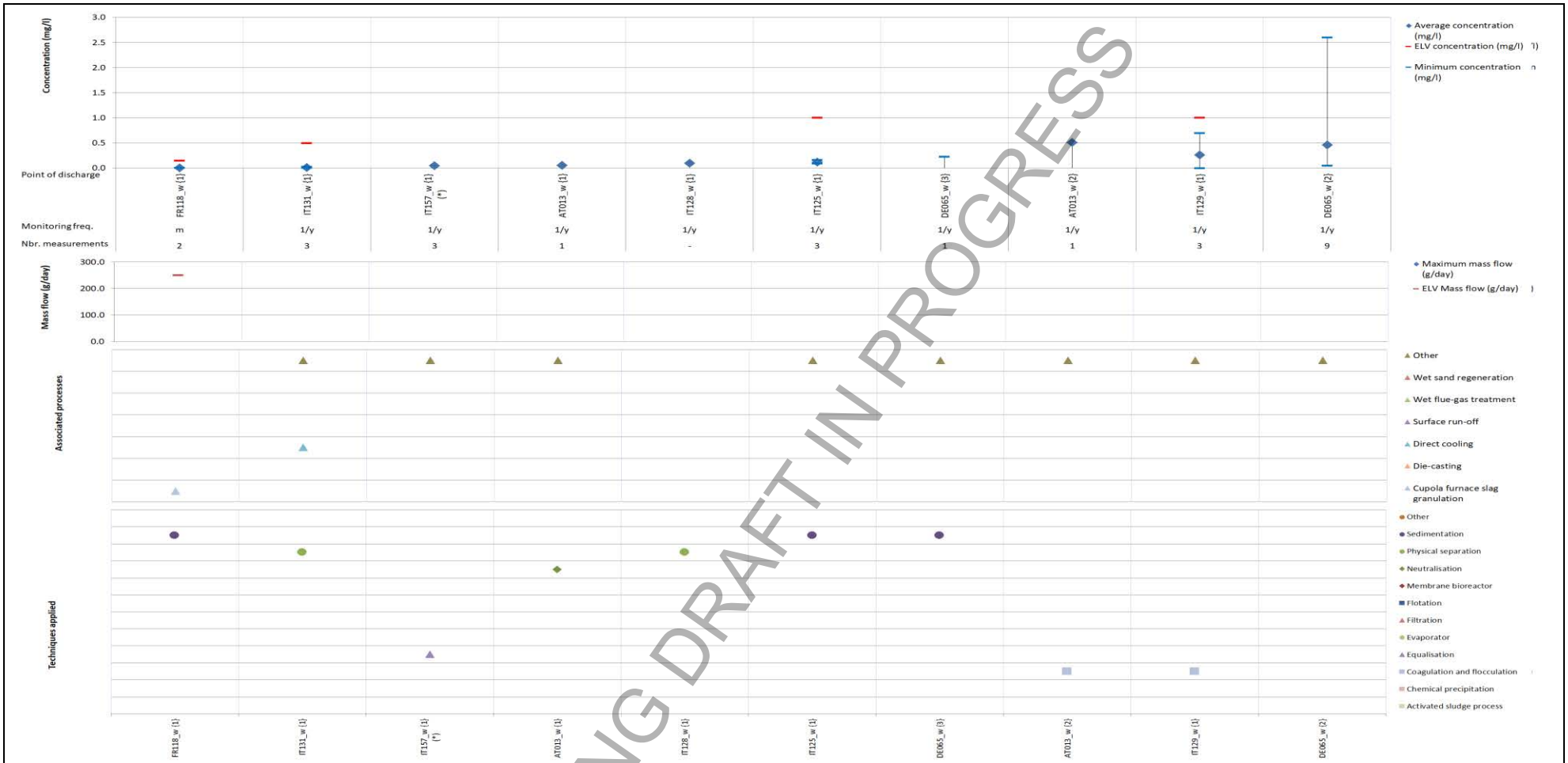
NB: For better visualisation, the ELVs over 2.0 µg/l are not shown. The range of ELVs not shown is from 5.0 µg/l to 10 µg/l.
(*) IT157_w {1} reported a % of waste water discharged from foundry below 50 %.
Source: [169, TWG 2021]

Figure 2.147:Mercury (Hg) emissions for indirect discharges



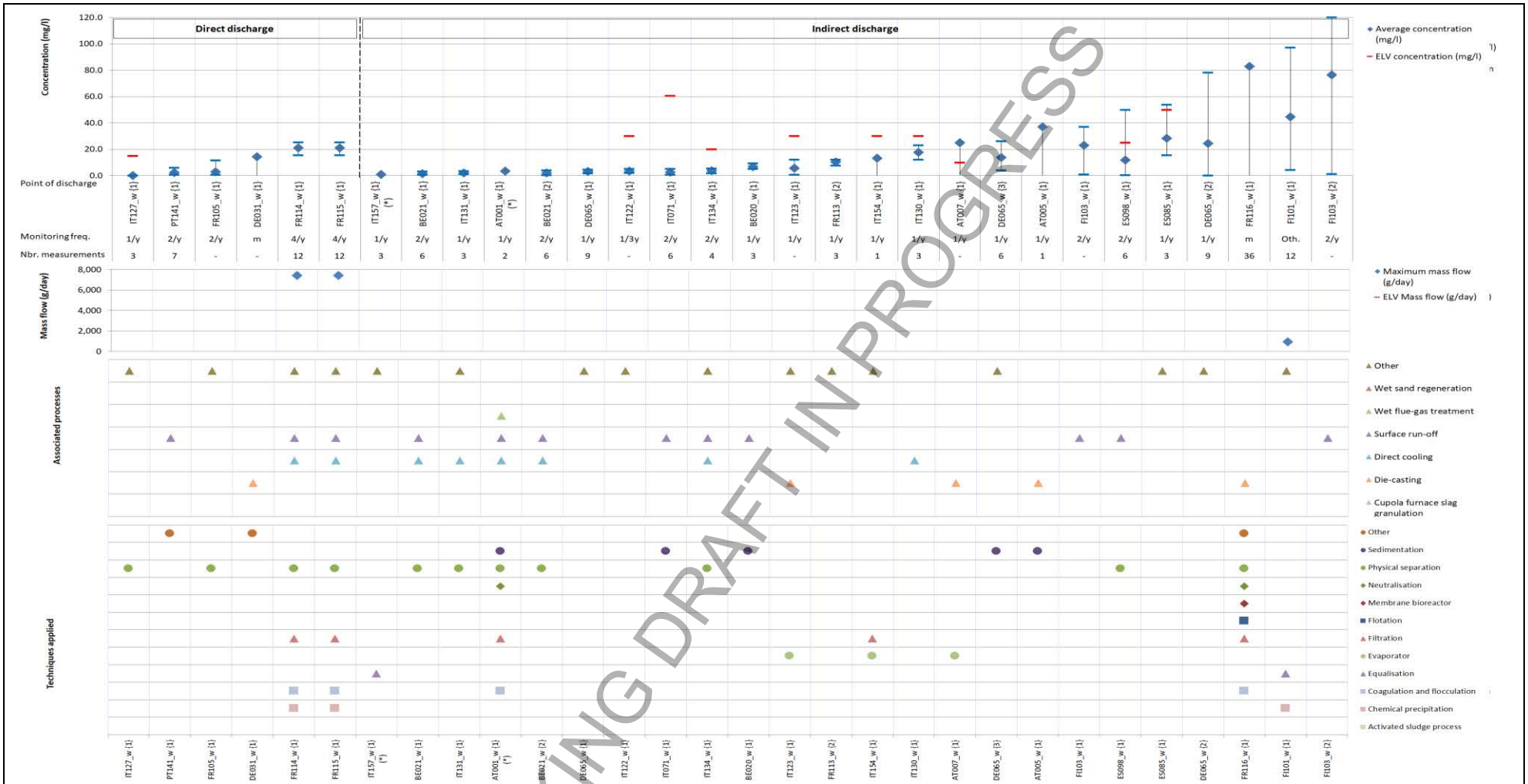
NB: For better visualisation, the ELVs over 0.3 mg/l are not shown. The range of ELVs not shown is from 0.5 mg/l to 5mg/l. In addition, the values reported by DE051_w {1} (max. = 0.52 mg/l), DE046_w {1} (avg. = 0.7 mg/l) and FI103_w {1} (avg. = 0.6 mg/l, max. = 2.5 mg/l) are not shown in the figure.
(*) IT157_w {1} and CZ025_w {1} reported a % of waste water discharged from foundry below 50 %.
Source: [169, TWG 2021]

Figure 2.148:Nickel (Ni) emissions for direct and indirect discharges



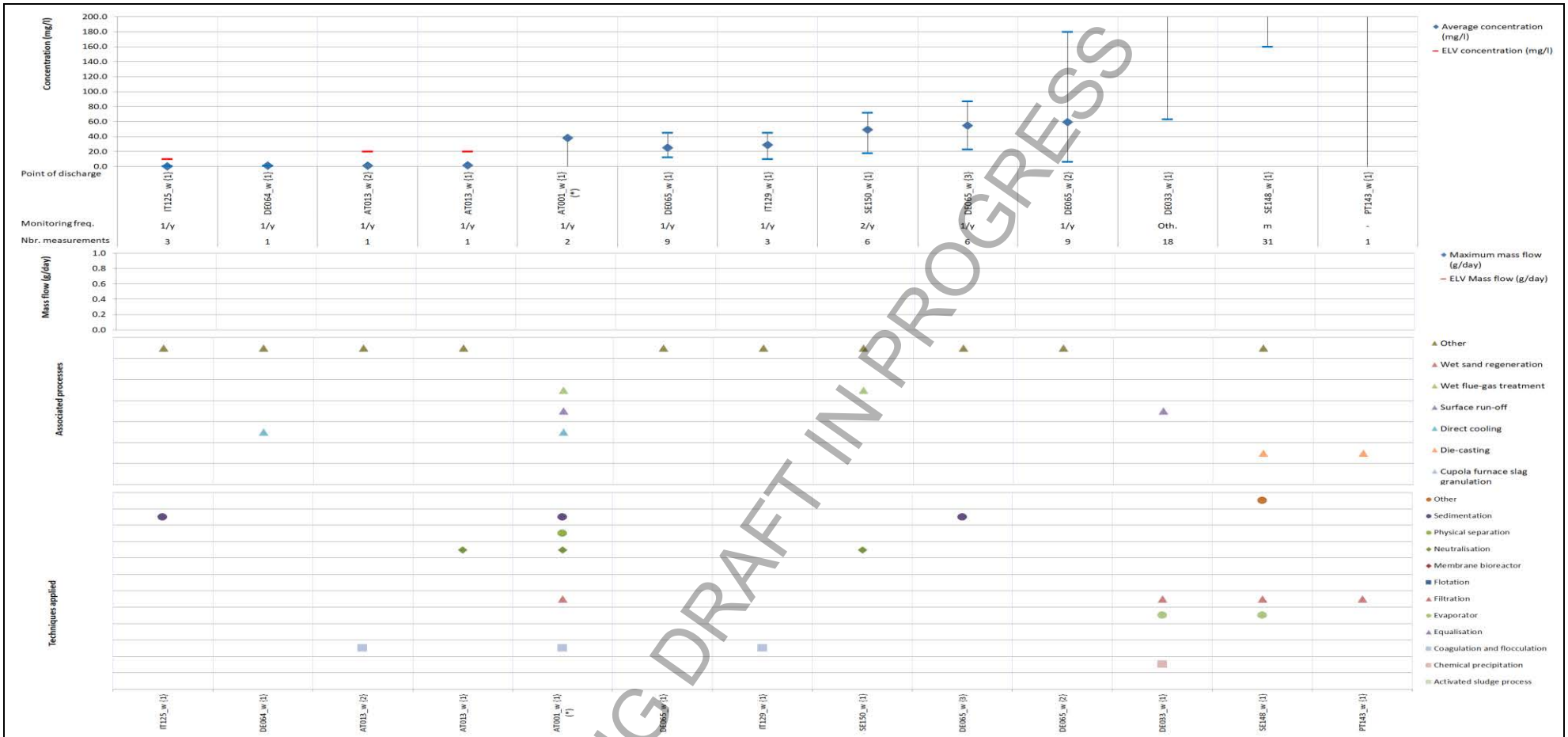
NB: For better visualisation, the ELV reported by AT013_w {1} and AT013_w {2} of 10 mg/l is not shown in the figure.
(*) IT157_w {1} reported a % of waste water discharged from foundry below 50 %.
Source: [169, TWG 2021]

Figure 2.149:Phenol index (PI) emissions for indirect discharges



NB: (*) IT157_w {1} and AT001_w {1} reported a % of waste water discharged from foundry below 50 %.
Source: [169, TWG 2021]

Figure 2.150:Total nitrogen (Total N) emissions for direct and indirect discharges

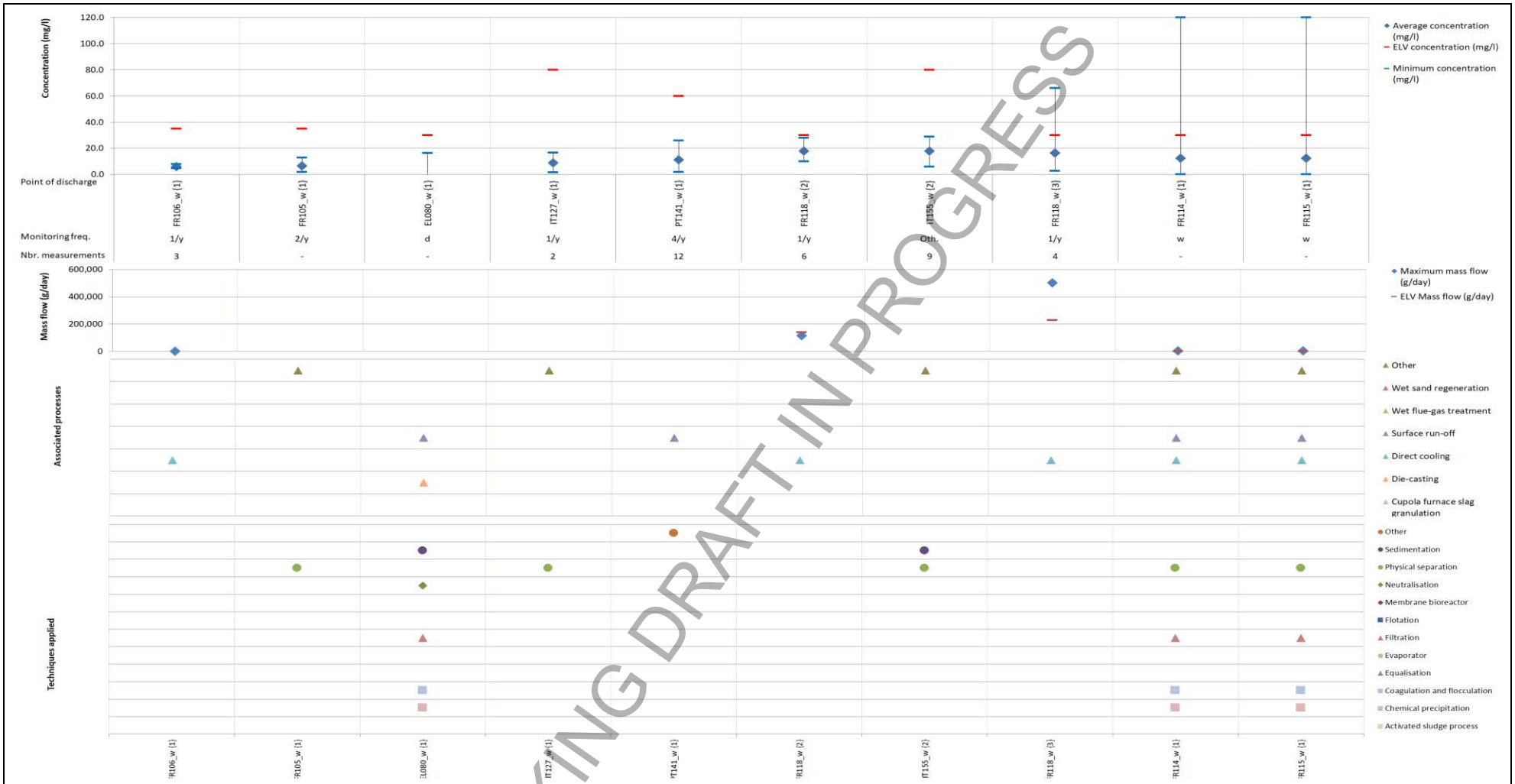


NB: For better visualisation, the values reported by DE033_w {1} (avg. = 306 mg/l, max. = 760 mg/l), SE148_w {1} (avg. = 453 mg/l, max. = 1 100 mg/l) and PT143_w {1} (max. = 4 000 mg/l) are not shown in the figure.

(*) AT001_w {1} reported a % of waste water discharged from foundry below 50 %.

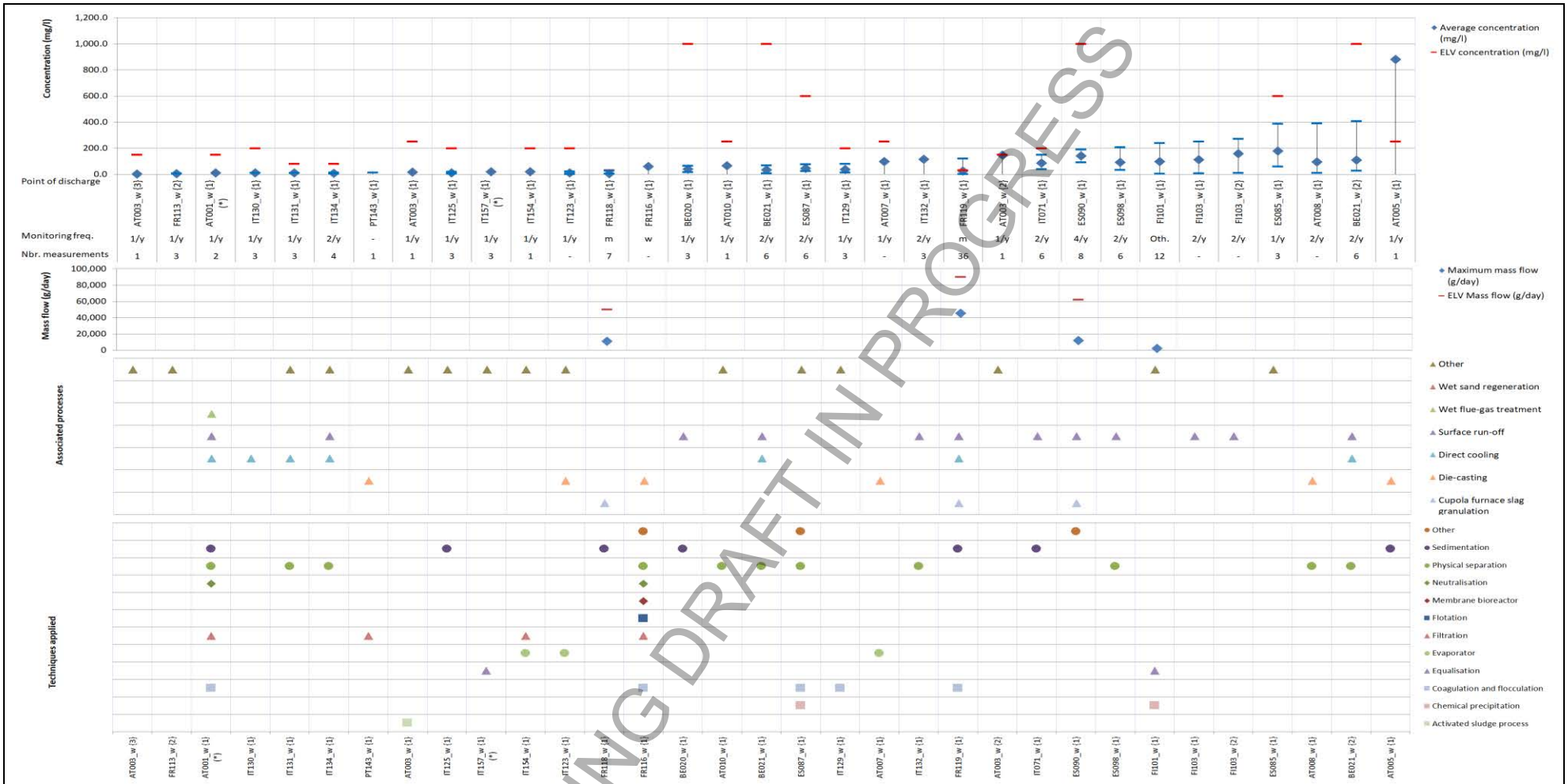
Source: [169, TWG 2021]

Figure 2.151:Total organic carbon (TOC) emissions for indirect discharges



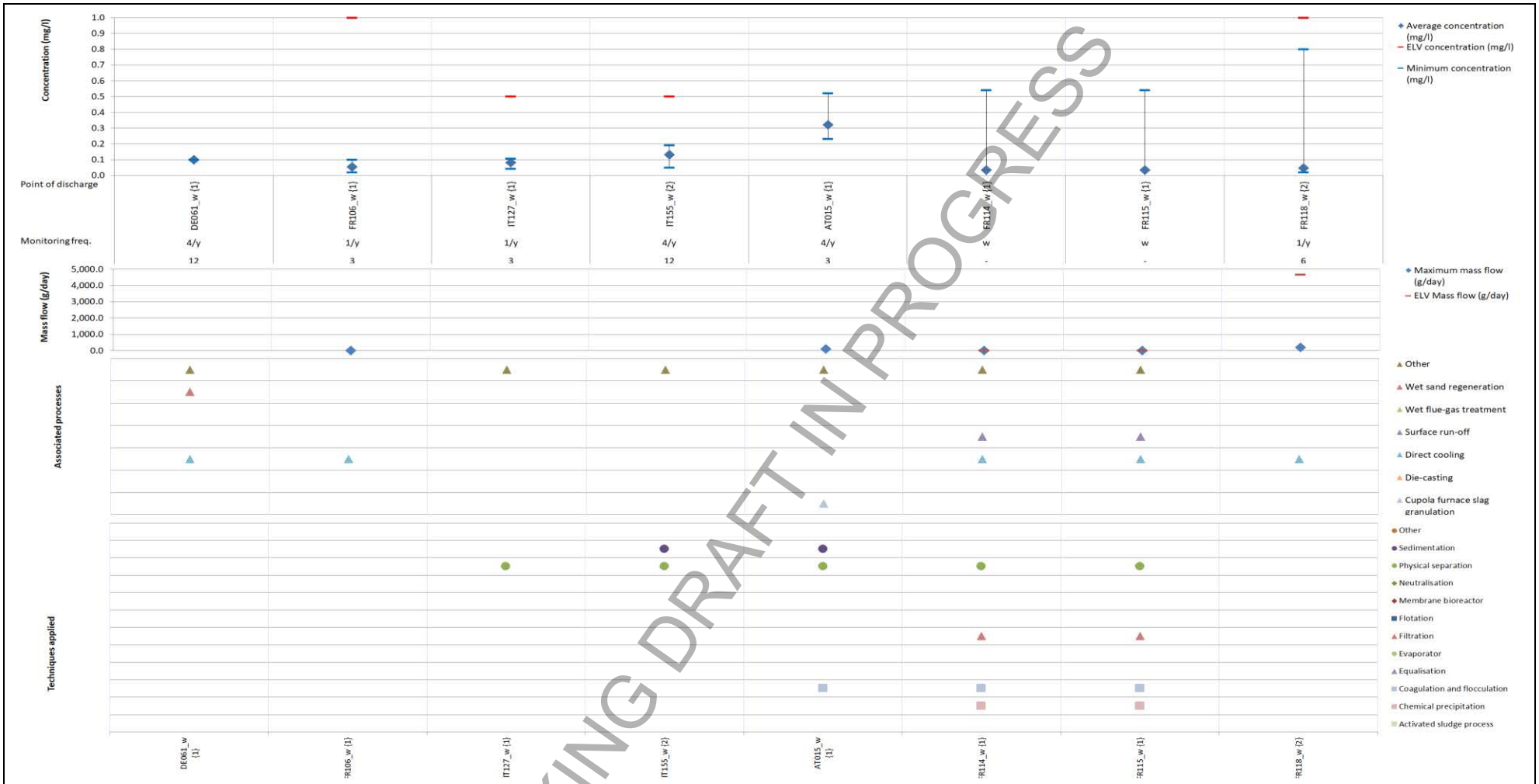
Source: [169, TWG 2021]

Figure 2.152:Total suspended solids (TSS) emissions for direct discharges



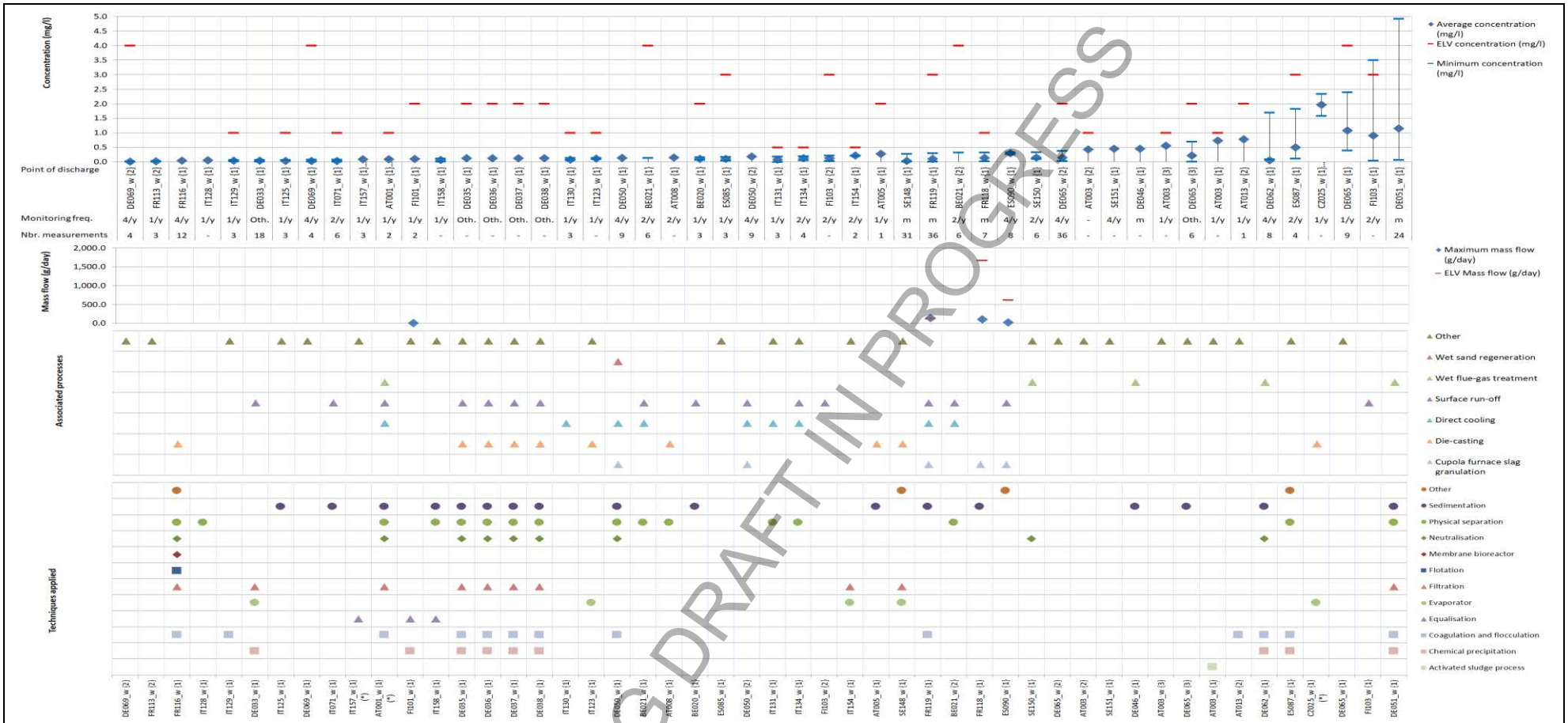
NB: (*) IT157_w {1} and AT001_w {1} reported a % of waste water discharged from foundry below 50 %.
Source: [169, TWG 2021]

Figure 2.153:Total suspended solids (TSS) emissions for indirect discharges



NB: For better visualisation, the ELVs over 1.0 mg/l are not shown. The ELVs range not shown is from 2.0 mg/l to 4 mg/l.
Source: [169, TWG 2021]

Figure 2.154:Zinc (Zn) emissions for direct discharges



NB: For better visualisation, the ELVs reported by ES090_w{1} of 10 mg/l is not shown in the figure.
(*) IT157_w {1}, AT001_w {1} and CZ025_w {1} reported a % of waste water discharged from foundry below 50 %.
Source: [169, TWG 2021]

Figure 2.155:Zinc (Zn) emissions for indirect discharges

2.3.4 Water consumption and waste water generation

2.3.4.1 Processes associated with water consumption

[169, TWG 2021]

Table 2.89 below shows the number of plants that reported data for specific water consumption (expressed in m^3 per tonne of liquid metal) for specific foundry processes.

Table 2.89: Number of plants which reported specific water consumption levels for specific foundry processes

Process	Number of plants which reported water consumption data
Moulding with wet sand	36
High-pressure die-casting	23
Wet treatment of used sand	12
Wet scrubbing for cold-box mould / core-making	10
Finishing process	5
Cooling	4
Wet scrubbing for core-making using the SO_2 process	4
Cupola furnace wet scrubbing	3

The reported levels of specific water consumption at plant level, expressed in m^3 per tonne of liquid metal, are presented in Figure 2.156, Figure 2.157 and Figure 2.158.

In Figure 2.159, the distribution of reported water consumption levels at process level, for specific foundry processes is presented.

2.3.4.2 Waste water generation from scrap storage

Scrap may have adhering soil, and external scrap typically exhibits production-specific impurities. The adhering impurities may be washed off when it rains and may then enter the soil and groundwater. An overview of the possible impurities is given in the following table.

Table 2.90: Possible impurities for specified scrap types

Scrap type	Adhering impurities
Swarf	Cutting oils, emulsions (may contain chlorine)
Punching scrap	Punching oils (may contain chlorine)
Broken machine castings, not conforming to specifications	Hydraulic oils, gear oils
Scrap from cold forming and smitheries	Phosphates, zinc soaps, graphite, forming oils
Source: [93, UBA 2003]	

If the adhering impurities are substances constituting a hazard to water (oils, emulsions), then requirements on the storage of substances constituting a hazard to water must be complied with.

2.3.4.3 Waste water generation from wet scrubbers used in cupola melting

Wet scrubbers are in use in melting shops to clean the cupola off-gases. Wet scrubbers use water to remove dust particles (average loading: 10-15 g/Nm^3) and gases such as sulphur dioxide from cupola off-gases. In the settling tank, a large part of the solid particles are captured and thereby almost completely removed from the scrubbing water.

The partly acid gases washed out of the cupola off-gases, such as sulphur dioxide, accumulate in the scrubbing water, causing its salt concentration to increase (e.g. the formation of sodium sulphate) and its pH to decrease. This salt accumulation is supported by evaporation losses, so it is necessary to draw the water off from time to time.

Waste water from wet dedusting systems in melting shops mainly contains:

- solids such as oxides of silicon, iron and aluminium, calcium carbonates and cyanides;
- heavy metals, although, with the exception of zinc, these are present only in very low concentrations;
- organic pollutants, which can enter waste water via soiled scrap.

AOX (adsorbable organically bound halogens) levels in water used for the scrubbing of cupola off-gases can amount to several milligrams. Possible causes of AOX are scrap coatings and adhering chlorinated organic compounds entering the water during the gas scrubbing process. Chlorinated organic compounds can also reach the water via auxiliaries, such as commercial-grade hydrochloric acid or iron and aluminium chlorides, which are used as flocculants.

Table 2.91 gives an overview of the pollutant concentrations in filter effluent from the dewatering of sludge from the wet scrubbers of cupola furnaces.

Table 2.91: Pollutant concentrations in filter effluent from dewatering the sludge from the wet scrubbers of cupola furnaces

Analyte	Units	Value
pH value		7.2 - 9.9
El. conductivity	µS/cm	1400 - 18400
Lead	mg/l	<0.01 - 2.5
Cadmium	mg/l	<0.01 - 0.03
Chromium	mg/l	<0.01 - 0.13
Copper	mg/l	0.02 - 0.89
Nickel	mg/l	0.04 - 0.23
Mercury	mg/l	< 0.001
Zinc	mg/l	1.8 - 27.9
Sulphate	mg/l	430 - 1550
Chloride	mg/l	1330 - 3947
COD	mg/l	154 - 7580
Source: [93, UBA 2003]		

2.3.4.4 Waste water generation from the casting, cooling and shake-out area and from mould production / sand preparation

In the casting, cooling and shake-out area and in mould production / sand preparation, insoluble fines from the moulding material are captured during dedusting, along with small organic proportions from the bonding agent used. If wet dedusting is applied, these compounds are found in the waste water flow. The inorganic solids are iron oxides and clays, which are in part finely dispersed and difficult to remove.

2.3.4.5 Waste water generation from core-making

In core-making shops, chemical scrubbers are in use. They use either acid (cold-box process) or basic (SO_2 process and Croning). The quantity of waste water discharged is dependent upon the accumulation of pollutants and salts in the circulating water. If pollution levels are too high, part of the polluted water must be drawn off.

Scrubbing solutions from cold-box and hot-box core-making contain readily biodegradable amines and phenols.

The treatment of amine-containing scrubbing solutions requires a nitrification/denitrification stage. These treatment steps can also be carried out in an external biological waste water treatment plant. An alternative to discharge is the recovery of the amines.

Following oxidation, scrubbing solutions from the SO_2 process mainly contain sodium sulphate. Since high sulphate concentrations (> 600 mg/l) can lead to damage to sewerage systems, a limit value is set by the respective competent authority according to local conditions (e.g. the presence of sulphate-resistant piping and dilution with other waste water).
[93, UBA 2003]

2.3.4.6 Data for specific water consumption levels

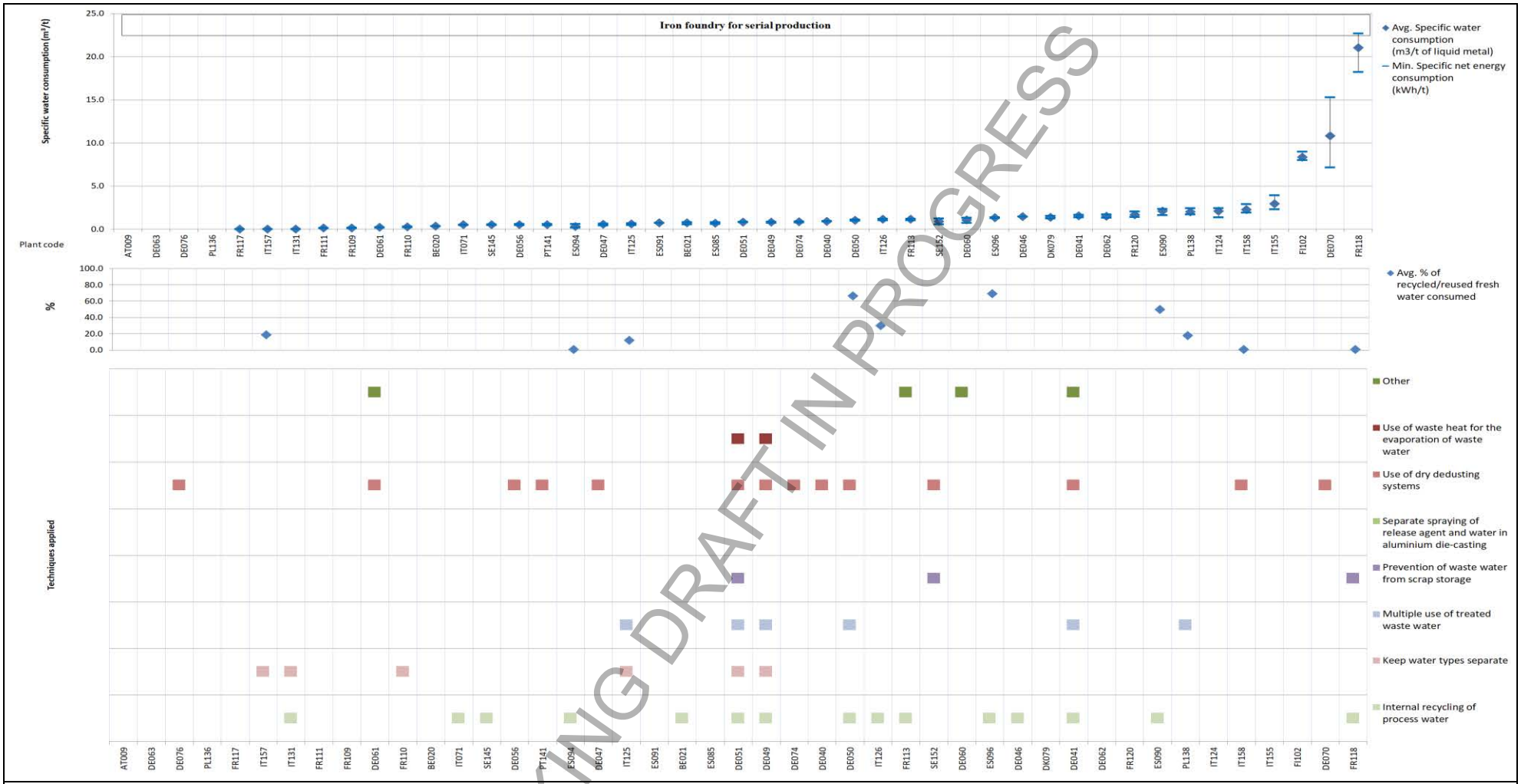
[TWG members, please check again the reported levels, especially some extremely high or low values reported]

The figures related to specific water consumption which are presented in this section are composed of three parts (sections):

- The upper part (first section) of the figure always shows the maximum, average and minimum reported values of specific water consumption for the 3 reporting years and the average values obtained over the reporting period. Below the x-axis, additional contextual information is included such as the plant number and the type of foundry.
- In the second part (section) of the figure, information is given related to the recycled/reused water expressed as a percentage (%) (over the 3-year reporting period) of the fresh water consumed.
- The third section of the figure contains information on the applied techniques to reduce water consumption.

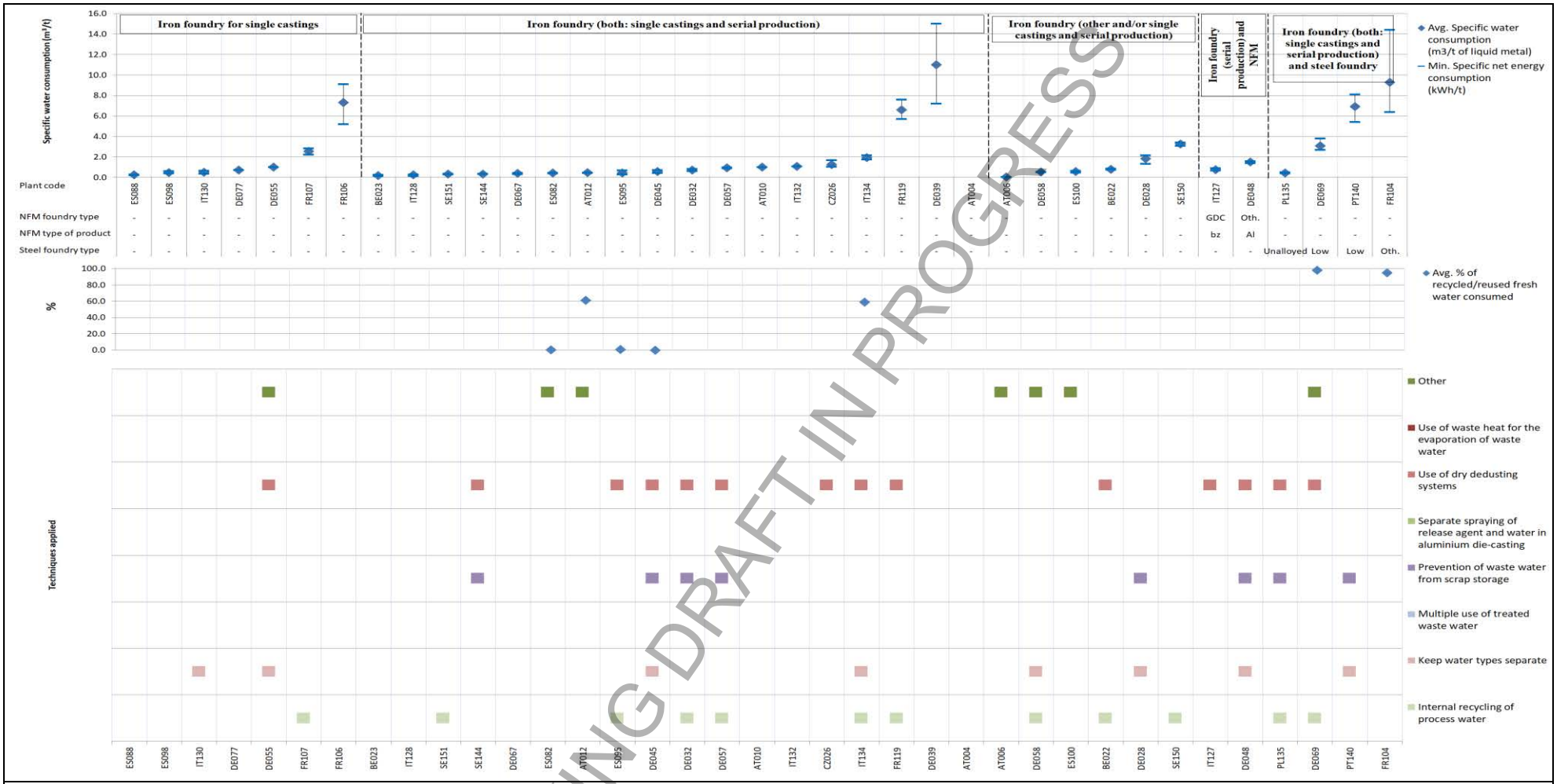
In addition to the three figures containing the reported data on specific water consumption at plant level, an additional figure presents the distribution of specific water consumption at process level. The relevant processes (according to the submitted data) are:

- high-pressure die casting;
- moulding with wet sand;
- wet treatment of used sand;
- wet scrubbing of col-blast cupola off-gases;
- finishing processes (machining);
- wet scrubbing for core-making off-gases.



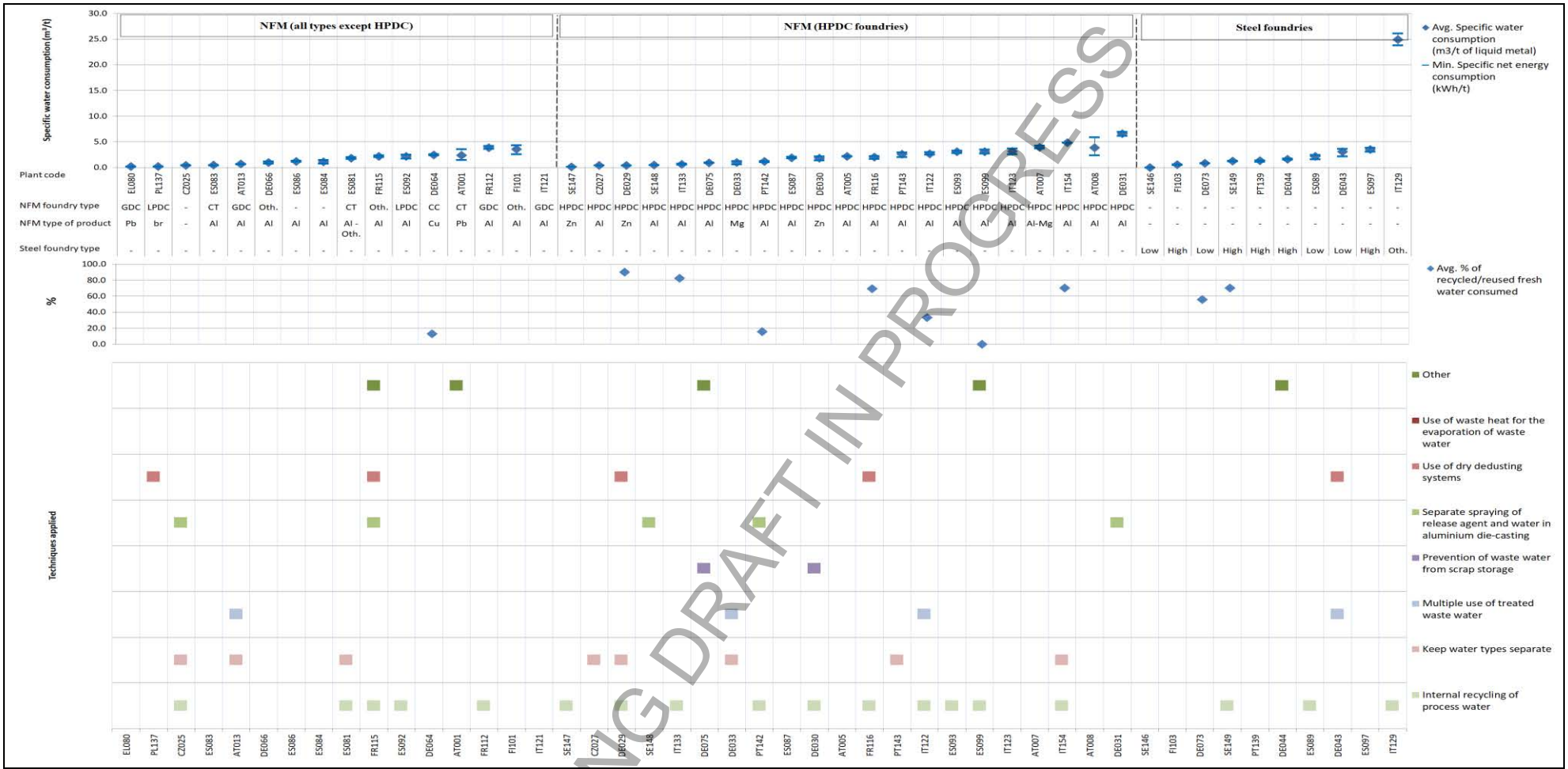
Source: [169, TWG 2021]

Figure 2.156:Specific water consumption (at plant level) (1/3)



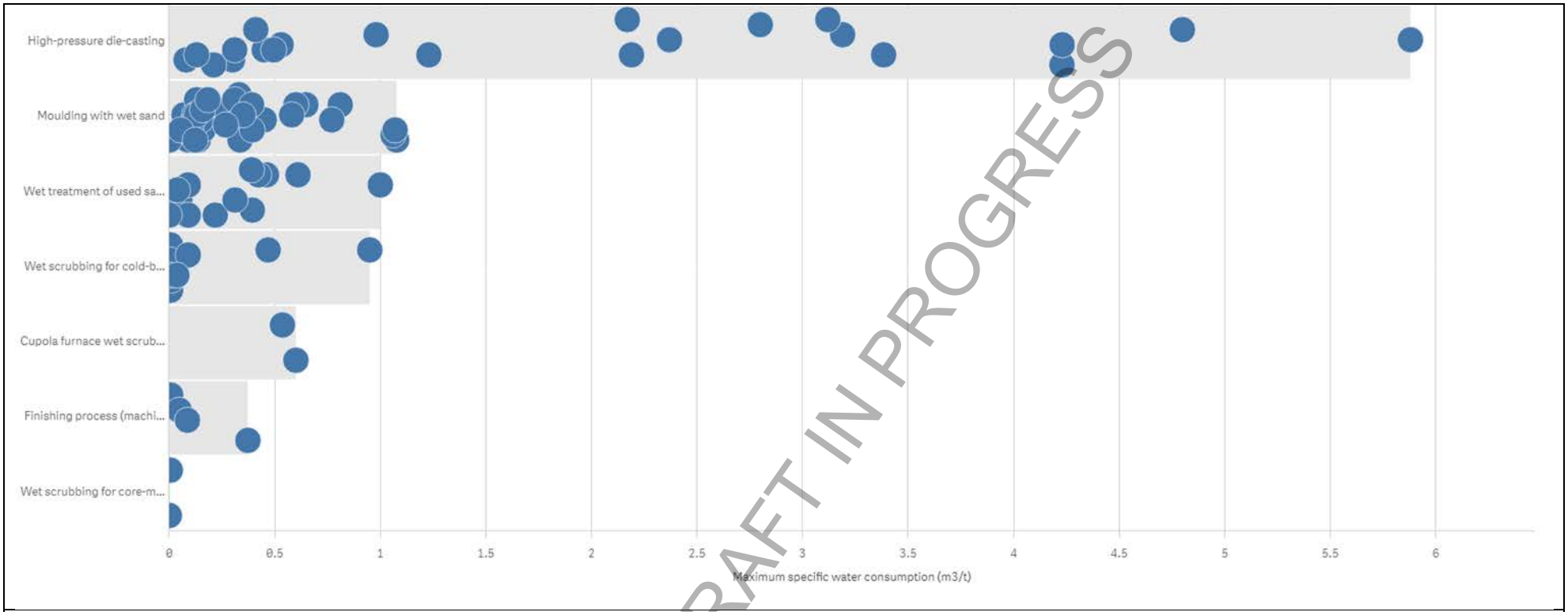
NB: For better visualisation, the values reported by AT004 of 57 330 m^3/t of liquid metal are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.157:Specific water consumption (at plant level) (2/3)



NB: For better visualisation, the values reported by IT121 (min. = 3 584 m³/t of liquid metal, avg. = 5 949 m³/t of liquid metal, max. = 10 284 m³/t of liquid metal) are not shown in the figure.
Source: [169, TWG 2021]

Figure 2.158:Specific water consumption (at plant level) (3/3)



Source: [169, TWG 2021]

Figure 2.159:Distribution of specific water consumption at process level

2.3.5 ~~Metal yield -~~ Operational Material Efficiency (OME)

The ~~metal yield~~ Operational Material Efficiency (OME), also called metal yield, is the ratio ~~of the amount of metal melted to the weight of the finished good castings.~~ of the total yearly amount (expressed in t) of final castings without defects divided by the total yearly amount of liquid metal output. Five main factors affect the OME ~~metal yield~~, i.e.:

- quality requirement;
- choice of mould-box size;
- the extent of runner and feeder systems;
- metal shrinkage;
- scrap casting rate.

[30, ETSU 1995]

Good castings loss (and therefore reduction in OME) occurs during all the following process steps [182, Salonitis et al. 2016]:

- melting: in the form of dross;
- holding: in the form of dross;
- casting: in the form of dross;
- fettling: the main process of generated recycling scrap;
- machining: the second major process of generated recycling scrap;
- inspection: recycling of rejected products.

Fettling is used to separate the casting from its running system. The casting itself is only about 50 % by weight of the entire casting system, although this depends on a number of aspects such as the number of castings per shot, the feeding and running system, etc. and can be up to 90 % for applications such as in the aerospace sector. Thus, reducing the weight of the running system can reduce the metal loss in fettling. Machining (including grinding, drilling and milling) contributes to metal losses as well. Therefore, the closer the casting is produced to net shape, the more the need for machining operations is reduced. The yield is finally affected by the rejections during the inspection process. Defects such as poor tolerance, poor surface finish, inclusions and porosity lead to rejection during the inspection. The last three types of losses are internal scrap. [182, Salonitis et al. 2016]

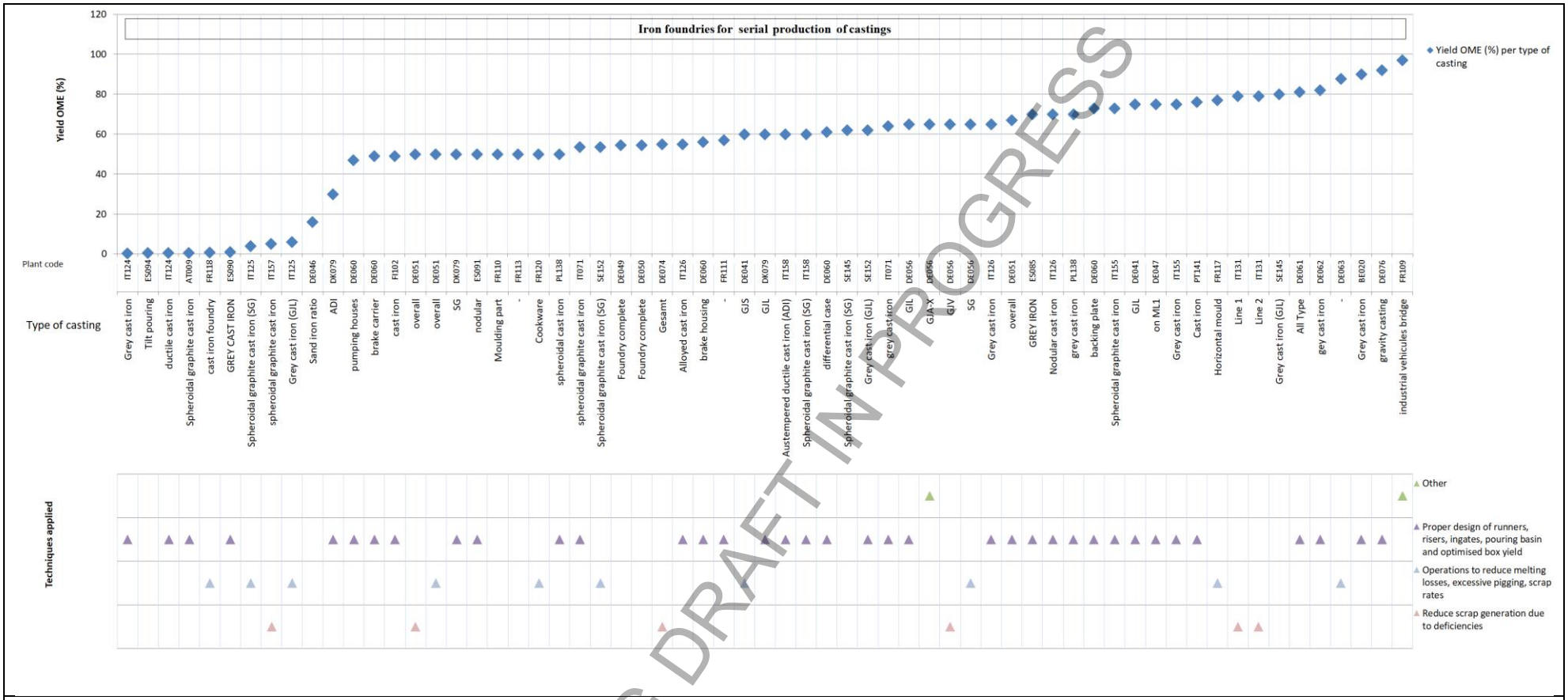
The reported levels of OME for various foundry types are presented in Figure 2.160, Figure 2.161, Figure 2.162 and Figure 2.163.

[TWG members please check again the reported OME data, especially some extremely low reported data e.g. < 1 %]

Some statistical data on the reported levels of OME for specific foundry types are presented ion the following table.

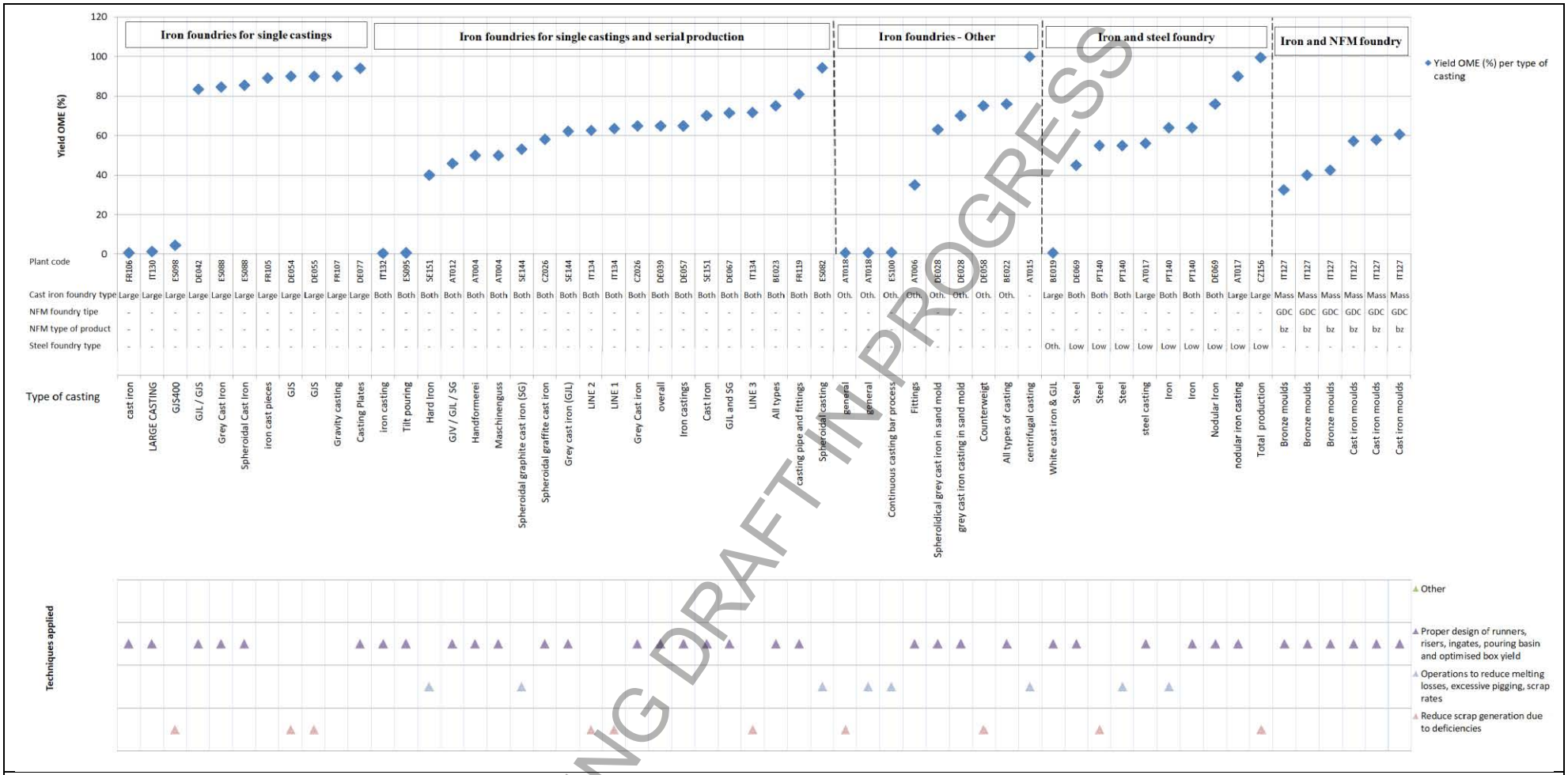
Table 2.92: Statistical parameters on the reported OME levels for specific foundry types

Foundry type / Parameter	Number of data	Min	10th percentile	Average	Median	90th percentile	Max
Iron foundries (serial production	63	0.3	4.2	54.5	60	79.8	97
Iron foundries (single castings)	11	0.6	1.24	64.8	85.5	90	94
Iron foundries (serial production and single castings)	20	0.46	36.07	57.3	63.1	75.6	94.3
Iron foundries (other)	9	0.7	-	46.8	63	-	100
Iron and steel foundries	10	0.6	-	40.56	60.5	-	99.5
Iron and NFM foundries	6	32.6	-	48.5	49.8	-	60.6
NFM (all types except HPDC)	33	0.5	28	62.7	63.5	96.2	98
NFM HPDC foundries	21	0.44	0.98	59.0	60.8	98	98
Steel foundries	17	0.5	0.67	49.3	55	68.4	100
Source: [169, TWG 2021]							



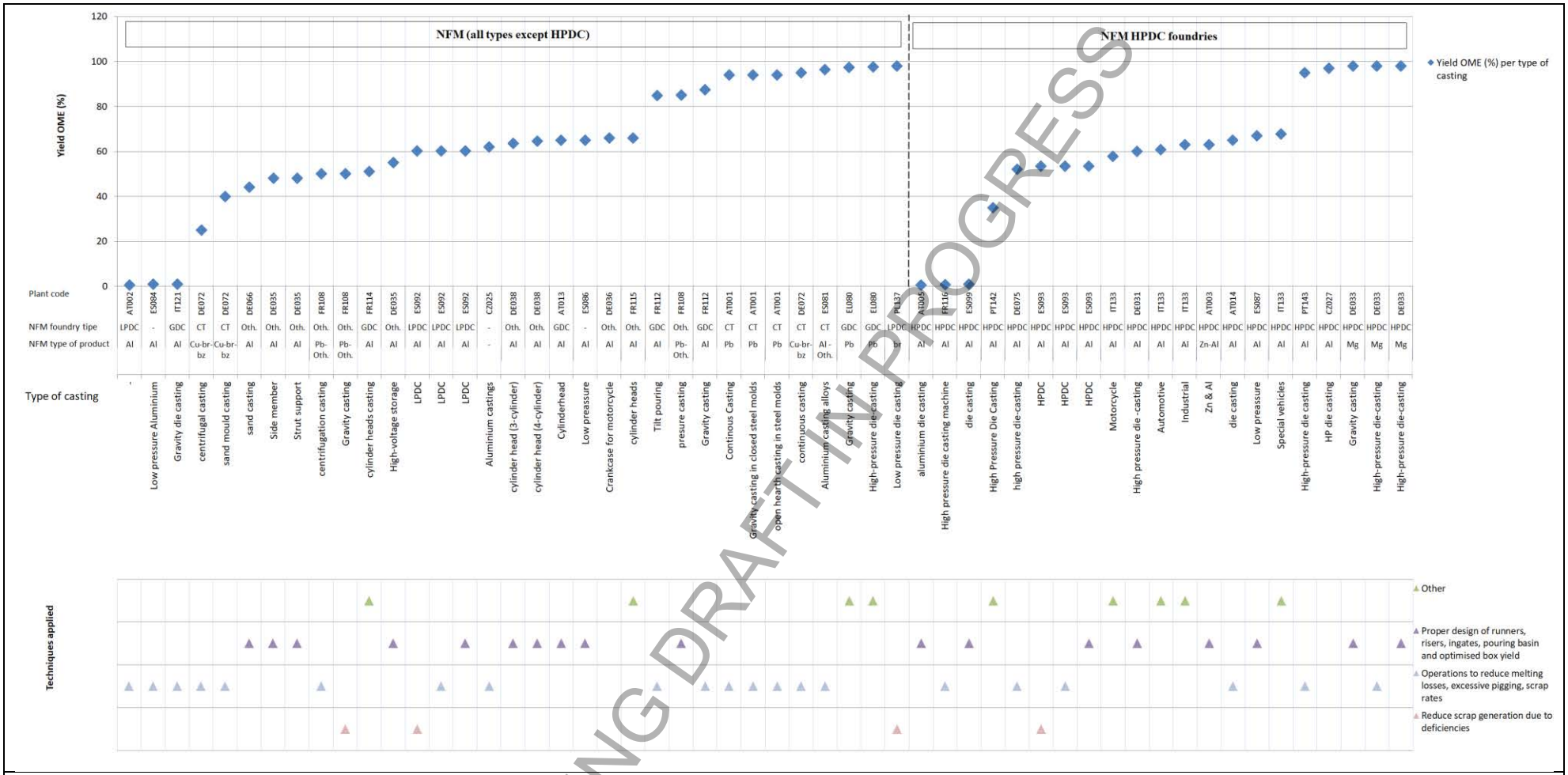
Source: [169, TWG 2021]

Figure 2.160:Operational material efficiency (1/4)



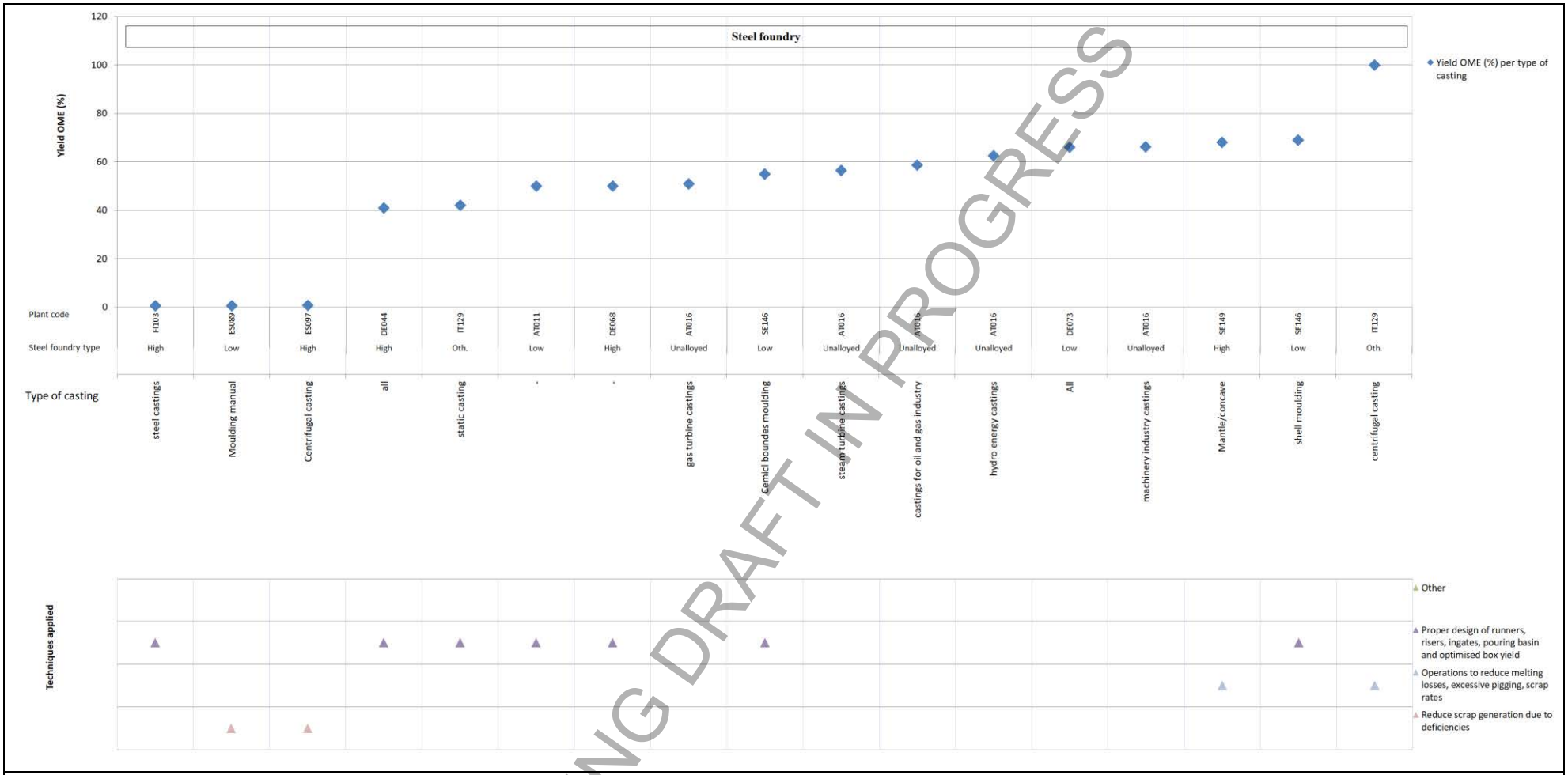
Source: [169, TWG 2021]

Figure 2.161:Operational material efficiency (2/4)



Source: [169, TWG 2021]

Figure 2.162:Operational material efficiency (3/4)

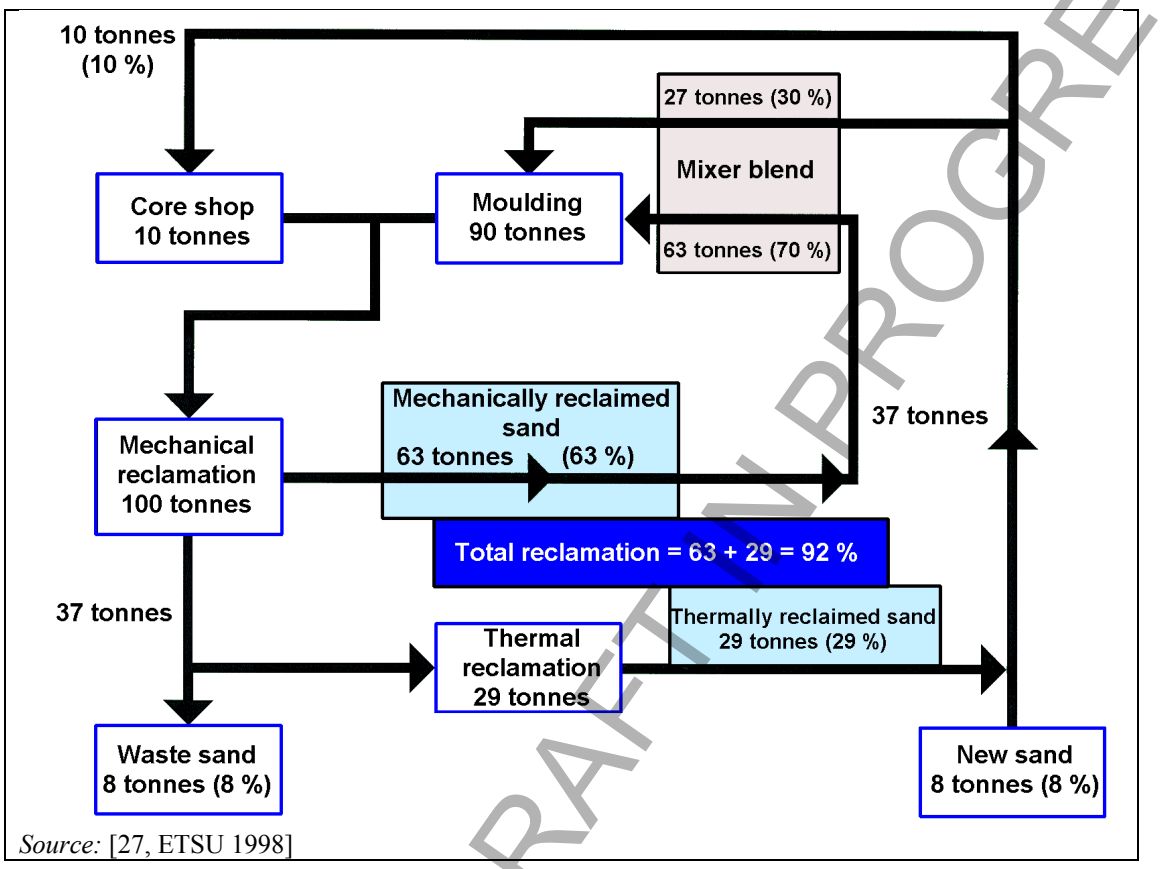


Source: [169, TWG 2021]

Figure 2.163:Operational material efficiency (4/4)

2.3.6 Sand regeneration ratio

The application of both primary and secondary regeneration in a mixed sand foundry in order to achieve a total regeneration of 92 % is shown in Figure 2.164. This simplified scheme does not take into account the various losses in the processing steps. The addition of new sand can be reduced to a minimum by integrating (the coarse fraction of) the filter dust sands (from the exhaust of hand forming lines, de-coring lines, storage silos, etc).



Source: [27, ETSU 1998]

Figure 2.164:Sand balance diagram for a thermal/mechanical regeneration system

An overall reclamation ratio of 92 %, as given above, is a normal value for mixed green sand / chemically bonded sand systems. Regeneration ratios of up to 98 % have been reported. The actual ratio depends on the volume and chemical composition of the used cores. For furan cold-setting monosands, values ~~around 78~~ of more than 90 % are reported.

Generally, the mixing of different types of sands has a negative effect on the strength of the cores and subsequently the moulds made with the regenerated sand, although there are a few exceptions to this general principle. In order to produce a good-quality regenerated sand, it is therefore of great importance to keep incompatible sand types separate. Optimisation of the regeneration potential may therefore imply changing to compatible binder systems, if mixed sands are used, or the application of (shake-out) techniques that allow the separation of various sand types. Table below provides an overview of cross-compatibility.

Table 2.93: Compatibility of regenerated sources sands with various binders

Source system \ Goal system		Bentonite	Silicate	Cold-setting	Hot-box	Croning	Cold-box		
							Methyl-formate	Amine	SO_2
Bentonite		+	0	0	-	0	0	0	0
Silicate		0	+	-	-	-	-	-	-
Cold-setting		+	-	+	-	0	-	0	+
Hot-box		0	-	+	+	+	-	0	+
Croning		+	+	+	+	+	+	+	+
Cold-box	Methyl-formate	0	+	0/-	-	-	0	0	-
	Amine	+	+	+	+	+	0	+	+
	SO_2	+	-	+	-	0	0	+	+

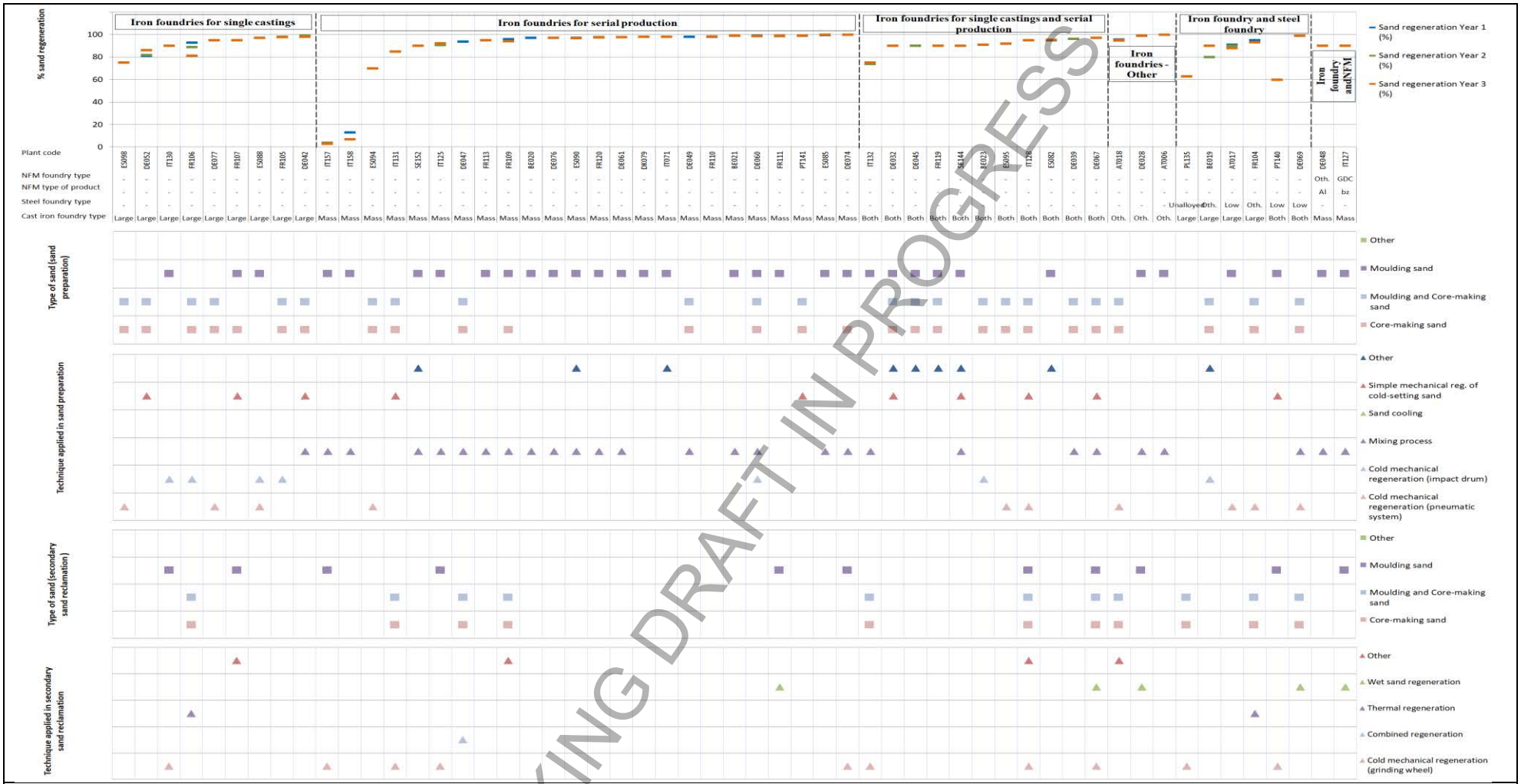
NB: +: Compatible, 0: Limited compatibility, -: Incompatible
Source: [17, Winterhalter et al. 1992], [120, TWG 2003]

Reported data on sand regeneration rate values (expressed as a percentage) are presented in this section.

It is noted that the collected data for sand regeneration rate refer to the ratio of the amount of reused sand divided by the amount of total sand, where:

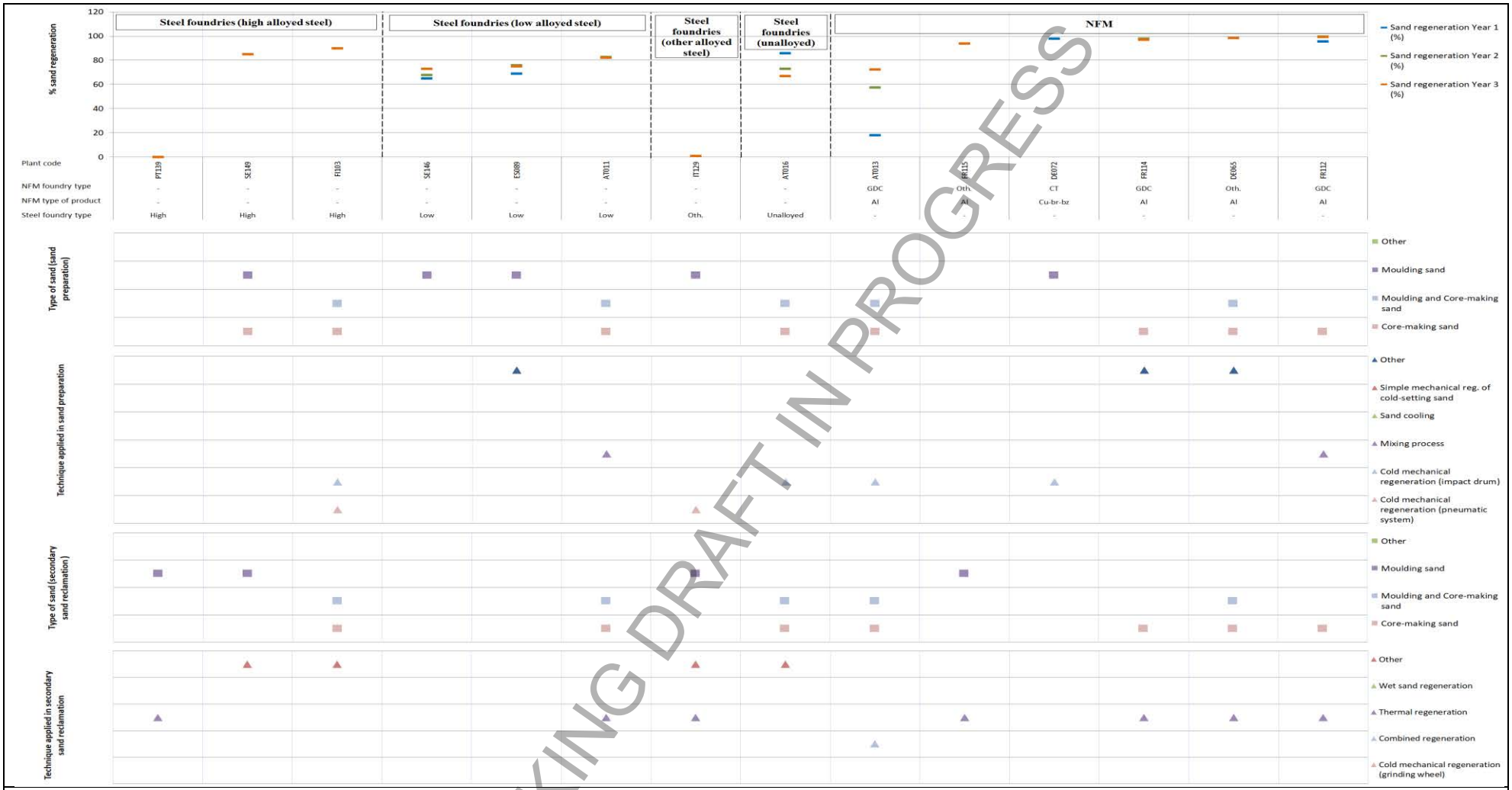
- reused sand is the quantity of primary reclaimed sand and of the secondary regenerated sand if relevant; and
- total sand is the quantity of reused sand and new sand.

[TWG members, please check again the reported levels, especially some extremely low values reported]



Source: [169, TWG 2021]

Figure 2.165:Sand regeneration ratio (1/2)



Source: [169, TWG 2021]

Figure 2.166:Sand regeneration ratio (2/2)

2.3.7 Residues/waste generation

[TWG members, please check again the reported levels, especially some extremely high values reported]

The main types of residues generated in foundries are the slag, dross and spent refractory linings from the melting/holding processes, the spent sand from the sand reconditioning/regeneration circuit and the filter dust collected in the dedusting systems.

2.3.7.1 Slag

Slags contain oxides that float upon the melt and which arise from impurities in the feed material, wearing of the furnace refractory and from the ash of coke and from the melting loss of the metal charge [120, TWG 2003]. Slags are bonded through the addition of binders, such as vermiculite.

The typical composition of cupola slag is given in the following table. A cupola furnace typically produces 40-80 kg slag per tonne of liquid iron.

Table 2.94: Typical cupola slag composition

Compound	%
SiO_2	45 – 55
CaO	25 – 40
Al_2O_3	8 – 20
MgO	1 – 3
MnO	1 – 4
FeO	1 – 6
Sulphides	<1
TiO_2	<1
ZnO	<0.1
Source: [71, Neumann, F. 1994], [59, Godinot 2001]	

Cupola slag consists of 30 % refractory material, 10 % sand (from internal scrap), 40 % CaO (flux), 10 % coke ashes, and 10 % burn-off material.

An important aspect of cupola slag is its high SiO_2 content. After quenching, the slag has a vitrified structure. This generates an inert non-leaching material.

The chemical composition of EAF slags are given in the following table. The reported values were based on the analyses of three samples.

Table 2.95: Chemical composition of EAF slag

Compound	Average (%)	Range (%)
SiO_2	36.2	28.6 – 41.8
CaO	12.4	7.2 – 17.7
MgO	22.1	18.3 – 27.0
Al_2O_3	8.4	7.4 – 0.1
FeO	0.7	0.5 – 1.0
MnO	14.8	4.0 – 29.6
TiO_2	1.2	0.39 – 2.7
Na_2O	0.3	0.11 – 0.57
K_2O	0.1	0.1 – 0.23
Source: [70, The Castings Development Centre 1999]		

The typical properties of induction furnace slags generated in ferrous foundries are given in the following table. Induction furnaces produce 10-20 kg slag per tonne metal charge. The amount of slag produced depends on the quality of the charge material. The lower limit of the given range applies if internal scrap is cleaned (blasted) before remelting.

Table 2.96: Typical composition of induction furnace slag

Compound	%
SiO_2	40 – 70
FeO	10 – 30
Al_2O_3	2 – 15
MnO	2 – 10
CaO	0 – 3
MgO	0 – 3
Source: [71, Neumann, F 1994]	

In aluminium foundries, the generated slag is estimated as follows:

- for shaft furnaces, the slag (with 35-40 % Al) generation is of the order of 40.3 kg/t of good casting [76, Silva Ribeiro, C. A. 2002];
- for crucible furnaces, the slag generation is of the order of 61 kg/t of good casting [76, Silva Ribeiro, C. A. 2002].

Slag from the AOD converter is particularly 'clean' of metal oxides, since, due to the peculiarity of the process, they are usually consumed. The slag composition is given in Table 2.97.

Table 2.97: AOD converter slag composition

Compound	%
CaO	50 – 70
Al_2O_3	5 – 25
SiO_2	10 – 25
MgO	5 – 15
Source: [202, TWG 2002]	

The reported levels for slag generation and management are presented in Section 2.3.7.6.

2.3.7.2 Dross

The reported levels for dross generation and management are presented in Section 2.3.7.6.

2.3.7.3 Waste refractory linings

The cupola furnace has the specific feature that the lining material (quartz-clay mixture) of the furnace at the melting zone only lasts for one melting campaign. The main part of the refractory is converted into slag. The amount to be removed and disposed of as waste is much smaller than the applied amount.
The reported levels for waste refractory linings' generation and management are presented in Section 2.3.7.6.

2.3.7.4 Filter dust

The reported levels for filtter dust generation and management are presented in Section 2.3.7.6.

2.3.7.5 Spent sand

Data and contextual information on the management of spent sand has been reported by:

- 88 plants for moulding sand;
- 40 plants for core-making sand;
- 19 plants for undefined use of sand.

The reported data (by management technique) are presented in the following tables.

[All TWG Member States' representatives are kindly asked to check with the operators that the spent sand information was correctly reported according to the definition of each option (re-use / recycling / recovery / disposal) indicated in the end notes of the questionnaires.]

Table 2.98: Reported data for re-use of spent sand (in kg/t of liquid metal)

Plant number	Min.	Average	Max.
ES088	2	3	3
DK079	55	75	95
DE052	286	308	345
PT140	705	786	920
FR114	997	1 028	1 060
FR115	997	1 028	1 060
FR105	1 551	1 587	1 631
FR104	1 450	2 097	2 640
SE150	2 998	3 044	3 088
AT017	3 013	3 159	3 232
FR106	4 320	5 101	5 938
IT071	6 814	6 904	6 993
DE040	6 643	6 898	7 241
ES082	7 005	7 109	7 283
FI102	7 412	7 418	7 423
FR109	10 000	10 000	10 000
DE070	9 589	10 125	10 510
SE151	307	5 683	11 058
FR111	15 486	17 283	20 086
DE066	31 620	31 760	31 960
DE077	360 000	531 000	788 000

Table 2.99: Reported data for recycling of spent sand (in kg/t of liquid metal)

Plant number	Min.	Average	Max.
IT157	0	0	0
FI103	1	1	1
DE043	1	1	1
DE069	1	1	1
DE049	1	1	2
ES082	-	2	3
FR109	0	4	5
AT006	9	11	13
FR114	2	11	21
FR105	21	22	23
ES096	1	18	26

FR119	4	20	38
IT071	14	26	39
BE023	20	33	41
DE065	8	32	51
ES091	1	29	64
FR115	62	64	67
DE039	59	63	69
DE058	70	76	81
BE020	68	76	83
AT017	70	83	100
IT130	89	103	114
DE040	118	121	122
AT011	124	130	139
AT009	124	134	143
FR110	0	92	164
IT127	166	183	211
AT012	198	206	214
FR111	187	206	238
FR112	54	122	238
BE022	37	127	255
PT141	11	122	255
FR113	232	241	257
SE149	313	330	358
IT134	266	342	419
DE070	276	346	432
SE150	449	471	494
IT125	410	471	526
ES092	578	597	617
ES089	362	546	748
PL135	950	1 007	1 100
PT140	116	1 058	2 300
AT004	2 167 000	2 403 500	2 640 000

Table 2.100: Reported data for recovery of spent sand (in kg/t of liquid metal)

Plant number	Min.	Average	Max.
FR118	3	3	4
SE150	6	13	18
AT010	24	24	24
DE039	55	58	63
FR112	34	47	67
ES085	25	60	88
DE051	32	79	125
ES094	136	136	136
DE049	131	140	149
DE050	0	82	167
DE057	174	174	174
FI102	14	111	209
IT132	193	214	235
PL138	65	157	249
DE041	26	151	349
DE056	348	357	376
BE023	126	271	438
SE151	491	491	491

ES095	368	448	527
DE046	103	403	796

Table 2.101: Reported data for disposal of spent sand (in kg/t of liquid metal)

Plant number	Min.	Average	Max.
DE043	0	0	0
DE061	0	0	0
PT139	0	0	0
AT012	1	1	1
DK079	2	4	5
DE050	0	4	8
SE150	5	8	12
FR107	18	18	18
ES096	19	19	19
DE054	21	21	21
FR118	26	28	30
DE072	13	24	34
AT009	3	19	34
DE065	0	15	34
AT015	36	36	36
FR113	15	28	40
DE070	0	13	40
ES085	5	20	43
ES082	58	60	63
DE060	3	35	70
DE042	56	63	75
DE040	80	83	86
FR117	4	32	94
DE052	59	84	106
DE074	45	76	107
ES094	105	141	159
FR104	112	139	166
DE053	128	150	179
DE067	153	177	194
SE145	20	124	230
DE032	213	224	234
DE045	244	254	263
SE152	16	140	264
ES095	293	293	293
SE144	210	245	296
FR120	278	285	298
DE046	22	139	301
DE048	266	290	314
DE047	20	166	329
AT017	234	281	335
IT124	278	311	343
DE068	269	298	357

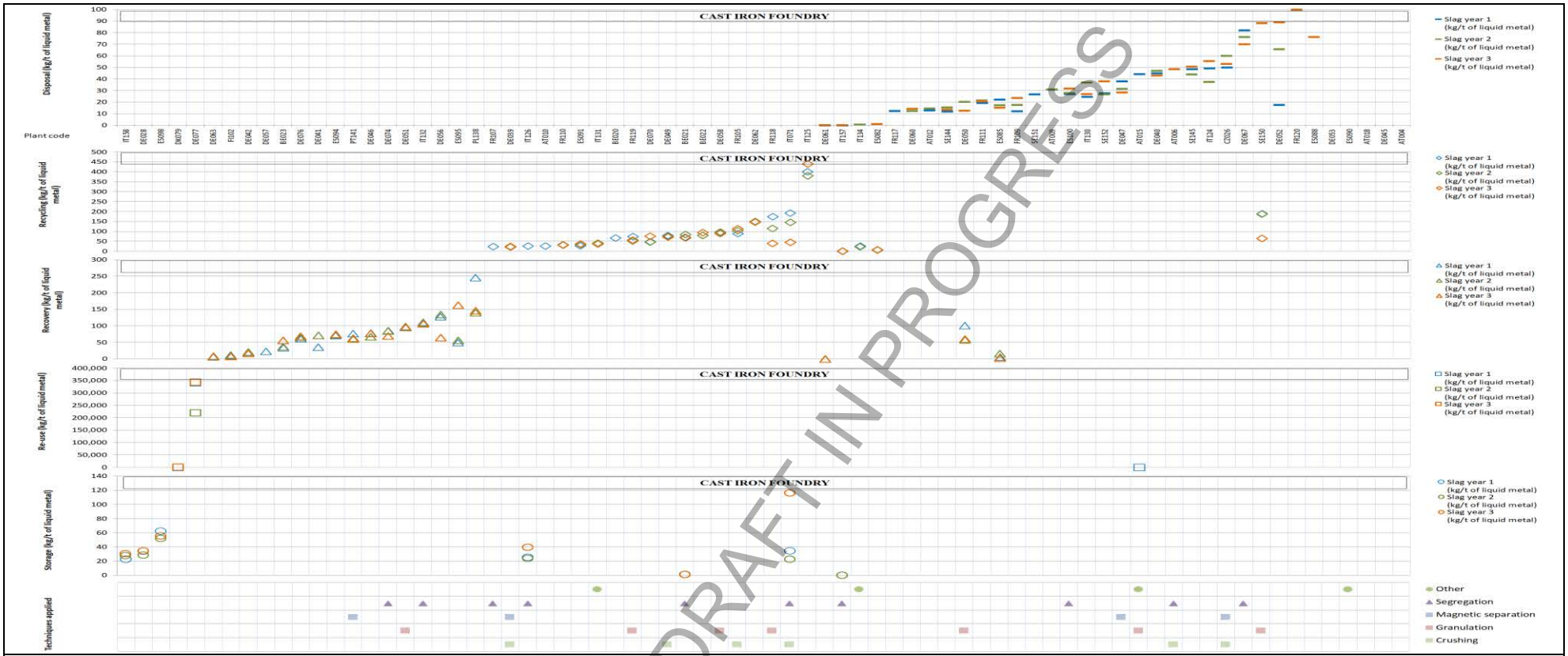
DE066	260	315	380
PL137	355	378	422
AT018	114	264	485
DE044	54	281	509
SE146	304	401	523
DE076	12	262	525
DE069	427	514	592
ES090	562	588	606
CZ026	687	698	716
ES089	476	608	777
FR106	540	730	980
CZ156	1 526	2 184	3 358
AT013	101	2 329	6 728

2.3.7.6 Figures showing residues quantities by residue type

In the following figures in this section, the specific quantities of residues are presented structured by residue type (i.e. slag, dross, filter dust and spent refractory linings) and by management technique (i.e. disposal, recycling, recovery, reuse and storage).

Dedicated figures present the specific quantities for each residue type sent for disposal with additional contextual information on the furnace type and the applied residue management techniques.

[All TWG Member States' representatives are kindly asked to check with the operators that the reported values / information was correctly reported according to the definition of each option (re-use / recycling / recovery / disposal) indicated in the end notes of the questionnaires.]



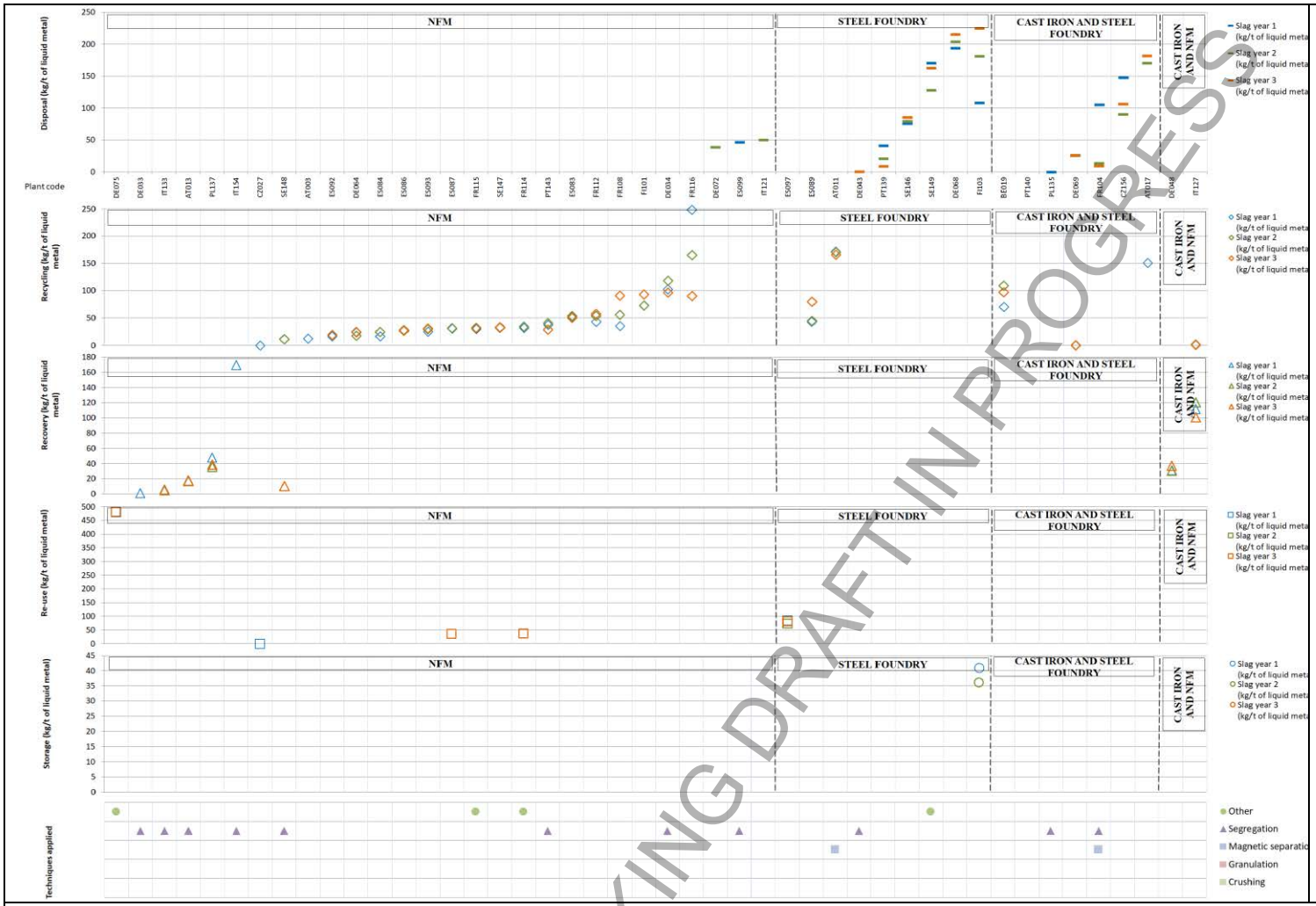
NB: For better visualisation, the following values are not shown in the figure.

Plant name	Year1 (kg/t of liquid metal)	Year2 (kg/t of liquid metal)	Year3 (kg/t of liquid metal)
FR120	99.97	100.01	99.98
ES088	140.95	139.087	76.25
DE053	107.96	122.4	151.35
ES090	137.83	144.19	158.61

Plant name	Year1 (kg/t of liquid metal)	Year2 (kg/t of liquid metal)	Year3 (kg/t of liquid metal)
AT018	138	180	176
DE045	269	121	-
AT004	240 000	-	-

Source: [169, TWG 2021]

Figure 2.167:Residues generation: Slag (1/2)



NB: For better visualisation, the following values are not shown in the figure.

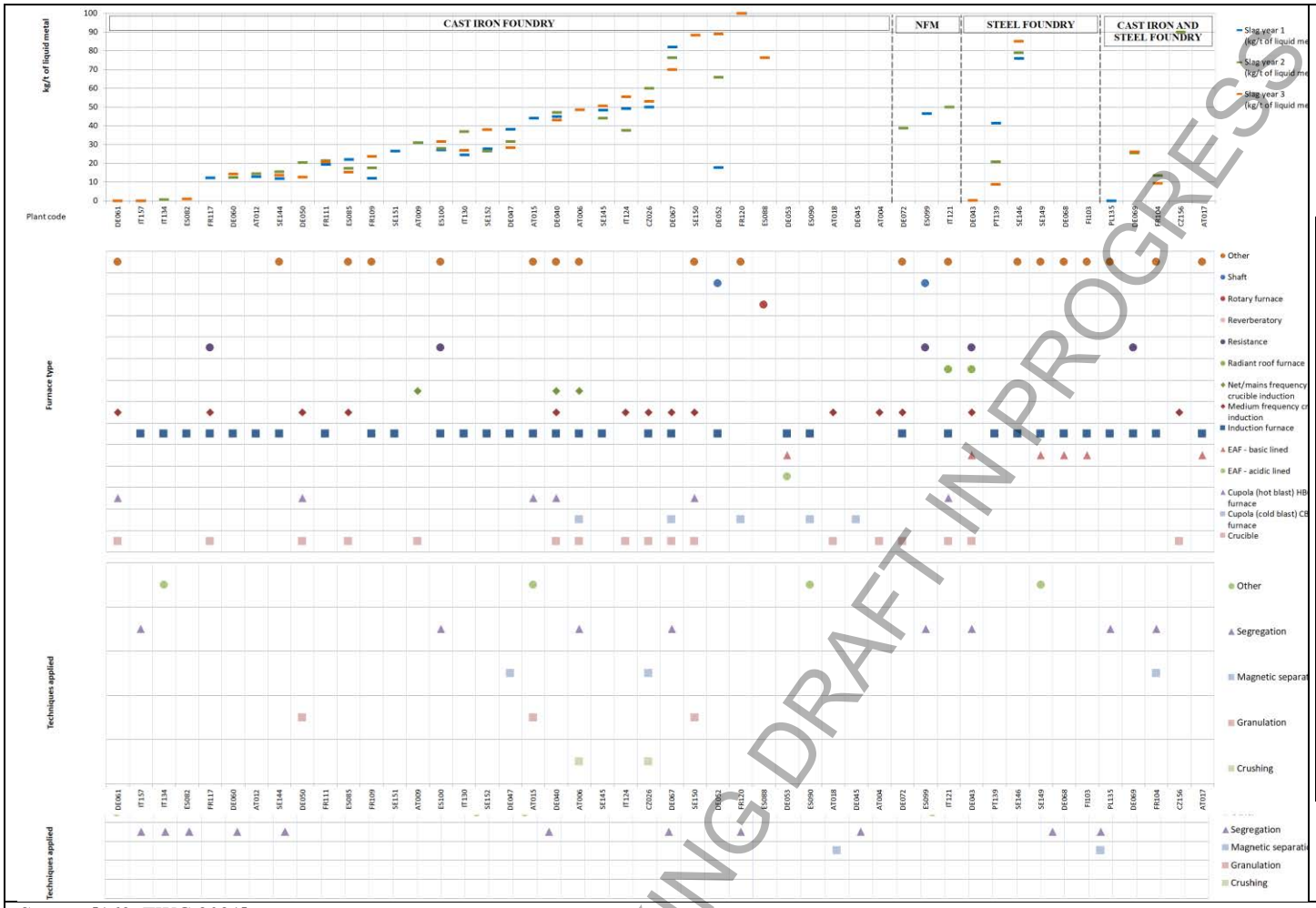
Plant name	Year1 (disposal) (kg/t of liquid metal)	Year2 (disposal) (kg/t of liquid metal)	Year3 (disposal) (kg/t of liquid metal)
IT121	28540	50	1000
SE149	170.8	127.5	162.4
DE068	193.91	203.96	215.2
FI103	108	181	225
FR104	105	13.4	9.3
CZ156	148	90	106
AT017	-	170.14	181.61

Plant name	Year1 (recycling) (kg/t of liquid metal)	Year2 (recycling) (kg/t of liquid metal)	Year3 (recycling) (kg/t of liquid metal)
IT121	-	13 140	-
PT140	266.12	474	375.32

Plant name	Year1 (re-use) (kg/t of liquid metal)	Year2 (re-use) (kg/t of liquid metal)	Year3 (re-use) (kg/t of liquid metal)
IT121	-	-	199 140
PT140	1 929.28	2 426	2 507.61

Source: [169, TWG 2021]

Figure 2.168:Residues generation: Slag (2/2)

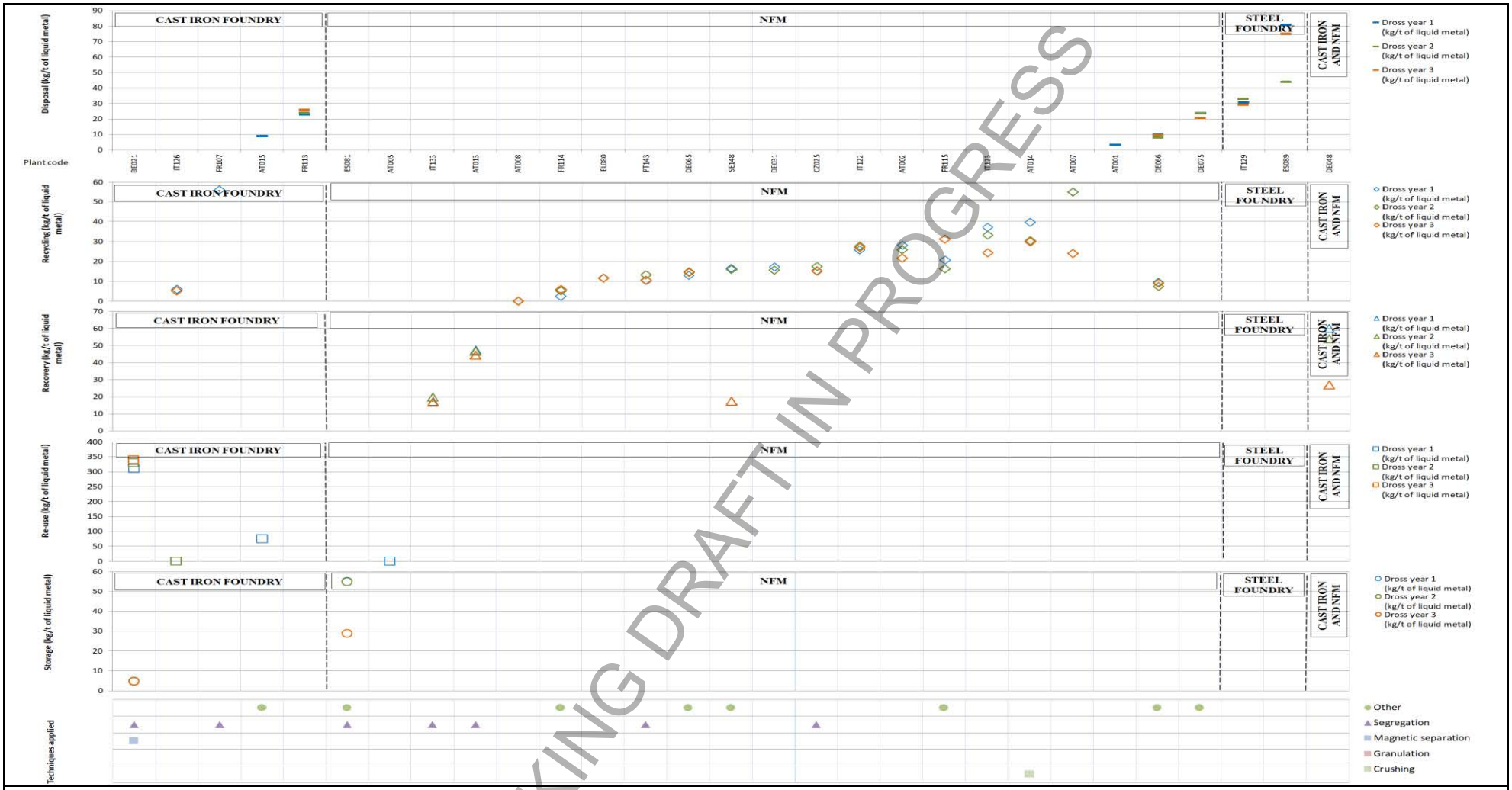


NB: For better visualisation, the values over 100 kg/t of liquid metal reported by the following plants are not shown in the figure.

Plant name	Year1 (kg/t of liquid metal)	Year2 (kg/t of liquid metal)	Year3 (kg/t of liquid metal)
FR120	99.97	100.01	99.98
ES088	140.95	139.08	76.25
DE053	107.96	122.4	151.35
ES090	137.83	144.19	158.61
AT018	138	180	176
DE045	269	121	-
AT004	240000	-	-
Plant name	**Year1 (kg/t of liquid metal)**	**Year2 (kg/t of liquid metal)**	**Year3 (kg/t of liquid metal)**
IT121	28540	50	1000
SE149	170.8	127.5	162.4
DE068	193.91	203.96	215.2
FI103	108	181	225
FR104	105	13.4	9.3
CZ156	148	90	106
AT017	-	170.14	181.61

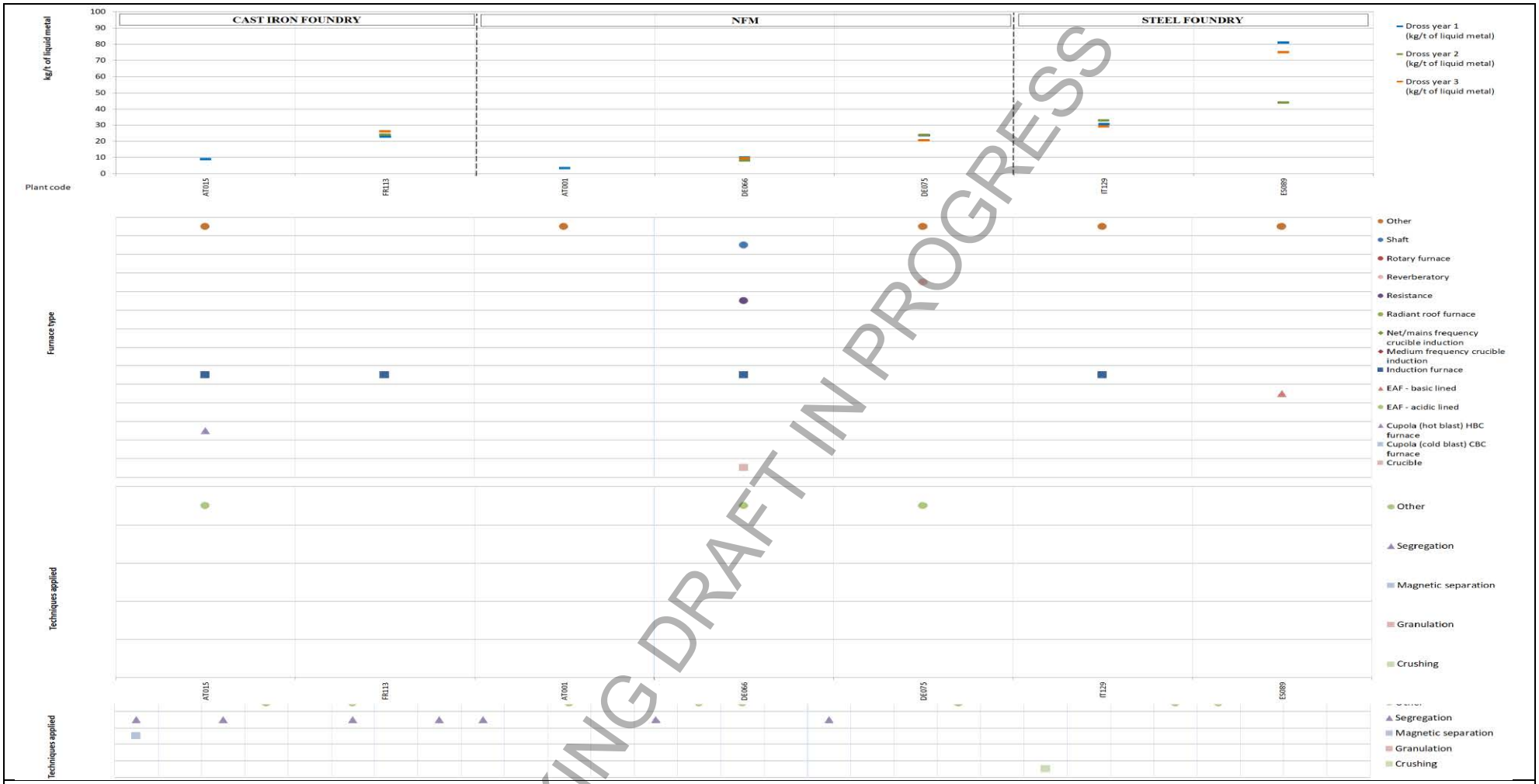
Source: [169, TWG 2021]

Figure 2.169:Slag sent for disposal



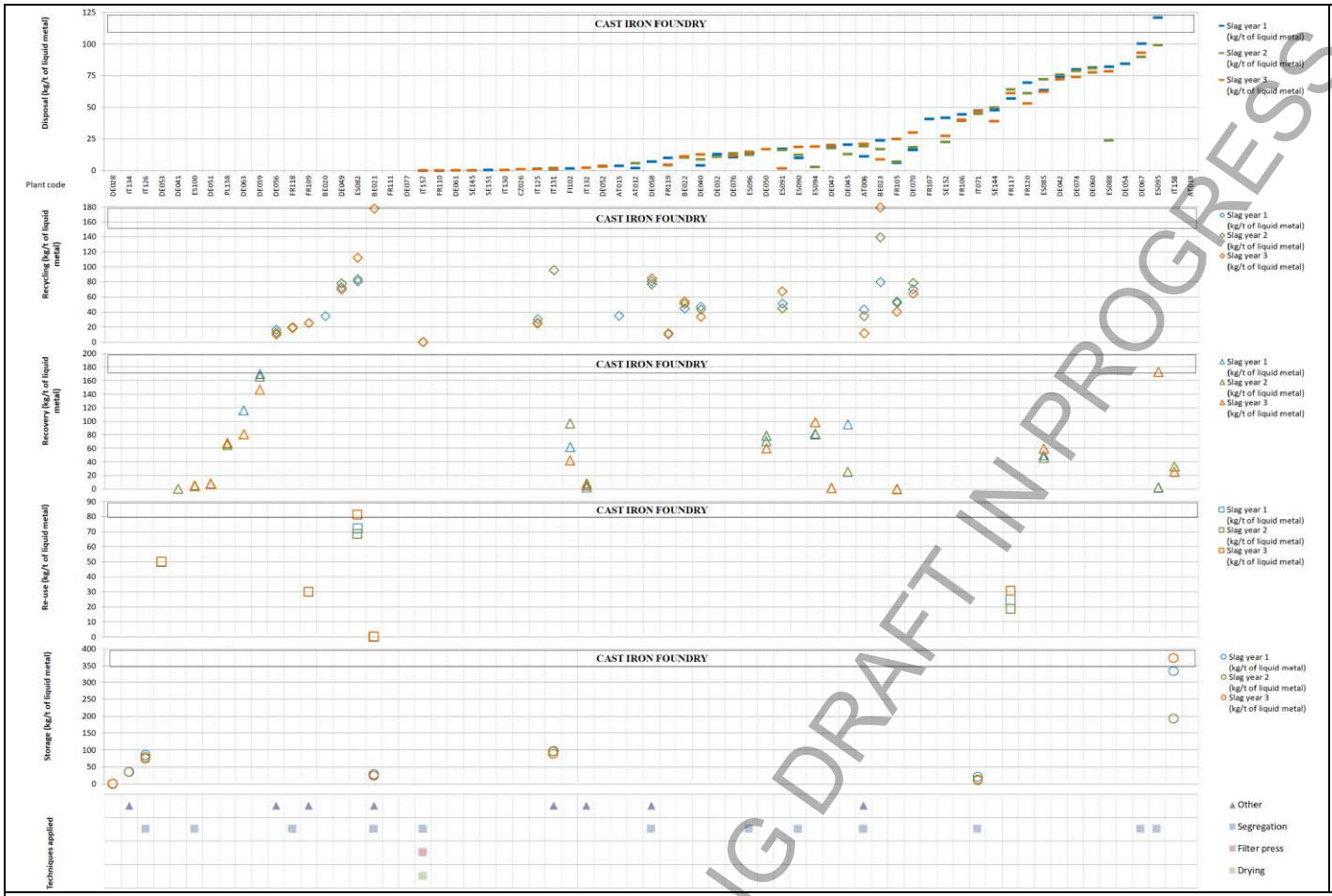
Source: [169, TWG 2021]

Figure 2.170:Residues generation: Dross



Source: [169, TWG 2021]

Figure 2.171:Dross sent for disposal

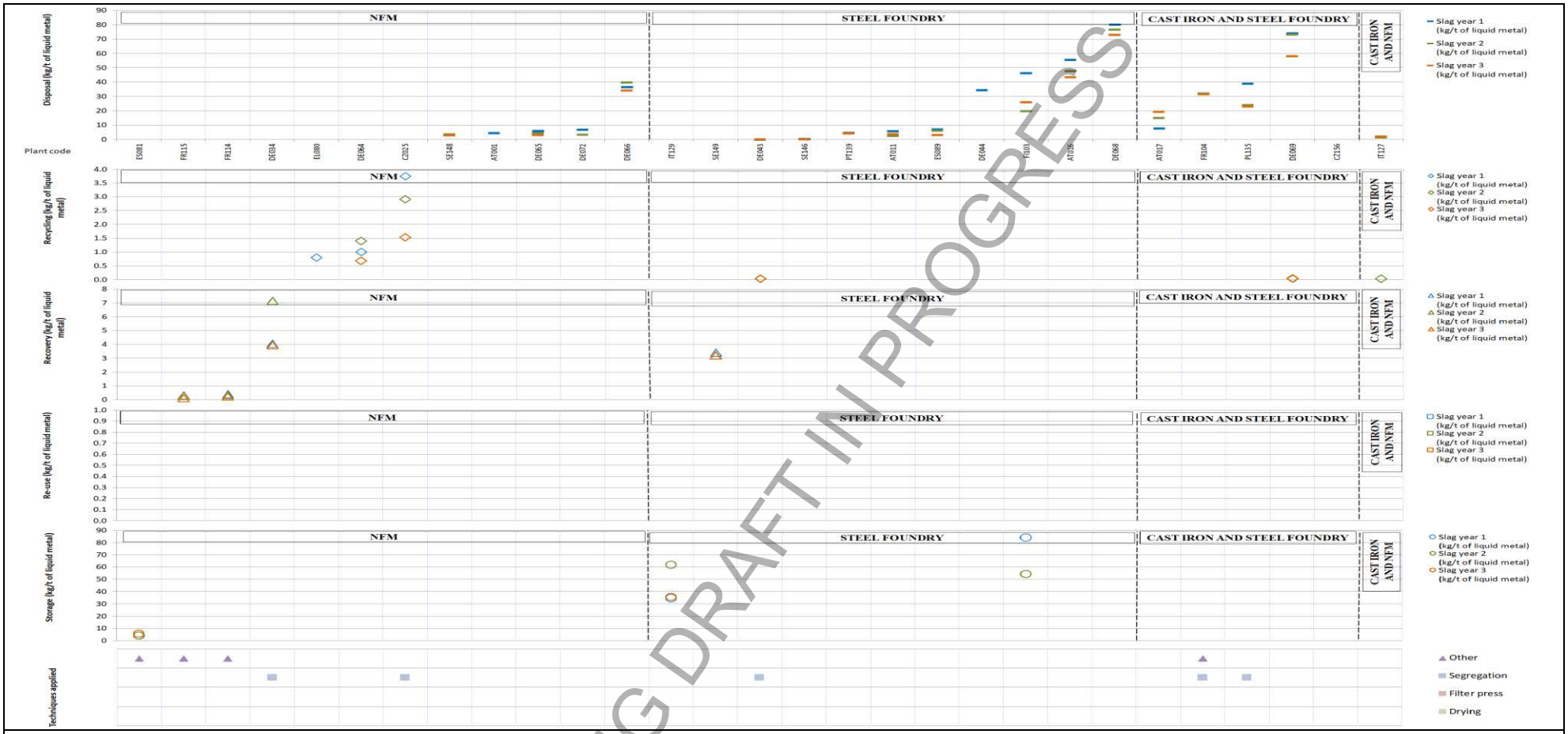


NB: For better visualisation, the following values are not shown in the figure.

Plant name	Year1 (disposal) (kg/t of liquid metal)	Year2 (disposal) (kg/t of liquid metal)	Year3 (disposal) (kg/t of liquid metal)
IT158	352.52	472.7	399.8
AT018	478	907	863
Plant name	**Year1 (re-use) (kg/t of liquid metal)**	**Year2 (re-use) (kg/t of liquid metal)**	**Year3 (re-use) (kg/t of liquid metal)**
DE077	67 050	31 760	44 500
Plant name	**Year1 (recycling) (kg/t of liquid metal)**	**Year2 (recycling) (kg/t of liquid metal)**	**Year3 (recycling) (kg/t of liquid metal)**
BE021	191.50	204.12	177.99
FR111	630.75	519.97	572.1
DE077	43860	42300	17908

Source: [169, TWG 2021]

Figure 2.172:Residues generation: Filter dust (1/2)

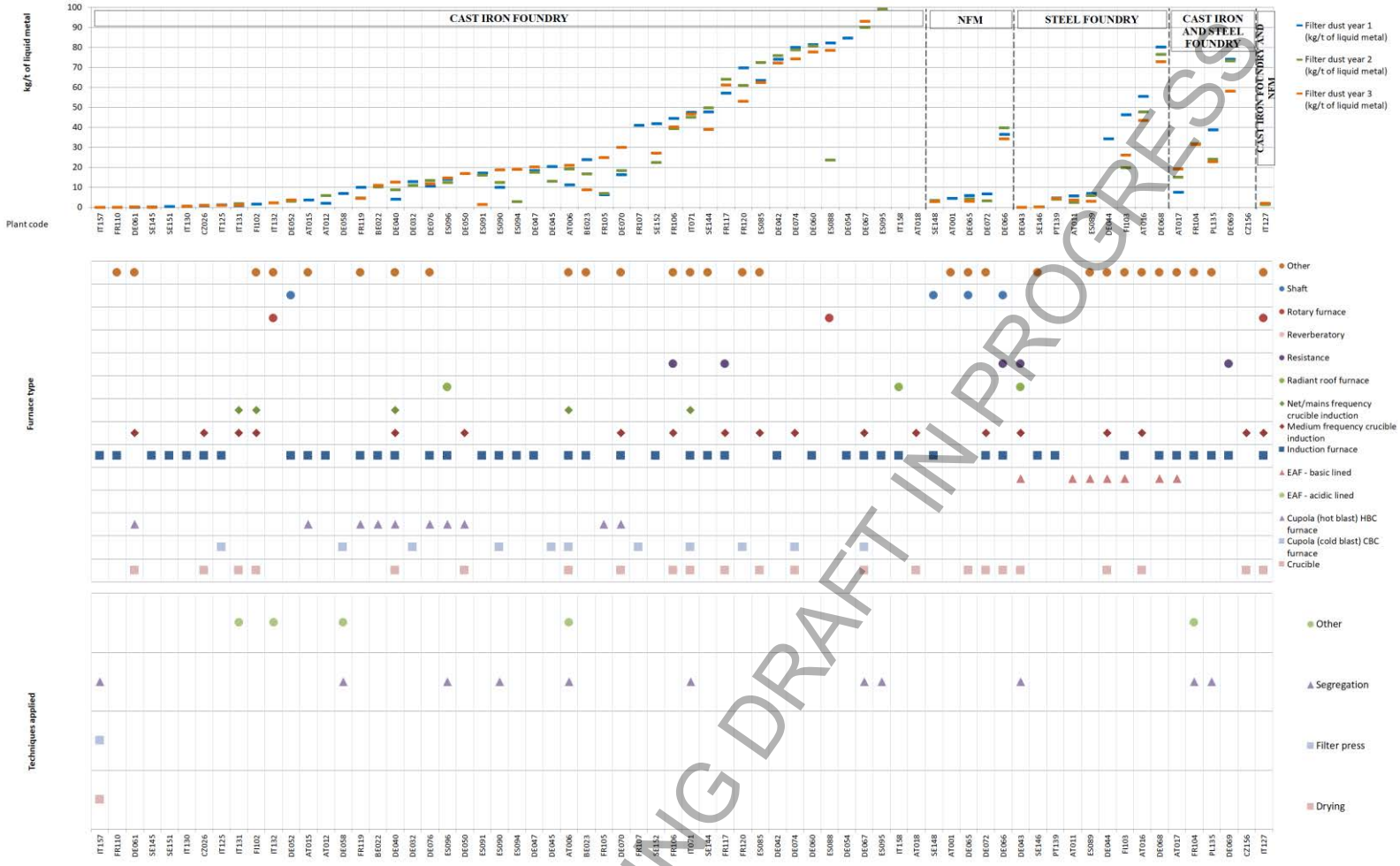


NB: For better visualisation, the following values are not shown in the figure.

Plant name	Year 1 (kg/t of liquid metal)	Year 2 (kg/t of liquid metal)	Year 3 (kg/t of liquid metal)
CZ156	308	477	444

Source: [169, TWG 2021]

Figure 2.173:Residues generation: Filter dust (2/2)

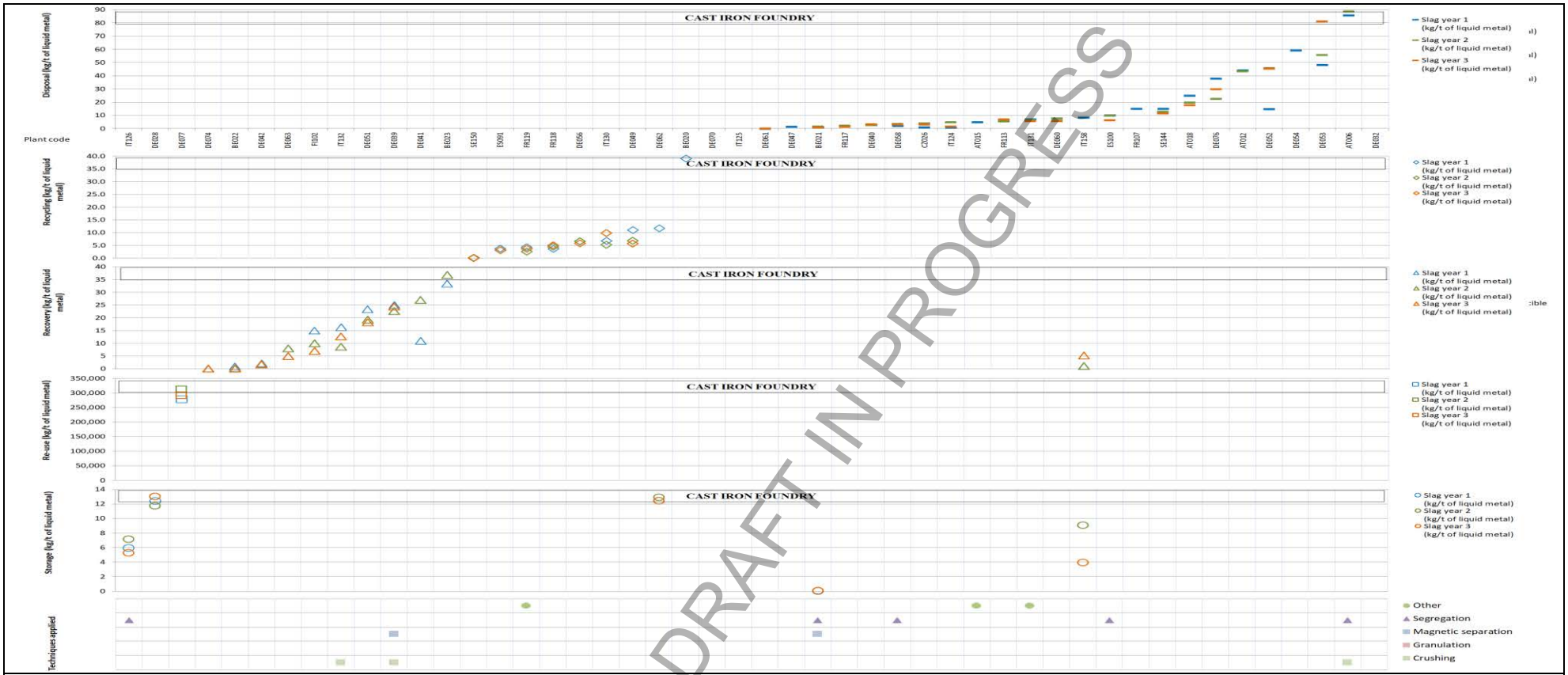


NB: For better visualisation, the values over 100 kg/t of liquid metal reported by the following plants are not shown in the figure.

Plant name	Filter dust year 1 (kg/t of liquid metal)	Filter dust year 2 (kg/t of liquid metal)	Filter dust year 3 (kg/t of liquid metal)
DE067	100.6	89.9	93.1
ES095	121.13	99.18	-
IT158	352.52	472.7	399.8
AT018	478	907	863
CZ156	308	477	444

Source: [169, TWG 2021]

Figure 2.174:Filter dust sent for disposal



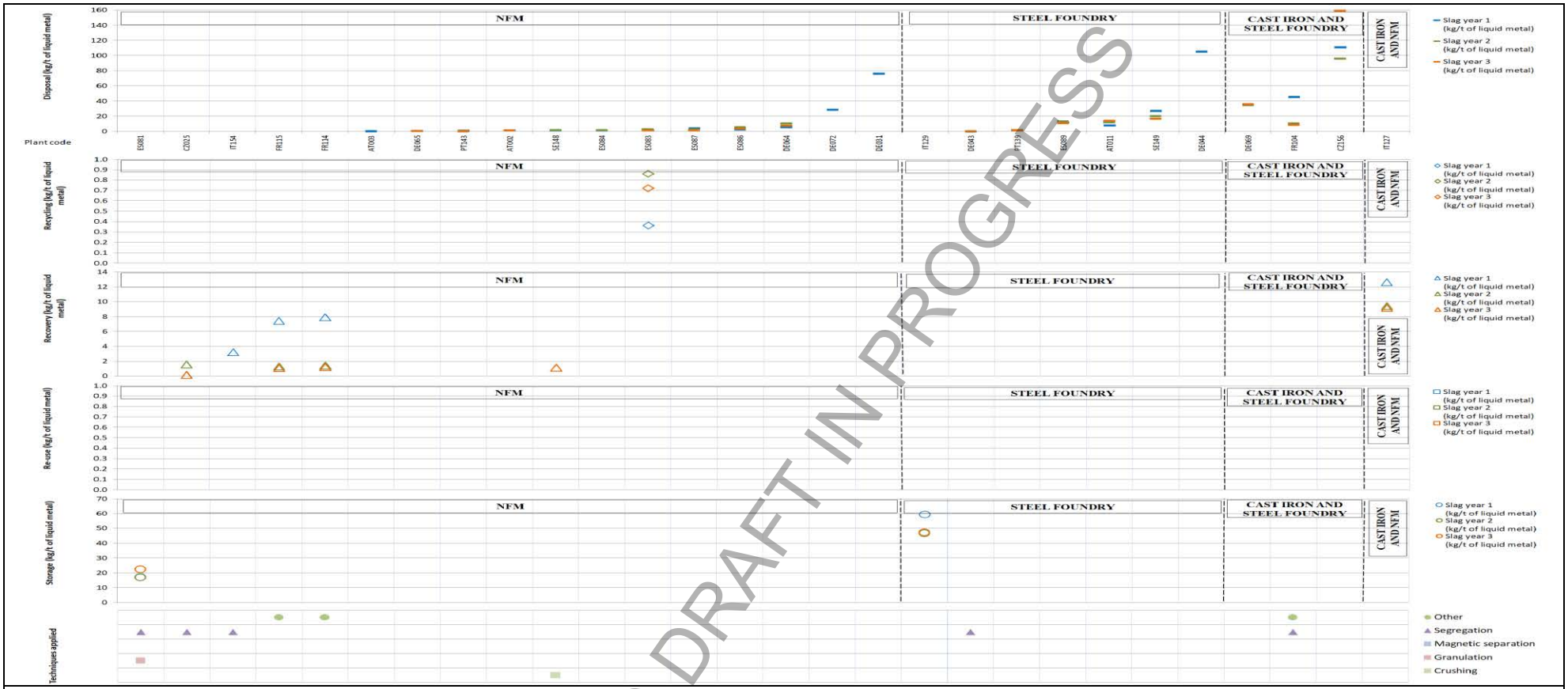
NB: For better visualisation, the following values are not shown in the figure.

Plant name	Year 1 (disposal) (kg/t of liquid metal)	Year 2 (disposal) (kg/t of liquid metal)	Year 3 (disposal) (kg/t of liquid metal)
AT006	85.71	88.57	111.42
DE032	138	128	-

Plant name	Year 1 (recycling) (kg/t of liquid metal)	Year 2 (recycling) (kg/t of liquid metal)	Year 3 (recycling) (kg/t of liquid metal)
DE070	55.12	71.29	56.26
IT125	126	90	148

Source: [169, TWG 2021]

Figure 2.175:Residues generation: Refractory lining (1/2)

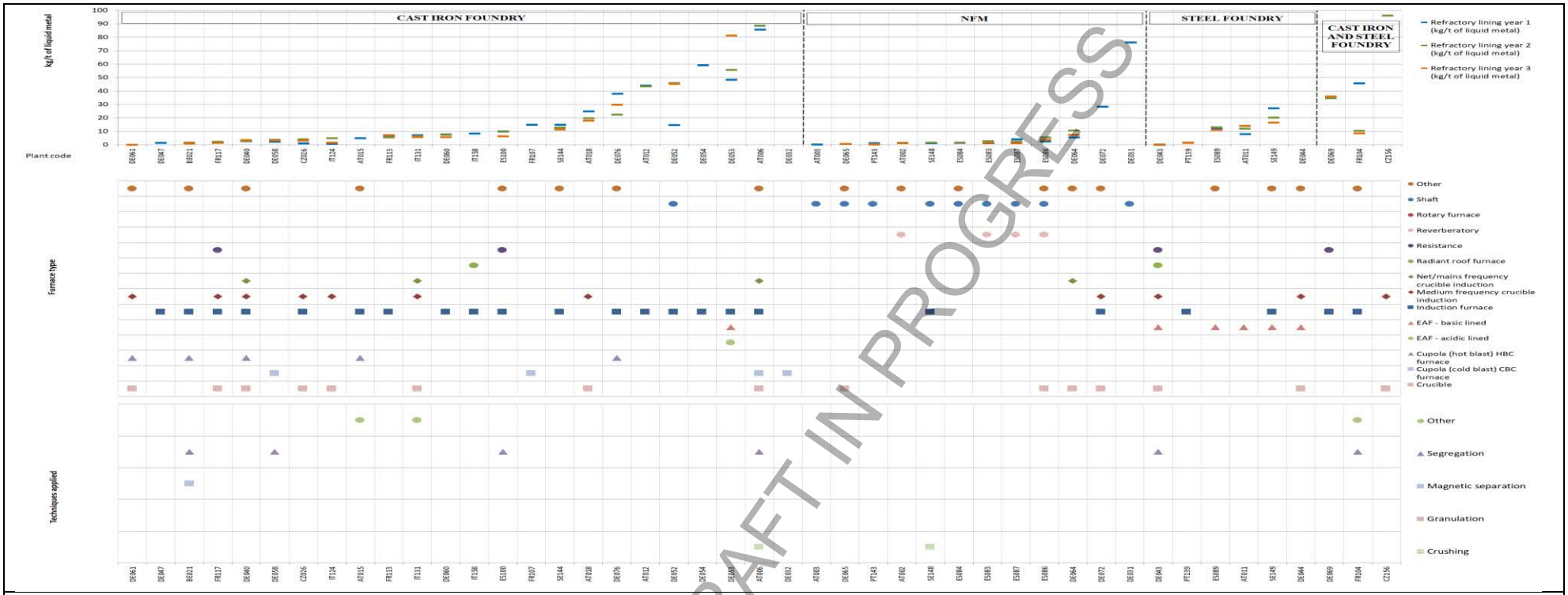


NB: For better visualisation, the following values are not shown in the figure

Plant name	Refractory lining year 1 (kg/t of liquid metal)	Refractory lining year 2 (kg/t of liquid metal)	Refractory lining year 3 (kg/t of liquid metal)
DE031	76.24	213.26	-

Source: [169, TWG 2021]

Figure 2.176:Residues generation: Refractory lining (2/2)



NB: For better visualisation, the values over 100 kg/t of liquid metal reported by the following plants are not shown in the figure.

Plant name	Refractory lining year 1 (kg/t of liquid metal)	Refractory lining year 2 (kg/t of liquid metal)	Refractory lining year 3 (kg/t of liquid metal)
AT006	85.71	88.57	111.42
DE032	138	128	-
DE031	76.24	213.26	-
DE044	105.5	-	-
CZ156	111	96	159

Source: [169, TWG 2021]

Figure 2.177:Refractory lining sent for disposal

2.3.8 Energy consumption

Metal melting and the holding of molten metal in the molten state generally take up a significant part of a foundry's energy consumption. In many foundries, more energy is used in holding the metal in the molten state than in the actual melting process. Furthermore, considerable energy is expended in areas other than that of metal supply. For example, foundries are generally large users of compressed air. Other large users of energy are likely to be items such as high-pressure die-casting machines, whose mainly hydraulic power units are also driven by electricity. Sand and gravity die foundries may employ hot core-making processes, such as shell or hot-box, using gas or electricity to heat the boxes. The heating of dies and ladle and furnace linings can amount to an appreciable fraction of the total energy used. The typical relative distribution of energy use in two foundry types is given in the following table.
[64, ETSU, 1997]

Table 2.102: Typical energy use in a non-ferrous and EAF steel foundry

Activity	Non-ferrous foundry (%)	EAF steel foundry (10 000 t/yr good casting) (%)
Melting	30	44
Holding	30	-
Plant actuation	15	-
Air compression	14	10
Tool heating	3	-
Heat treatment (gas)	-	7
Others*	8	39
* Includes all activities for which no values are given in the same column and activities which are not mentioned *Source:* [64, ETSU, 1997], [202, TWG, 2002]		

These data show that foundry services (i.e. all but melting and holding) are responsible for up to half of foundry energy consumption. This includes activities using items such as motors and drives, compressed air, lighting, space heating and the boiler plant. Energy efficiency measures should have regards to both the melting and the services field. [46, ETSU, 1995]

Energy-efficient operation is brought about by applying good practice measures to reduce energy use in all of the mentioned steps. Improved energy efficiency is one of the main environmental benefits mentioned throughout the techniques discussed in this chapter. The following sections focus on specific techniques aimed at heat recovery and heat transfer to other parts of the foundry.

Data from energy audits in 17 European foundries in the frame of the Foundrybench project indicate that the energy consumption data in iron foundries data was relatively uniform but the deviation in steel and non-ferrous foundries depends to a great extent on the production technology, steel quality and castings. In particular, this depends on the heat treatments needed for the steel castings (see Table 2.103). [183, Foundrybench project 2012]

Table 2.103: Average energy use in different foundry types

Unit/Foundry type	Iron foundry	Steel foundry	NFM foundry
Energy/tonne (MWh/t)	2.5	5-8	4-10
Energy cost of business value (%)	5-8	6-11	4-8
Source: [183, Foundrybench project 2012]			

The energy-saving potential range differs from foundry to foundry. There are significant differences among foundries related, for example, to the quality of the material produced and the climatic conditions of the location. The savings potential of the 17 audited foundries showed a value of 17 % (+ 7 %). [183, Foundrybench project 2012]

Table 2.104: Average energy use in different foundry types

Unit processes	Iron foundry energy share (%) and the range (±%)	Steel foundry energy share (%) and the range (±%)	Non-ferrous foundry energy share (%) and the range (±%)	Savings potential (%)
Melting	55 ± 10	45 ± 5	65 ± 10	6 – 10
Annealing	1 ± 1	25 ± 2	-	steel (3)
Drives	12 ± 4	9 ± 2	11 ± 5	1
CA-system	7 ± 3	5 ±'2	5 ± 3	2
Ladle preheating	4 ± 2	4 ± 2	3 ± 2	2
Ventilation	14 ± 5	7 ± 5	10 ± 8	4 – 7
Heating	3 ± 2	2 ± 1	3 ± 2	1
Lighting	4 ± 1	3 ± 1	3 ± 1	1
Total	100	100	100	17 - 24
Source: [183, Foundrybench project 2012]				

A survey of 58 steel foundries located in the USA provided statistics of energy consumption in steel foundries. The reported energy consumption for steel melting varies between 350 kWh/t and 700 kWh/t, with an average of 527 kWh/t. [197, Biswas et al. 2012]

2.3.8.1 Coke and energy cosumption in cupola furnaces

In cold blast operations, the coke consumption between the charges is generally 90-120 kg/tonne of metal charge, but can be less than 70 kg/tonne of metal charge, e.g. in the case of counterweights. Accounting for the amount of coke in the bed gives a total coke consumption of 110-140 kg/tonne of metal charge. As the calorific value of European cokes is 8.5 kWh/kg, this corresponds to a calorific input of 950-1 200 kWh/tonne of metal charge.

The total coke ratio in a hot blast cupola is generally 110-145 kg/tonne of metal charge. However, as the average steel percentage is 50 %, and the recarburisation consumes about 1.5 %, the real burned coke ratio is 95-130 kg/tonne of metal charge, which is 810-1 100 kWh/tonne of metal charge. This corresponds to a thermal efficiency of 35-45 %.

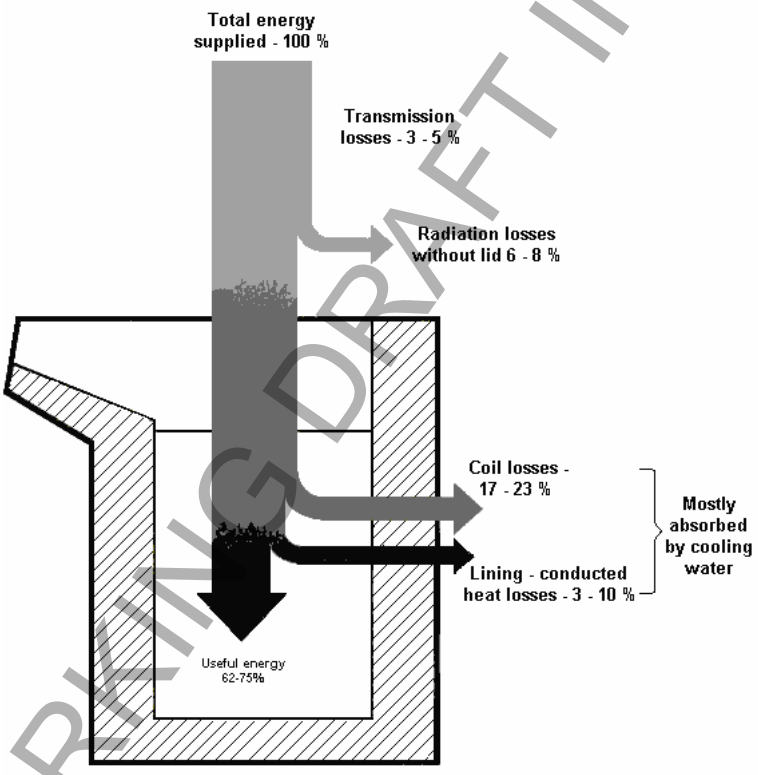
Depending on the plant layout, the energy consumed by the fume treatment equipment and the holding furnace, as given in Table 2.105, must be added. German data indicate a specific electricity use for the flue-gas cleaning equipment of around 20 kWh per tonne of good casting. [202, TWG, 2002]

Table 2.105: Average energy consumption for off-gas treatment and holding

Energy carrier type	Average consumption kWh/tonne metal charge
Gas for the combustion chamber	40
Electricity for the flue-gas cleaning equipment (fans, etc.)	40
Electricity for the holding furnace	60
Source: [202, TWG, 2002]	

2.3.8.2 Energy cosumption in coreless induction furnaces

A coreless induction furnace can melt a tonne of iron and raise the temperature of the liquid metal to 1 450 ºC using under 600 kWh of electricity. However, in practice, only a few foundries can achieve this level of specific consumption on a week-by-week basis. The actual energy consumption varies according to the size and working regime of the furnace. Large furnaces, working 24 hours a day and using a molten heel can achieve a 600 kWh/tonne value. Surveys of foundries show that consumption levels of 520-800 kWh/tonne of metal charge are common, the variation being due to individual melting practice, such as the rate at which the pouring line will accept the molten metal and whether furnace lids are used effectively. Attention to energy-saving measures should allow figures of 550-650 kWh/tonne of metal charge to be achieved. The typical heat losses from a coreless induction furnace are shown in Figure 3.2. [47, ETSU, 1992], [174, Brown, 2000], [202, TWG, 2002]



Source: [47, ETSU, 1992]

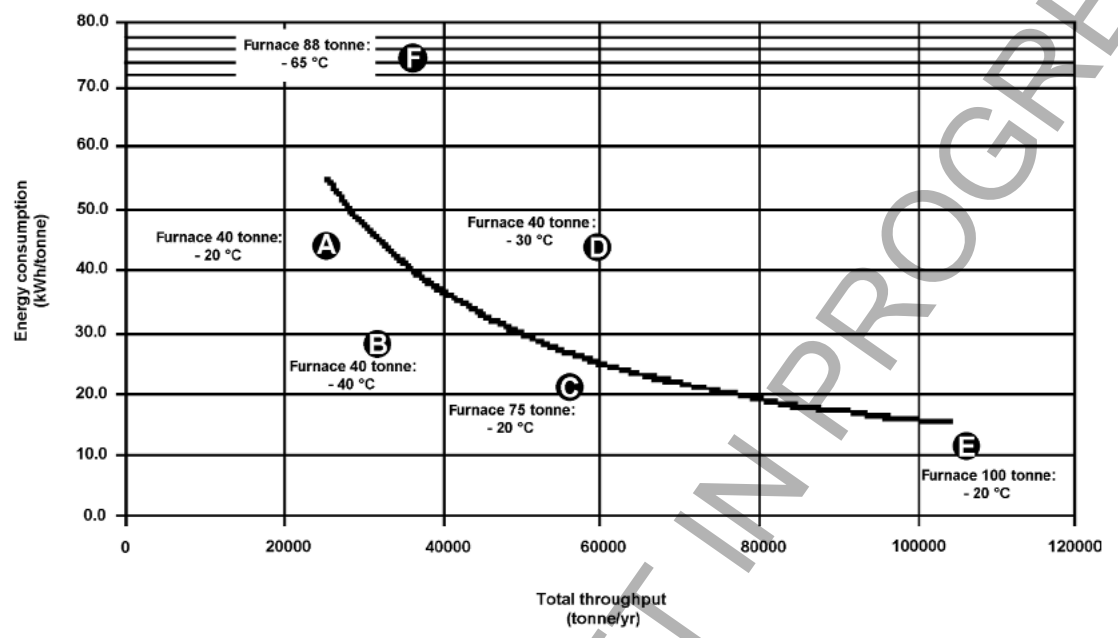
Figure 2.178:Typical energy losses from a mains frequency coreless induction furnace

2.3.8.3 Energy consumption in channel induction furnaces

In ferrous metal foundries, the channel induction furnace is mainly used as a holding furnace. It is the furnace of choice for duplex operation with the hot blast cupola. In this case, its function is either to hold or to homogenise the chemical composition of the metal, or to serve as a

reservoir of the melted metal for the casting. The furnace's role is not to increase the metal temperature, but rather to prevent unwanted cooling.

Figure 2.179 presents the energy consumption levels of some representative channel induction furnaces. The consumption depends on process-related parameters, such as the holding time. The graph shows that the consumption decreases with increasing annual tonnage. The extreme values are 80 kWh and 20 kWh per tonne transferred.



Source: [140, EU Thematic Network Foundry Wastes, 2001]

Figure 2.179:Energy consumption (kWh/tonne) as a function of transferred tonnage and loss of temperature for channel induction furnaces

2.3.8.4 Energy cosumption in aluminium induction furnaces

Induction furnaces are energy-efficient melters. The energy consumption for melting is affected by the density of the charge and the melting practice used. Batch melting is less efficient than using a molten heel. A 50 % molten heel is the most efficient. The energy consumption varies from 540 kWh/tonne for a high bulk density charge (small scrap and ingot) to 600 kWh/tonne if a lower density scrap (such as pressure die-casting runners and ingot) is melted. While the energy consumption is low, the costs for melting may be higher than for gas-fired furnaces because of the generally higher cost of electricity as a source of heat. [175, Brown, 1999], [148, Eurofine, 2002]

2.3.8.5 Figures for specific energy consumption

In the following figures, the reported levels for specific energy consumption expressed in kWh/t of liquid metal are presented.

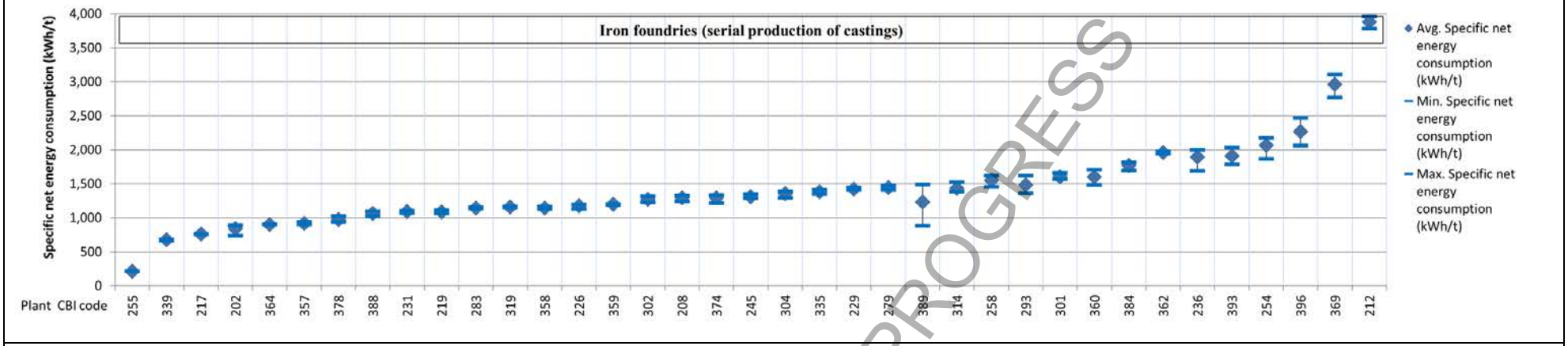
The specific energy consumption data were considered confidential business information (CBI) by the TWG. In order to maintain the confidentiality of this information, the plant name is not given in the figures and tables presented in this document. Plant names are systematically replaced by randomly attributed CBI codes for each individual plant. In addition, no contextual information (e.g. process parameters or techniques applied) is included as this could reveal the

identity of the plants. All the energy consumption figures are presented in ascending order of the maximum specific energy consumption values.

The average specific energy consumption for the 3-year period is represented by a blue diamond and the minimum and maximum specific energy consumption by error bars.

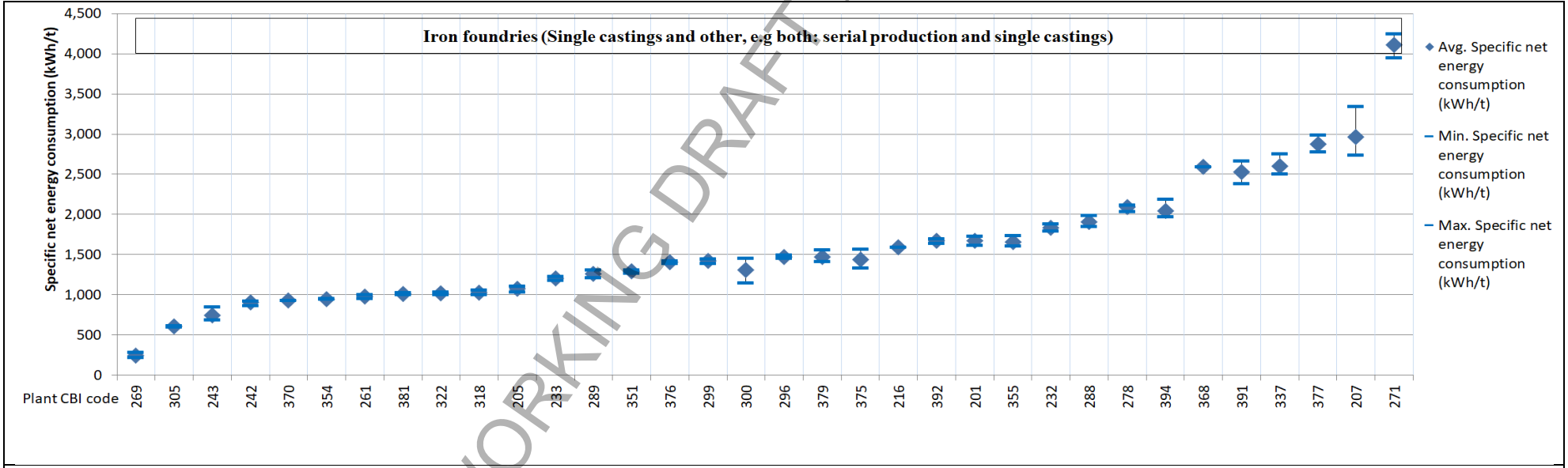
In addition to the four figures containing the reported data on specific energy consumption at plant level (for specific foundry types), an additional figure is included to present the distribution of specific energy consumption at process level. The relevant processes (according to the submitted data) are:

- metal melting;
- heat treatment;
- holding-pouring;
- hadle preheating;
- drying.



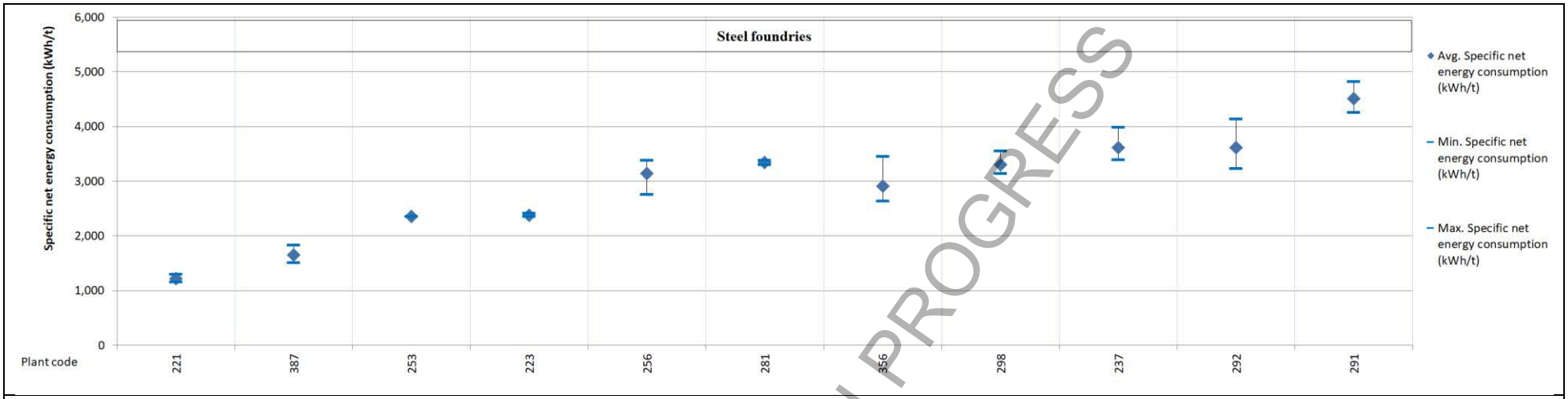
Source: [169, TWG 2021]

Figure 2.180:Specific energy consumption (at plant level) in cast iron foundries for serial production of castings (1/4)



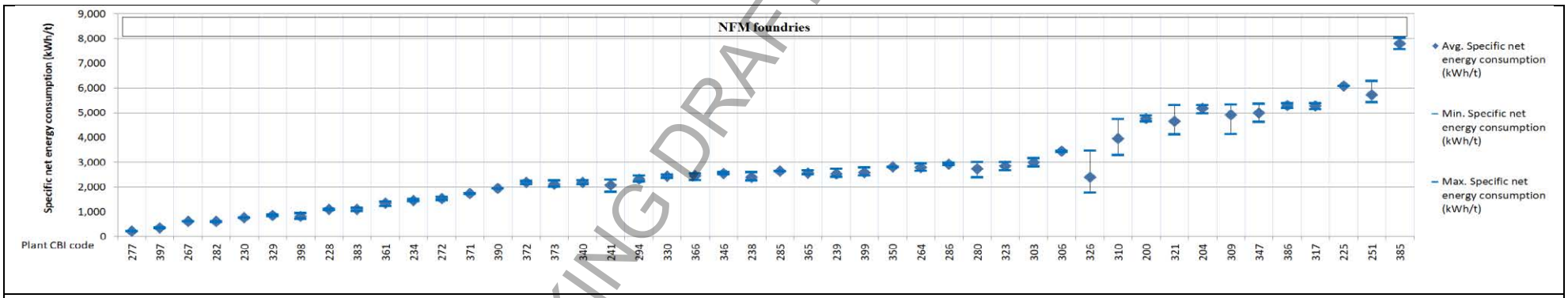
Source: [169, TWG 2021]

Figure 2.181:Specific energy consumption (at plant level) in cast iron foundries for single castings and other (e.g. both serial production and single castings) (2/4)



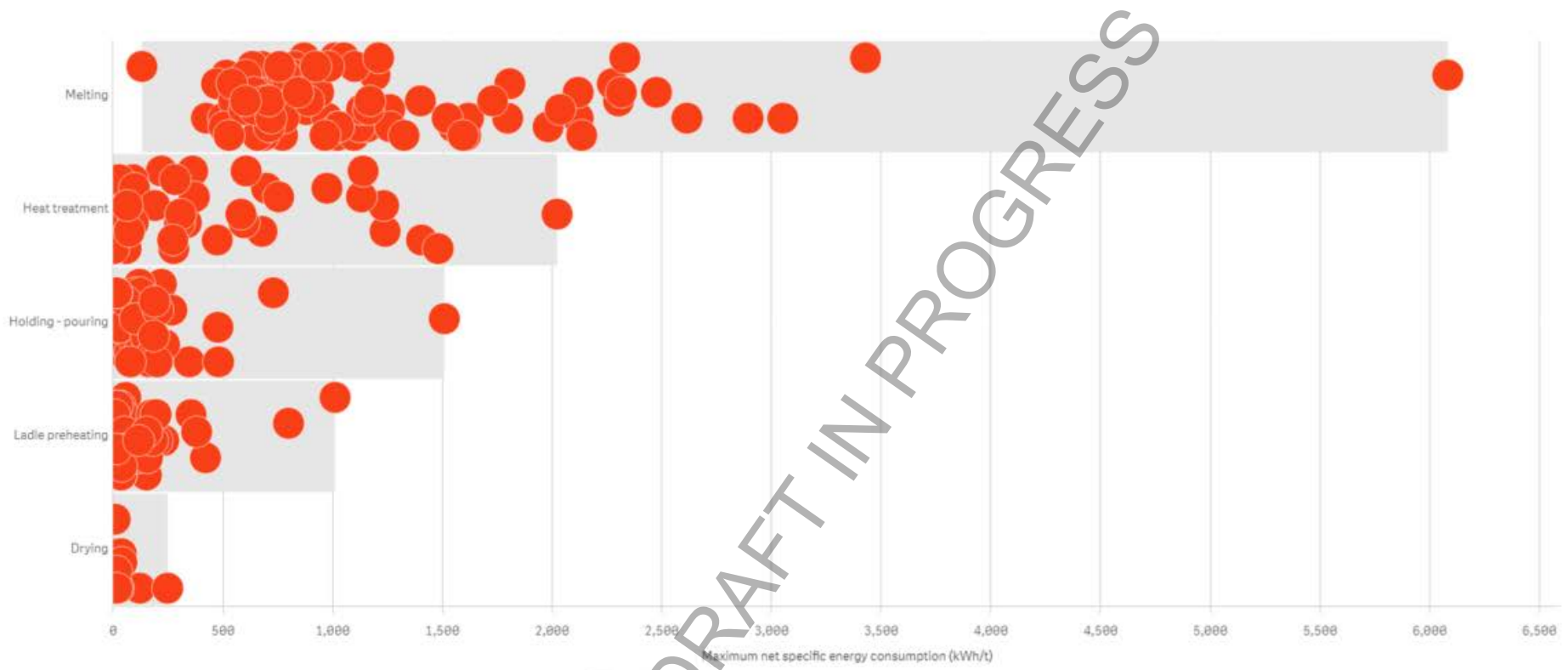
Source: [169, TWG 2021]

Figure 2.182:Specific energy consumption (at plant level) in steel foundries (3/4)



Source: [169, TWG 2021]

Figure 2.183:Specific energy consumption (at plant level) in NFM foundries (4/4)



Source: [169, TWG 2021]

Figure 2.184: Distribution of specific energy consumption at process level

3 TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT

~~In this section, techniques for environmental protection and energy saving measures are given for individual processing steps. The various techniques are structured into generic topics, which allows a thematic approach to be taken for assessing the various different foundry processes and steps.~~

~~The techniques all aim to either optimise the process or to reduce the environmental effects by, e.g.:~~

- ~~careful selection and optimisation of each unit operation i.e. in: storage, melting and metal treatment, mould and core production, casting~~
- ~~the reduction of emissions to air and water~~
- ~~the increase in the efficient use of energy~~
- ~~the minimisation and re-use of residues.~~

This section describes techniques (or combinations thereof), and associated monitoring, considered to have the potential for achieving a high level of environmental protection in the activity within the scope of this document. The techniques described will include both the technology used and the way in which the installations are designed, built, maintained, operated and decommissioned.

It covers environmental management systems as well as process-integrated and end-of-pipe techniques. Waste prevention and management, including waste minimisation and recycling procedures, are also considered, as well as techniques that reduce the consumption of raw materials, water and energy by optimising use and reuse. The techniques described also cover the prevention or limiting of the environmental consequences of accidents and incidents. They also cover the prevention or reduction of emissions under other than normal operating conditions (such as start-up and shutdown operations, leaks, malfunctions, momentary stoppages and the definitive cessation of operations).

Annex III to the Directive lists a number of criteria for determining BAT, and the information within this chapter will address these considerations. As far as possible, the standard structure in **Table 3.1** is used to outline the information on each technique, to enable a comparison of techniques and the assessment against the definition of BAT in the Directive.

This section does not necessarily provide an exhaustive list of techniques that could be applied in the sector. Other techniques may exist, or may be developed, which could be considered in the determination of BAT for an individual installation.

Table 3.1: Information for each technique

Heading within the sections	Type of information included
Description	A brief description of the technique with a view to being used in the BAT conclusions.
Technical description	A more detailed and yet concise technical description using, as appropriate, chemical or other equations, pictures, diagrams and flow charts.
Achieved environmental benefits	The main potential environmental benefits to be gained through implementing the technique (including reduced consumption of energy; reduced emissions to water, air and land; raw material savings; as well as production yield increases, reduced waste, etc.).
Environmental performance and operational	Actual and plant-specific performance data (including emission levels, consumption levels – of raw materials, water, energy – and amounts of residues/wastes generated) from well-performing installations/plants (with

data	respect to the environment taken as a whole) applying the technique accompanied by the relevant contextual information. Any other useful information on the following items: • how to design, operate, maintain, control and decommission the technique; • emission monitoring issues related to the use of the technique; • sensitivity and durability of the technique; • issues regarding accident prevention. Links between inputs (e.g. nature and quantity of raw material and fuel, energy, water) and outputs (emissions, residues/wastes, products) are highlighted, in particular where relevant to enhancing an understanding of different environmental impacts and their interaction, for example where trade-offs have been made between different outputs such that certain environmental performance levels cannot be achieved at the same time. Emission and consumption data are qualified as far as possible with details of relevant operating conditions (e.g. percentage of full capacity, fuel composition, bypassing of the (abatement) technique, inclusion or exclusion of other than normal operating conditions, reference conditions), sampling and analytical methods, and statistical presentation (e.g. short- and long-term averages, maxima, ranges and distributions). Information is included on conditions/circumstances hampering the use of the (abatement) technique at full capacity and/or necessitating full or partial bypassing of the (abatement) technique and measures taken to restore full (abatement) capacity.
Cross-media effects	Relevant negative effects on the environment due to implementing the technique, allowing a comparison between techniques in order to assess the impact on the environment as a whole. This may include issues such as: • consumption and nature of raw materials and water; • energy consumption and contribution to climate change; • stratospheric ozone depletion potential; • photochemical ozone creation potential; • acidification resulting from emissions to air; • presence of particulate matter in ambient air (including microparticles and metals); • eutrophication of land and waters resulting from emissions to air or water; • oxygen depletion potential in water; • persistent/toxic/bioaccumulable components (including metals); • generation of residues/waste; • limitation of the ability to reuse or recycle residues/waste; • generation of noise and/or odour; • increased risk of accidents. The Reference Document on Economics and Cross-media Effects (ECM) should be taken into account.
Technical considerations relevant to applicability	It is indicated whether the technique can be applied throughout the sector. Otherwise, the main general technical restrictions on the use of the technique within the sector are indicated. These may be: • an indication of the type of plants or processes within the sector to which the technique cannot be applied; • constraints to implementation in certain generic cases, considering, e.g.: – whether it concerns a new or an existing plant, taking into account

	factors involved in retrofitting (e.g. space availability) and interactions with techniques already installed; – plant size, capacity or load factor; – quantity, type or quality of product manufactured; – type of fuel or raw material used; – animal welfare; – climatic conditions. These restrictions are indicated together with the reasons for them. These restrictions are not meant to be a list of the possible local conditions that could affect the applicability of the technique for an individual plant.
Economics	Information on the costs (capital/investment, operating and maintenance costs including details on how they have been calculated/estimated) and any possible savings (e.g. reduced raw material or energy consumption, waste charges, reduced payback time compared to other techniques), or revenues or other benefits including details on how these have been calculated/estimated. Cost data are preferably given in euros (EUR). If a conversion is made from another currency, the data in the original currency and the year when the data were collected are indicated. The price/cost of the equipment or service is accompanied by the year it was purchased. Information on the market for the sector is given in order to put costs of techniques into context. Information relevant to both newly built, retrofitted and existing plants is included. This should allow assessment, where possible, of the economic viability of the technique for the sector concerned and possible economic limitations to its application. Information on the cost-effectiveness of the technique (e.g. in EUR per mass of pollutant abated) and related assumptions for its calculation can be reported. The Reference Document on Economics and Cross-media Effects (ECM) and the Reference Report on Monitoring of Emissions to Air and Water from IED Installations (ROM) are taken into account with regard to economic aspects and monitoring costs, respectively.
Driving force for implementation	Where applicable, specific local conditions, requirements (e.g. legislation, safety measures) or non-environmental triggers (e.g. increased yield, improved product quality, economic incentives – e.g. subsidies, tax breaks) which have driven or stimulated the implementation of the technique to date are provided. This subsection should be very short and use a list of bullet points.
Example plants	Reference to a plant(s) where the technique has been implemented and from which information has been collected and used in writing the section. An indication of the degree to which the technique is in use in the EU or worldwide.
Reference literature	Literature or other reference material (e.g. books, reports, studies) that was used in writing the section and that contains more detailed information on the technique. When the reference material consists of many pages, reference will be made to the relevant page(s) or section(s).

3.1 Common techniques to consider in the determination of BAT for smitheries and foundries

3.1.1 Overall environmental performance

This section covers the areas, processes and activities of the installation that are not covered elsewhere, as they refer to issues that are common for both the smitheries and foundries sectors.

3.1.1.1 Environmental management system (EMS)

Description
A formal system to demonstrate compliance with environmental objectives.

Technical description
The Industrial Emissions Directive defines 'techniques' (under the definition of 'best available techniques') as 'both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned'.

In this respect, an environmental management system (EMS) is a technique allowing operators of installations to address environmental issues in a systematic and demonstrable way. EMSs are most effective and efficient where they form an inherent part of the overall management and operation of an installation.

An EMS focuses the attention of the operator on the environmental performance of the installation; in particular through the application of clear operating procedures for both normal and other than normal operating conditions, and by setting out the associated lines of responsibility.

All effective EMSs incorporate the concept of continuous improvement, meaning that environmental management is an ongoing process, not a project which eventually comes to an end. There are various process designs, but most EMSs are based on the plan-do-check-act cycle (which is widely used in other company management contexts). The cycle is an iterative dynamic model, where the completion of one cycle flows into the beginning of the next (see Figure 3.1).

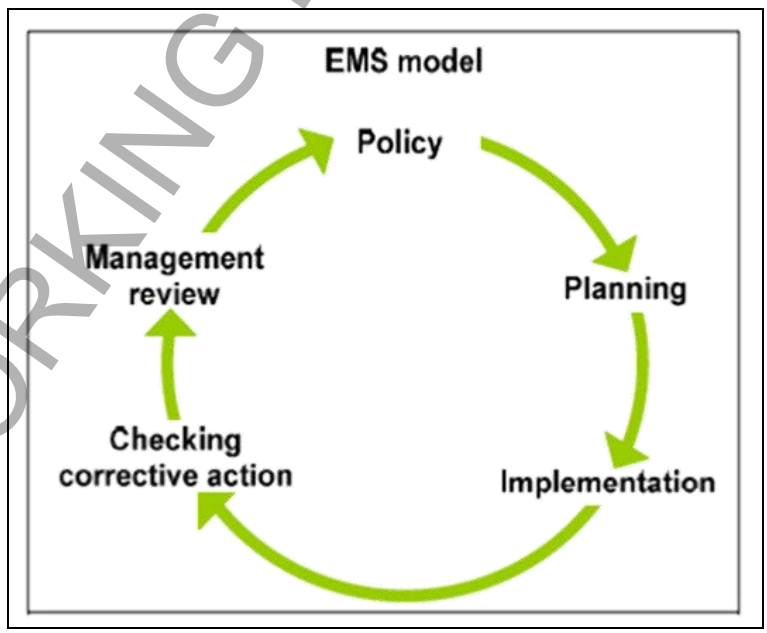


Figure 3.1: Continuous improvement in an EMS model

An EMS can take the form of a standardised or non-standardised ('customised') system. Implementation and adherence to an internationally accepted standardised system, such as EN ISO 14001:2015, can give higher credibility to the EMS especially when subjected to a properly performed external verification. The European Union eco-management and audit scheme (EMAS) according to Regulation (EC) No 1221/2009 provides additional credibility due to the interaction with the public through the environmental statement and the mechanism to ensure compliance with the applicable environmental legislation. However, non-standardised systems can, in principle, be equally effective provided that they are properly designed and implemented.

While both standardised systems (EN ISO 14001:2015 or EMAS) and non-standardised systems apply in principle to organisations, this document takes a narrower approach, not including all activities of an organisation, e.g. with regard to their products and services, due to the fact that the Directive only regulates installations.

An EMS can contain the following features:

i. commitment, leadership, and accountability of the management, including senior management, for the implementation of an effective EMS;
ii. an analysis that includes the determination of the organisation's context, the identification of the needs and expectations of interested parties, the identification of characteristics of the installation that are associated with possible risks for the environment (or human health) as well as of the applicable legal requirements relating to the environment;
iii. development of an environmental policy that includes the continuous improvement of the environmental performance of the installation;
iv. establishing objectives and performance indicators in relation to significant environmental aspects, including safeguarding compliance with applicable legal requirements;
v. planning and implementing the necessary procedures and actions (including corrective and preventive actions where needed), to achieve the environmental objectives and avoid environmental risks;
vi. determination of structures, roles and responsibilities in relation to environmental aspects and objectives and provision of the financial and human resources needed;
vii. ensuring the necessary competence and awareness of staff whose work may affect the environmental performance of the installation (e.g. by providing information and training);
viii. internal and external communication;
ix. fostering employee involvement in good environmental management practices;
x. establishing and maintaining a management manual and written procedures to control activities with significant environmental impact as well as relevant records;
xi. effective operational planning and process control;
xii. implementation of appropriate maintenance programmes;
xiii. emergency preparedness and response protocols, including the prevention and/or mitigation of the adverse (environmental) impacts of emergency situations;
xiv. when (re)designing a (new) installation or a part thereof, consideration of its environmental impacts throughout its life, which includes construction, maintenance, operation and decommissioning;
xv. implementation of a monitoring and measurement programme; if necessary, information can be found in the Reference Report on Monitoring of Emissions to Air and Water from IED Installations;
xvi. application of sectoral benchmarking on a regular basis;
xvii. periodic independent (as far as practicable) internal auditing and periodic independent external auditing in order to assess the environmental performance and to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained;

xviii. evaluation of causes of nonconformities, implementation of corrective actions in response to nonconformities, review of the effectiveness of corrective actions, and determination of whether similar nonconformities exist or could potentially occur;
xix. periodic review, by senior management, of the EMS and its continuing suitability, adequacy and effectiveness;
xx. following and taking into account the development of cleaner techniques.

Specifically for the smitheries and foundries sector, the following features are included in the EMS:

xxi. an inventory of inputs and outputs (see Section 3.1.1.2);
xxii. a chemicals management system (see Section 3.1.1.3);
xxiii. a plan for the prevention and control of leaks and spillages (see Section 3.1.1.4.1);
xxiv. an OTNOC management plan (see Section 3.1.1.5);
xxv. an energy efficiency plan (see Section 3.1.3.1);
xxvi. a water management plan (see Section 3.2.1.16.1);
xxvii. a noise and/or vibration management plan (see Section 3.1.5.1);
xxviii. a residues management plan (see Section 3.1.6.1);
xxix. an odour management plan for foundries (see Section 3.2.1.15.1).

Achieved environmental benefits
An EMS promotes and supports the continuous improvement of the environmental performance of the installation. If the installation already has a good overall environmental performance, an EMS helps the operator to maintain the high performance level.

Cross-media effects
None reported. The systematic analysis of the initial environmental impacts and scope for improvements in the context of the EMS sets the basis for assessing the best solutions for all environmental media.

Technical considerations relevant to applicability
The components described above can typically be applied to all installations within the scope of this document. The level of detail and the degree of formalisation of the EMS will generally be related to the nature, scale and complexity of the plant, and the range of environmental impacts it may have.

Driving force for implementation
The driving forces for the implementation of an EMS include:

- improved environmental performance;
- improved insight into the environmental aspects of the company which can be used to fulfil the environmental requirements of customers, regulatory authorities, banks, insurance companies or other stakeholders (e.g. people living or working in the vicinity of the installation);
- improved basis for decision-making;
- improved motivation of personnel (e.g. managers can have confidence that environmental impacts are controlled and employees can feel that they are working for an environmentally responsible company);
- additional opportunities for operational cost reduction and product quality improvement;
- improved company image;
- reduced liability, insurance and non-compliance costs.

Example plants
EMSs are applied in a number of installations throughout the EU.

Reference literature

[140, IAF 2010], [141, EU 2009], [142, COM 2010], [144, CEN 2015]

3.1.1.2 Inventory of inputs and outputs

Description
The compilation of relevant basic data on input and ouput streams of resources (e.g. inputs like materials, energy, water, and outputs like waste gases, waste waters, wastes, energy losses, etc.). Basic data for streams include the information on environmentally important characteristics, like presence of hazardous substances, their toxicity, composition and quantities. These data are used in mass balances, efficiency plans and for monitoring of emissions.

Technical description
All environmental problems are directly linked to input/output streams. In the interests of identifying options and priorities for improving environmental and economic performance, it is therefore vital to know as much as possible about their quality and quantity.

Input/output stream inventories can be drawn up on different levels. The most general level is an annual site-specific overview.

As part of the EMS (see Section 3.1.1.1), an inventory of inputs and outputs has to be established, maintained and regularly reviewed (including when a significant change occurs), that incorporates all of the following features:

i. information about the production processes, including:
   (a) simplified process flow sheets that show the origin of the emissions to air, water and soil;
   (b) descriptions of process-integrated techniques and waste water/waste gas treatment techniques to prevent or reduce emissions, including their performance (e.g. abatement efficiency);
(ii) information about the quantity and characteristics of raw materials (e.g. scrap, feedstock) and fuels (e.g. coke) used;
(ii) information about water consumption and usage (e.g. flow diagrams and water mass balances);
(iii) information about energy consumption and usage;
(iv) information about the characteristics of the waste water streams, such as:
   (a) average values and variability of flow, pH, temperature and conductivity;
   (b) average concentration and mass flow values of relevant substances (e.g. total suspended solids, TOC or COD, hydrocarbon oil index, metals) and their variability;
(v) information about the quantity and characteristics of the process chemicals used:
   (a) the identity and the characteristics of process chemicals, including properties with adverse effects on the environment and/or human health;
   (b) the quantities of process chemicals used and the location of their use;
(vi) information about the characteristics of the waste gas streams, such as:
   (a) average values and variability of flow and temperature;
   (b) average concentration and mass flow values of relevant substances (e.g. dust, NO_X, SO_2, CO, metals) and their variability;
   (c) presence of other substances that may affect the waste gas treatment system (e.g. oxygen, nitrogen, water vapour) or installation safety.
   (vii) information about the quantity and charactersistics of residues/waste generated.

Achieved environmental benefits
The described evaluation and inventory of input/output mass streams is an essential management tool for the identification of optimisation potential, both environmental and economic. It is the prerequisite for a continuous improvement process.

Environmental performance and operational data
The application of such a management tool requires qualified staff and the commitment of the management.

The input/output streams inventory allows cross-media effects to be taken into consideration during the assessment of potential optimisation options. This means the achievement of a high level of protection of the environment as a whole.

Cross-media effects
None identified.

Technical considerations relevant to applicability
The technique is applicable to both new and existing installations. The level of detail and the degree of formalisation of the inventory will generally be related to the nature, scale and complexity of the plant, and the range of environmental impacts it may have.

Economics
Associated personnel cost.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plant
Widely used.

Reference literature
[169, TWG 2021]

3.1.1.3 Chemicals management system (CMS)

Description
The chemicals management system (CMS) is part of the EMS (see Section 3.1.1.1) and is a set of technical and organisational measures to limit the impact of the use of process chemicals on the environment.

Technical description
In order to improve the overall environmental performance, the elaboration and implementation of a chemicals management system (CMS), as part of the EMS, is implemented.

The chemicals management system (CMS) contains the following features:

I. A policy to reduce the consumption and risks associated with process chemicals, including a procurement policy to select less harmful process chemicals and their suppliers with the aim of minimising the use of and risks associated with hazardous substances and substances of very high concern as well as to avoid the procurement of an excess amount of process chemicals. The selection of process chemicals is based on:
    a) the comparative analysis of their bioeliminability/biodegradability, eco-toxicity and potential to be released into the environment in order to reduce emissions to the environment;
    b) the characterisation of the risks associated with the process chemicals, based on the chemicals' hazards classification, pathways through the plant, potential release and level of exposure;
    c) the potential for recovery and reuse;

d) the regular (e.g. annual) analysis of the potential for substitution with the aim to identify potentially new available and safer alternatives to the use of hazardous substances and substances of very high concern; this may be achieved by changing process(es) or using other process chemicals with no or lower environmental impacts;
e) the anticipatory monitoring of regulatory changes related to hazardous substances and substances of very high concern, and safeguarding compliance with applicable legal requirements.

The inventory of process chemicals may be used to provide and keep the information needed for the selection of process chemicals.

II. Goals and action plans to avoid or reduce the use and risks associated with hazardous substances and substances of very high concern.

III. Development and implementation of procedures for the procurement, handling, storage, and use of process chemicals, disposal of waste containing process chemicals and return of unused process chemicals, to prevent or reduce emissions to the environment.

Achieved environmental benefits

- Improvement of the overall environmental performance.
- Reduction of the use of hazardous chemicals.
- Reduction of emissions of hazardous chemicals to the environment.
- Reduction of the amount of hazardous chemicals in waste.

Environmental performance and operational data

The need to implement a chemicals management system in relevant IED installations depending on the amount, quantity and diversity of chemicals used is described in more detail in the conclusions of the HAZBREF project (Work package 3 – Activity 3.2). [176, HAZBREF 2021]

Cross-media effects

None.

Technical considerations relevant to applicability

The level of detail and degree of formalisation of the CMS will generally be related to the nature, scale and complexity of the plant.

Economics

TWG please provide information.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

No information provided.

Reference literature

[176, HAZBREF 2021]

3.1.1.4 Prevention or reduction of emissions to soil and groundwater

3.1.1.4.1 Set-up and implementation of a plan for the prevention and control of leaks and spillages

Description

A plan for the prevention and control of leaks and spillages is part of the EMS (see Section 3.1.1.1) and includes, but is not limited to:

- site incident plans for small and large spillages;
- identification of the roles and responsibilities of persons involved;
- ensuring staff are environmentally aware and trained to prevent and deal with spillage incidents;
- identification of areas at risk of spillage and/or leaks of hazardous materials and ranking them according to the risk;
- identification of suitable spillage containment and clean-up equipment and regularly ensuring it is available, in good working order and close to points where these incidents may occur;
- waste management guidelines for dealing with waste arising from spillage control;
- regular (at least on an annual basis) inspections of storage and handling areas, testing and calibration of leak detection equipment and prompt repair of leaks from valves, glands, flanges, etc.

Achieved environmental benefits
This technique prevents or minimises the contamination of surface waters, groundwaters and soils, and assists in site decontamination on cessation of activities.

Environmental performance and operational data
Small spills are likely to happen more often and the sum effect of these if not detected and dealt with is significant increases of fugitive emissions to air, soil and groundwater.

Cross-media effects
None.

Technical considerations relevant to applicability
The level of detail of the plan will generally be related to the nature, scale and complexity of the plant, as well as to the type and quantity of liquids used.

Economics
The following costs need to be considered:

- staff time for training and updating plans;
- materials savings through the minimisation of spillage.
- use of materials for spillage clean-up.

Driving force for implementation
- Reduced risks of liability from contamination.
- Reduced risks of associated accidents, e.g. preventing slippery floors, risk of fire.

Example plants
Widely used.

Reference literature
TWG, please provide information.

3.1.1.4.2 Structuring and management of process areas and raw material storage areas

Description
Process areas and raw material storage areas need to be structured and managed.

Techniques include:

I. impermeable (e.g. cemented) floor for process areas and for scrap/feedstock yards;

II. separate storage for various types of raw materials, close to the production lines; this can be achieved using for example compartments or boxes in the storage areas and bunkers.

Technical description
Structuring and management of process areas and raw material storage areas ensure that raw materials are efficiently stored and handled.

For example, in foundries, the scrap/feedstock storage area can be structured and managed in such a way that the following factors are taken into account:

- The composition of the furnace charge necessitates knowledge of the feed material. Applying separate storage for various metal types or grades allows control of the charge composition. This can be achieved using compartments or boxes in the storage area or bunker.
- The introduction of mineral and oxide materials such as rust, soil or dirt causes increased refractory wear. The use of a cemented scrap yard prevents the entrainment of soil, dirt or water.
- A water collection and treatment system can be used to prevent contamination of soil or water.

Furthermore, the materials are well sorted, kept in a dry area under roofing (see Section 3.1.1.4.3) or in closed storage containers and can quickly be delivered to the production line.

Achieved environmental benefits
- Prevention or minimisation of the contamination of surface water, groundwater and soil.
- Efficient raw material management.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Efficient raw material management.
- Local conditions.

Example plants
Widely used.

Reference literature
[100, TWG 2002], [169, TWG 2021]

3.1.1.4.3 Prevention of the contamination of surface run-off water

Description
Production areas and/or areas where process chemicals, residues or waste are stored or handled, are protected against surface run-off water. This is achieved by using at least the following techniques:

- drainage channels and/or an outer kerb bund around the plant;
- roofing with roof guttering of process and/or storage areas.

Technical description
By using drainage channels and/or an outer kerb bund around the plant, surface run-off water is collected and process areas and storage areas (for chemicals, residues and waste) are protected against surface run-off water.

A roof constructed over the storage area can help keep rainwater out.

Achieved environmental benefits
- Prevention of contamination of surface run-off water.
- Reduction of waste water generation.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Protection of process and storage areas against surface run-off water
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
No information provided.

3.1.1.4.4 Collection of potentially contaminated surface run-off water

Description
Surface run-off water from areas that are potentially contaminated with process chemicals is collected separately. Collected waste water is discharged only after appropriate measures are taken, e.g. monitoring (see Sections 3.2.1.2.2), treatment (see Section 3.2.1.17).

Achieved environmental benefits
- Avoidance of cross-contamination of uncontaminated water streams.
- Reduction of waste water generation.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
Costs associated with the collection and potential treatment processes.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
No information provided.

3.1.1.4.5 Safe handling and storage of process chemicals

Description
This includes:

- storage in roofed and ventilated areas with floors that are impermeable to the liquids concerned;
- use of oil-tight trays or cellars for hydraulic stations and oil- or grease-lubricated equipment;
- collection of spilled liquid;
- loading/unloading areas for process chemicals, lubricants, coatings, etc. are designed and constructed in such a way that potential leaks and spillages are contained and sent to on-site treatment or off-site treatment;
- highly flammable liquids (e.g. methyl formate, TEA, DMEA, mould coatings containing isopropyl alcohol) are stored separately from incompatible substances (e.g. oxidisers) in enclosed and well-ventilated storage areas.

Technical description
Use of oil-tight trays or cellars:

Hydraulic stations and oil- or grease-lubricated equipment are situated in oil-tight trays or cellars to avoid penetration of oil into the ground in the event of leakage. Accidental releases are prevented by periodic checks and preventive maintenance of seals, gaskets, pumps and piping.

In foundries, binder chemicals carry specific manufacturer's recommendations for storage. Failure to comply with these recommendations will result in unusable or substandard products that either require disposal as special waste or lead to poor casting quality due to substandard moulds/cores. The following table summarises the quality problems arising from the incorrect storage of liquid binder chemicals. Correct storage takes account of these problems.

Table 3.2: Problems arising from an incorrect storage of liquid binder chemicals

Problem	Effect on product	Implications	Effect on castings
Exposure to excessive cold	Aqueous-based products may freeze	Product segregation may occur, causing mould failure. Affected products require disposal	Casting production may not be possible
Exposure to excessive heat and sunlight	Premature ageing, cross-linking of resin and increased viscosity	Poor mixing properties, low mould strengths and poor resistance to high temperatures	Fining defects
Prolonged storage or cold storage	Increased viscosity	Dispersion onto sand grains difficult. Sand mixture flows less well and is difficult to compact. Low-strength moulds	Erosion, exogenous (sandy) inclusions finning and dimensional faults
Contamination by moisture	Products containing isocyanates will deteriorate due to reaction with water	Binder performance is poor and product may need disposal	Increased risk of gas defects (pinholes)
Sediment disposal in bulk silicate storage tanks	Pumped liquid may become inconsistent	Low-strength moulds	Oversize castings and shrinkage effects
Source: [28, ETSU 1998]			

Some basic measures include:

- roofed and ventilated area;
- impermeable floors;
- collection of spilled liquid;
- locked storage area.

Depending on the climate, exposure to excessive cold or heat and to sunlight can be accounted for. Additional precautions are necessary for the storage of highly flammable liquids such as methyl formate, triethylamine (TEA), dimethylethylamine (DMEA) and mould coatings containing isopropyl alcohol.

Achieved environmental benefits

- Prevention of ~~oil (hydrocarbon)~~ contamination of surface and groundwater.
- Avoidance/reduction of generation of waste chemicals.
- Reduction of the amount of waste chemicals arising, which are unsuitable for use.

Most binder chemicals are hazardous and are characterised by one or more of the following properties: toxic, corrosive, flammable. These properties mean that even small spills can pose a danger to workers' health and safety, while larger releases can result in a serious incident. A major spill that is allowed to enter a surface water drain can cause serious pollution of watercourses.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable. This technique applies to all new and existing installations.

Economics
No information provided.

Driving force for implementation
- Safety measures and optimisation of foundry operations.
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[31, ETSU 1996], [169, TWG 2021], [168, COM 2021]

3.1.1.4.6 Good housekeeping

Description
A set of measures aiming at preventing, or reducing, the generation of emissions (e.g. regular maintenance and cleaning of equipment, working surfaces, floors and transport routes, and containment as well as rapid take-up of any spillages).

Achieved environmental benefits
- Prevention or reduction of fugitive emissions.
- Positive impacy on occupational health.

Environmental performance and operational data
No information provided.

Cross-media effects
When maintenance is carried out, additional residues may occur.

Technical considerations relevant to applicability
Generally applicable.

Economics
For many companies, simple, affordable good housekeeping measures are being effectively applied to minimise diffuse emissions, improve efficiency, achieve a cleaner workplace and reduce costs.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[169, TWG 2021]

3.1.1.5 Other than normal operating conditions (OTNOC)

Description
A risk-based OTNOC management plan includes all of the following elements:

- identification of potential OTNOC (e.g. failure of equipment critical to the protection of the environment ('critical equipment')), of their root causes and of their potential consequences;
- appropriate design of critical equipment (e.g. off-gas treatment, waste water treatment);
- set-up and implementation of an inspection and preventive maintenance plan for critical equipment (see Section 3.1.1.1 – point xii. of the EMS);
- monitoring (i.e. estimating or, where possible, measuring) and recording of emissions during OTNOC and of associated circumstances;
- periodic assessment of the emissions occurring during OTNOC (e.g. frequency of events, duration, amount of pollutants emitted) and implementation of corrective actions if necessary;
- regular review and update of the list of identified OTNOC under point i. following the periodic assessment of point v.;
- regular testing of backup systems.

Technical description
Oother than normal operating conditions (OTNOC) are associated (among others) with the following periods/instances:

- start-up;
- shutdown;
- momentary stoppages;
- holding mode in furnaces;
- leaks (chemicals or water solutions);
- malfunction or breakdown of the abatement equipment or part of the equipment, if available;
- malfunction of instruments related to the process control or used for emission monitoring (such as instrumentation drift);
- testing of new apparatus;
- calibration of the monitoring system.

In order to reduce the frequency of the occurrence of OTNOC and to reduce emissions during OTNOC, a risk-based OTNOC management plan as part of the environmental management system (see Section 3.1.1.1) is put into place and may include the elements described in the Description section above.

Achieved environmental benefits
Emissions associated with shutdown and start-up operations are in part avoided. Planning for and achieving a reduced number of shutdowns is likely to reduce the annual mass emission levels of any plant.

Environmental performance and operational data
Preventive maintenance and regular maintenance checks can prevent or avoid malfunctions regarding process control or emission abatement and monitoring equipment.

<u>Preventive maintenance</u>
Preventive maintenance is used to:

- ensure that maintenance requiring switching off emissions control equipment/systems (e.g. containment, extraction systems, off-gas treatment) is planned to take place when there are no emissions (e.g. shutdown times) or when emission levels are low;
- replace parts that require replacement on a regular basis, preferably planned to take place before breakdowns are likely;
- ensure that parts that are essential to the normal running of emission control equipment are kept in stock, can be replaced or repaired rapidly with minimum call-off times;
- carry out routine and non-routine maintenance including maintenance of covers and pipe joints for liquid and gaseous fuels, lubricants/chemicals storage and delivery systems.

Regular maintenance checks
A maintenance schedule and record of all inspections and maintenance activities is kept and includes the following:

- visually checking for leaking seals, flanges, valves, welds, tanks and vats;
- inspections by external experts where necessary;
- monitoring of key equipment for problems such as vibration, emission leaks and planning repairs (as above);
- test programmes, e.g. pressure-test pipelines and tanks, calibration of metering and monitoring equipment;
- checking the tightness of nuts and bolts;
- checking for wear and tear on machinery, valves and bunds, over-heating bearings, etc.;
- recalibrating metering systems;
- ensuring that extraction and abatement equipment is fully serviceable, if available.

Unplanned maintenance
Process operators and maintenance staff identify and report leaks, broken equipment, fractured pipes, etc. to focus unscheduled maintenance.

Cross-media effects
None.

Technical considerations relevant to applicability
The level of detail and degree of formalisation of the OTNOC management plan will generally be related to the nature, scale and complexity of the plant, and the range of environmental impacts it may have.

Economics
Avoiding plant shutdowns can reduce costs by:

- allowing continuous throughput and hence greater installation utilisation;
- decreasing furnace maintenance due to lower thermal stress on the process.

Driving force for implementation
- Reduction of downtime.
- Maintains product quality and throughput.

Example plants
Widely used.

Reference literature
No reference literature provided.

3.1.2 Monitoring

Description
Real data are required on the precise effects of the activities of the industrial site on the environment. It is thus necessary to conduct a planned, regular sampling and monitoring programme. The parameters monitored include:

- the yearly consumption of water, energy and materials used, including process chemicals;
- the yearly generation of waste water;
- the yearly amount of each type of materials recovered and/or reused;
- the yearly amount of each type of residues generated and of each type of waste sent for disposal.

Technical description
Monitoring preferentially includes direct measurements. Calculations or recording, e.g. using suitable meters or invoices, can also be used. The monitoring is broken down to the most appropriate level (e.g. to process or plant level) and considers any significant changes in the process or plant.

Monitoring, however, is not restricted to analytical measuring. It also includes regular maintenance, and visual and safety checks.

In parallel to this document, the reader is referred to the Reference Report on Monitoring of Emissions to Air and Water from IED installations (ROM).

Achieved environmental benefits
Monitoring the parameters mentioned above (see Description) helps to maintain the proper operation of the facility and to detect instances of malfunctioning and thus helps to prevent any possible adverse environmental effects.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
The costs associated with monitoring relate to personnel involved and equipment used.

Driving force for implementation
To ensure the proper operation of the installation.

Example plants
The majority of plants reported monitoring of the parameters mentioned above.

Reference literature
[169, TWG 2021]

3.1.3 Energy efficiency

In the following sections, general techniques related to energy efficiency are discussed. In addition to these, specific energy efficiency techniques are also discussed in the following sections:

- Section 3.2.1.3 for all foundry types;
- Section 3.2.2.1 for cast iron foundries;
- Section 3.2.4.1 for NFM foundries;
- Section 3.3.1 for smitheries.

3.1.3.1 Energy efficiency plan and energy audits

Description
An energy efficiency plan is part of the EMS (see Section 3.1.1.1) and entails defining and monitoring the specific energy consumption of the activity/processes, setting objectives in terms

of energy efficiency (e.g. kWh/t liquid metal) and implementing actions to achieve these objectives.

Energy audits are carried out at least once every year to ensure that the objectives of the energy management plan are met.

Technical description
Extensive information about energy efficiency can be found in the Energy Efficiency BREF (ENE BREF) [177, COM 2009]. Some techniques applicable to increase the energy efficiency of SF plants are as follows:

a. Appraising the costs and benefits of different energy options.
b. Monitoring energy flows (consumption and generation by source) and targeting areas for reductions.
c. Defining and calculating the specific energy consumption of the activity (or activities), and setting key performance indicators on an annual basis (e.g. MWh/tonne of product).
d. Carrying out an energy survey to identify the opportunities for further energy savings.
e. Using heat recovery techniques to recover heat from flue-gases.
f. Applying operating, maintenance and housekeeping measures to the most relevant energy consumption plants, such as:
    - air conditioning, process refrigeration and cooling systems (leaks, seals, temperature control, evaporator/condenser maintenance);
    - operation of motors and drives (e.g. high-efficiency motors);
    - compressed gas systems (leaks, procedures for use);
    - steam distribution systems (leaks, traps, insulation);
    - room heating and hot water systems;
    - lubrication to avoid high friction losses (e.g. mist lubrication);
    - boiler maintenance, e.g. optimising excess air;
    - other maintenance relevant to the activities within the plant;
    - reviewing equipment requirements on a regular basis.
g. Using techniques that reduce energy consumption and thereby reduce both direct (heat and emissions from on-site generation) and indirect (emissions from a remote power station) emissions. For example:
    - building insulation;
    - use of energy-efficient site lighting;
    - vehicle maintenance;
    - efficient plant layout to reduce pumping distances;
    - phase optimisation of electric motors;
    - heat recovery;
    - ensuring equipment is switched off, if safe to do so, when not in use;
    - ensuring on-site vehicle movements are minimised and engines are switched off when not in use.
h. Applying basic, low-cost, physical techniques to avoid gross inefficiencies; including insulation, containment methods (for example seals and self-closing doors) and avoiding unnecessary discharges of heated water or air (for example by fitting simple control systems).
i. Applying energy efficiency techniques to building services.
j. Using heat from the furnaces and engines for vaporisation, drying and for preheating activities.

Energy audits are carried out at least once a year to to ensure that the objectives of the energy management plan are met. Audits may be carried out using international standards which have been developed to support the implementation of energy audits under the Energy Efficiency Directive (e.g. EN 16247-1:2012 and ISO 50002:2014).

Achieved environmental benefits
Reduction of energy consumption and emissions relevant for that energy use.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
The level of detail of the energy efficiency plan and of the energy audits will generally be related to the nature, scale and complexity of the plant and the types of energy sources.

Economics
No information provided.

Driving force for implementation
Energy savings.

Example plants
Widely used.

Reference literature
[169, TWG 2021], [177, COM 2009].

3.1.3.2 Energy balance record

Description
The technique involves the drawing up on an annual basis of an energy balance record which provides a breakdown of the energy consumption and generation (including energy export) by the type of energy source (e.g. electricity, natural gas, renewable energy, imported heat and/or cooling). This includes:

(i) defining the energy boundary of the processes;
(ii) information on energy consumption in terms of delivered energy;
(iii) information on energy exported from the plant;
(iv) energy flow information (e.g. Sankey diagrams or energy balances) showing how the energy is used throughout the processes.

Achieved environmental benefits
Reduction of energy consumption.

Environmental performance and operational data
The reduction of emissions from the energy system can only be evaluated with a proper calculation of the actual emissions generated. The breakdown between generation and consumption can help to optimise the balance between them and hence to optimise the use of energy resources.

Cross-media effects
None.

Technical considerations relevant to applicability
The level of detail of the energy balance record will generally be related to the nature, scale and complexity of the plant and the types of energy sources used.

Economics
The requirements are basic and cost little.

Driving force for implementation
Reduction of energy costs.

Example plants
Widely used.

Reference literature
[177, COM 2009].

3.1.3.3 Use of general energy-saving techniques

Description
This includes techniques such as:

- burner maintenance and control;
- energy-efficient motors;
- energy-efficient lighting;
- optimising steam distribution systems;
- regular inspection and maintenance of the steam distribution systems to prevent or reduce steam leaks;
- process control systems;
- variable speed drives;
- optimising air conditioning and building heating.

Technical description
Optimisation of furnaces and furnace operation will yield major efficiency improvements because heating, heat treatment, melting and holding account for the majority of the total energy consumption. Energy consumption can also be reduced by optimising utilities such as air compressors, fans, motors, pumps and lights.

General energy-saving techniques are applied by process and equipment selection and optimisation.

<u>Energy-efficient motors</u>
- Measures include creating a motor management plan, selecting and purchasing motors strategically, performing ongoing maintenance, using properly sized motors, automating motors, using adjustable speed drives, using the correct power factor, minimising voltage imbalances and using soft starters.

<u>Energy-efficient lighting</u>
- This can be achieved by turning off lights in unoccupied areas, using occupancy sensors and other lighting controls, upgrading exit signs, replacing magnetic ballasts with electronic ballasts, replacing T-12 tubes with T-8 tubes, reducing the lighting system voltage, replacing mercury lights with metal halide or high-pressure sodium lights, replacing metal halide HID with high-intensity fluorescent lights, using daylighting and using LED lighting (see also the ENE BREF). [177, COM 2009]

Achieved environmental benefits
Reduction of energy consumption.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
Reduction of energy costs.

Example plants
Widely used.

Reference literature
[169, TWG 2021], [177, COM 2009].

3.1.4 Emissions to air

3.1.4.1 Use of electricity from fossil-free energy sources in thermal processes

Description
This technique consists of the:

- use of electric furnaces (e.g. coreless and channel induction, resistance, electric arc) in foundries for thermal processes (metal melting and heat treatment);
- use of electric furnaces in the smitheries heating, reheating and heat treatment processes.

In both cases, the electricity used is generated from fossil-free energy sources (e.g. hydroelectric, solar, wind, nuclear).

Technical description
Foundries
In foundries, metal melting and heat treatment constitute the two main thermal processes where electric furnaces are employed for the production of either ferrous or non-ferrous molten metal. This also includes remelting of molten metal and heat conservation of molten metal in holding furnaces. The various types of furnaces employed for metal melting or heat treatment are summarised below:

- *Cast iron foundries*: Besides cupola furnaces, cast iron is usually melted in electric furnaces, in particular coreless induction furnaces. Channel induction furnaces are also used but principally for holding purposes. Heat treatment of ductile iron (e.g. annealing, tempering, austempering) may be carried out either in electric or gas-fired furnaces.
- *Steel foundries*: A large majority of foundries use electric furnaces for metal melting, in particular electric arc or induction furnaces. Large steel foundries are usually equipped with electric arc furnaces, but the majority of smaller steel foundries useinduction furnaces. For heat treatment, carbon steel and low-alloy steel are generally submitted to normalising or to austenitising, quenching and tempering heat treatments. This may be carried out either in electric or gas-fired furnaces.
- *NFM foundries*: A variety of different melting furnaces are used depending on the type of alloy and melting capacity. Often, small foundries use either gas-fired or crucible induction furnaces. Large NFM foundries generally use either gas-fired furnaces (e.g. shaft or reverberatory) or electric furnaces (e.g. induction furnaces). For heat treatment (e.g. stress relieving, annealing, quenching, artificial ageing), either electric or gas-fired furnaces may be used.

Smitheries
In smitheries, the main thermal processes are heating/reheating to raise the temperature of the feedstock prior to the hammering process and heat treatment (e.g. annealing, tempering,

austempering) carried out after the hammering process in order to give the workpiece its required metallurgical properties. Heating/reheating of the feedstock is usually carried out either by direct or indirect heating as follows:

- *Direct heating*: Electric energy is used, either inductive or conductive.
- *Indirect heating*: Generally, this is carried out in natural-gas-fired chamber or continuous furnaces. In some cases, electric furnaces are also used.

In heat treatment, both electric and gas-fired furnaces may be used.

In the context of the decarbonisation and zero pollution objectives set in the EU Green Deal, the use of fossil fuels in thermal processes needs to be drastically reduced and/or eliminated. The electrification of thermal processes constitutes a possible way forward, provided that the source of electricity is from fossil-free energy sources (e.g. hydroelectric, solar, wind, nuclear).

Accordingly, the primary objective of a SF plant operator would be to obtain electricity from a fossil-free energy source depending on local conditions and availability of fossil-free energy supply. In this case, the possible replacement and/or conversion of existing gas-fired furnaces with new electric furnaces in both smitheries and foundries may be considered.

Achieved environmental benefits

- Elimination of emissions of CO_2, SO_2 and NO_X and reduction of dust emissions from SF heating processes on site.
- Reduction of emissions from the production of electricity used in the SF plant in the case of fossil-free electricity (although a lower emissions reduction is expected if electricity is produced by combustion of biomass).

Environmental performance and operational data

The use of electricity generated from fossil-free energy sources in the smitheries and foundries thermal processes can lead to substantial reductions in terms of CO_2, dust, SO_2 and NO_X emissions provided that electricity is not generated from biomass combustion.

Cross-media effects

None.

Technical considerations relevant to applicability

The technique is generally applicable.

The current energy policy of the European Union promotes decarbonisation of electricity generation. In addition, the electricity market has been liberalised in almost all EU Member States, meaning that the customer (user of electricity) has the option to select their electricity provider. Many electricity producers/distributors provide customers with the option to choose a fossil-free electricity supply. The share of fossil-free electricity in the European electricity mix is expected to rise drastically in the short to medium term.

Economics

The choice between the conversion of existing gas-fired furnaces to electric ones or their replacement with new electric furnaces will be based on the availability of both technical options and their respective costs.

Driving force for implementation

- Increased energy efficiency.
- Elimination of emissions from thermal processes on site (at the SF plant) and from the generation of electricity.
- Environmental legislation.
- Decarbonisation of the SF sector.

Example plants
Electric furnaces are widely used in foundries for metal melting (cast iron, steel and NFM). In steel foundries, the majority of plants use electric furnaces (i.e. induction and electric arc).

In smitheries, the results from the data collection showed that for heating/reheating the majority of plants in the data collection use gas-fired furnaces (e.g. pusher-type, bogie hearth). However, one plant reported the use of six induction furnaces for preheating (ES008) and another plant reported the installation of two new induction furnaces in 2019 (DE005).

Reference literature
[169, TWG 2021]

3.1.5 Noise and vibrations

Noise emissions and vibrations may occur throughout all the production processes of the smitheries and foundries installations, such as preparing and processing raw materials, heating, reheating, melting, forging/hammering, heat treatment, surface treatment, material transport and storage of products as well as from the dispatch and shipping of the final products. [139, Probst 2006], [169, TWG 2021]

The overall reduction of noise levels involves developing a noise reduction plan. All sources of noise emissions need to be checked and evaluated.

The foundry process contains various point sources of noise. These include:

- scrap handling;
- furnace charging;
- burners;
- HPDC machines ~~automates~~;
- shake-out;
- grit-blasting;
- core (and mould) shooting;
- finishing;
- all motors and hydraulic systems;
- transport (tipping, loading, etc.)

Techniques with lower noise levels may be applied and/or point sources may be enclosed.

Full enclosure of the foundry building may be considered as well. This will also require the setting up of a climate control system, to limit the temperature inside the building.

Where residential areas are located close to a plant, the planning of new buildings at the smitheries or foundries site is connected with a necessity to reduce noise emissions and vibrations.

More information on techniques to minimise vibrations in smitheries is given in Section 3.3.3.

3.1.5.1 Noise and vibration management plan

Description
To set up, implement and regularly review a noise and/or vibration management plan, as part of the EMS (see Section 3.1.1.1), that includes all of the following elements:

- a protocol containing appropriate actions and timelines;

- a protocol for monitoring emissions of noise and/or vibrations;
- a protocol for responding to identified noise and vibration events, e.g. managing complaints and/or taking corrective actions;
- a noise and/or vibration reduction programme designed to identify the source(s), to measure/estimate noise and/or vibration exposure, to characterise the contributions of the sources and to implement prevention and/or reduction measures.

Technical description
As part of the EMS, a noise and vibration management plan is implemented and regularly reviewed.

The overall reduction of noise levels involves developing a noise reduction plan. Here each of the sources needs to be checked and evaluated. Alternative techniques with lower noise levels may be applied and/or point sources may be enclosed.

Useful tools for the effective application of this technique may be:

- periodic noise monitoring (reported by the majority of plants with periodicity from once every year up to once every 5 years);
- development of noise maps and associated noise calculations (reported by Plant SE150);
- periodic meetings and discussions with neigbours to identify noise nuisance issues (reported by Plant AT006).

Achieved environmental benefits
Reduction of noise emissions and vibrations.

Environmental performance and operational data
A Belgian aluminium foundry ~~is currently developing~~ developed a noise reduction plan (data from 2005). The aim is for the general noise level to be reduced from 50 dBA to 40 dBA. This involves the study of 170 sources. Specific measures are taken to reduce the overall noise level between 22.00 h and 6.00 h. Additionally, air is blown into the foundry hall, creating a small pressure difference to keep the noise inside. The total inside air volume is refreshed 36 times each hour.

Cross-media effects
None.

Technical considerations relevant to applicability
The applicability is restricted to cases where a noise and/or vibration nuisance at sensitive receptors is expected and/or has been substantiated.

Economics
No information provided.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
MGG, Hoboken (BE): noise reduction plan, AT006, SE150.

Reference literature
[169, TWG 2021]

3.1.5.2 Appropriate location of equipment and buildings

Description
Increasing the distance between the emitter and the receiver, by using buildings as noise screens and by relocating equipment and/or buildings' exits or entrances.

Technical description
A reduction of noise emissions can often be achieved by directly applying techniques at the source of the noise. Increasing the distance between the emitter and the receiver, by using buildings as noise screens and by relocating equipment and/or exits or entrances of the buildings can decrease the noise level. Furthermore, construction of buildings or natural barriers, such as growing trees and bushes between the protected area and the noisy activity, can be carried out. See also specific information on noise emissions in smitheries in Section 3.3.4.

Achieved environmental benefits
Reduction of noise emissions and vibrations.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
For existing plants, the relocation of equipment and the exits or entrances of buildings may not be applicable due to a lack of space and/or excessive costs.

Economics
Relocation of equipment and exits entails an associated cost.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[169, TWG 2021]

3.1.5.3 Operational measures

Description
These include techniques such as:

- inspection and maintenance of equipment;
- closing of doors and windows of enclosed areas, if possible;
- equipment operation by experienced staff;
- avoidance of noisy activities at night, if possible;
- provisions for noise control, during production and maintenance activities, transport and handling of feedstock and materials, e.g. reducing the number of material transfer operations, reducing the height from which pieces fall on to hard surfaces.

Technical description
Operational measures are applied in order to prevent or to reduce noise emissions.

Doors and windows of covered areas have to be kept closed during noisy operations.

Noisy activities (e.g. transport) have to be avoided at night.

Achieved environmental benefits
Reduction of noise emissions and vibrations.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
Legal requirements.
Local conditions.

Example plants
Widely used.

Reference literature
[169, TWG 2021]

3.1.5.4 Low-noise equipment

Description
This includes techniques such as direct drive motors, low-noise compressors, pumps and fans.

Technical description
When new equipment is purchased, the associated noise levels are taken into consideration.

Low-noise equipment includes special blowing heads (reported by Plant ES099),

See also general measures for reduction of noise emissions in smitheries in Section 3.3.4.

Achieved environmental benefits
Reduction of noise emissions.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
Additional investment and maintenance costs may occur due to the noise prevention techniques.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[169, COM 2021]

3.1.5.5 Noise control equipment

Description
This includes techniques such as:

- use of noise reducers;
- use of acoustic insulation of equipment;
- enclosure of noisy equipment and processes (e.g. unloading of raw materials, hammering, compressors, fans, shake-out, finishing);
- use of building materials with high sound insulation properties (e.g. for walls, roofs, windows, doors).

Achieved environmental benefits
Reduction of noise emissions.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Applicability to existing plants may be limited by a lack of space.

Economics
Investment cost of the noise control equipment.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[169, COM 2021]

3.1.5.6 Noise abatement

Description
Inserting obstacles between emitters and receivers (e.g. protection walls, embankments).

Technical description
Examples of obstacles between noise emitters and receivers are:

- installation of noise walls (e.g. installation of 8-metre-high noise walls around noisy equipment was reported by Plant ES095);
- installation of soundproof panels for noisy equipment enclosure (reported by Plant PT139).

See also specific information on noise emissions in smitheries in Section 3.3.4.

Achieved environmental benefits
Reduction of noise emissions.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Only applicable to existing plants, as the design of new plants should make this technique unnecessary. For existing plants, the insertion of obstacles may not be applicable due to a lack of space.

Economics
No information provided.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[169, COM 2021]

3.1.6 Residues

3.1.6.1 Residues management plan

Description
A residues management plan is part of the EMS (see Section 3.1.1.1) and comprises a set of measures aiming to:

- minimise the generation of residues;
- optimise the reuse, recycling and/or recovery of residues; and
- ensure the proper disposal of waste.

Technical description
A variety of techniques can be used for residue optimisation and they range:

- from basic housekeeping techniques;
- through statistical measurement techniques;
- to the application of clean technologies;
- the use of process chemicals before their expiry date;
- to the use of residues as fuel; and
- the reuse or recycling of packaging.

In particular, a residue/waste management plan could be based on the five-stage hierarchy of the EU Directive 2008/98/EC and the Commission notice on technical guidance on the classification of waste 2018/C 124/01, and includes the following:

- Identifying, characterising and quantifying each of the residue/waste streams generated. Maintaining a residue/waste tracking system can help operators to record the quantity, nature, origin and, where relevant, the destination, frequency of collection, mode of transport and treatment method of any residue/waste which is disposed of or recovered on that site.
- Identifying the current or proposed handling arrangements, and possibilities to implement circular economy.
- Fully describing how each residue stream is proposed to be recovered or disposed of. If it is to be disposed of, the plan explains why recovery is not technically or economically possible and then describes/explains the measures planned to avoid or reduce the impact on the environment.
- Practical techniques to reduce the amount of waste sent for disposal may include the following:
    - applying housekeeping operations; these can be as simple as sweeping prior to washing floors and can substantially reduce residue waste volumes;
    - established criteria associated for example with the maximum storage time of process chemicals are clearly established and relevant parameters are monitored to avoid the process chemicals perishing or the expiry date being exceeded;
    - separate capture of high-loaded waste streams from low-concentrated effluent to allow more efficient treatment;
    - separate collection of unavoidable solid waste;
    - reduction of packaging;
    - use of returnable containers;

Achieved environmental benefits

- Increased material efficiency.
- Reduced amount of waste sent for disposal.
- Minimisation of residues through recycling of process residues and reuse of recycled materials along with raw material savings.

Environmental performance and operational data

No information provided.

Cross-media effects

None identified.

Technical considerations relevant to applicability

The level of detail and the degree of formalisation of the residues management plan will generally be related to the nature, scale and complexity of the plant.

Economics

No information provided.

Driving force for implementation

- Reduced costs due to increased material efficiency.
- The prevention of waste generation is a principle of the IED (Directive 2010/75/EU 2010) and the Waste Framework Directive (WFD, Directive 98/EC 2008)

Example plants

Widely used.

Reference literature

WFD, Directive 98/EC 2008.

3.1.7 Decommissioning

TWG, please note that industry (CAEF) proposes the deletion of this technique. You are kindly asked to provide more information in order to update this technique.

Description
Elaboration of plans and measures, applied throughout the installation's lifetime, related to minimising environmental impact and related costs of decommissioning.

Technical description
Some techniques to consider are:
- considering later de-commissioning at the design stage, thereby minimising risks and excessive costs during later de-commissioning
- for existing installations, where potential problems have been identified, putting in place a programme of improvements. These improvements designs need to ensure that:
  - underground tanks and pipework are avoided where possible (unless protected by secondary containment or a suitable monitoring programme);
  - there is provision for the draining and cleaning-out of vessels and pipework prior to dismantling;
  - lagoons and landfills are designed with a view to their eventual clean-up or surrender
  - insulation is used which can be readily dismantled without dust or hazards arising;
  - any materials used are recyclable (although bearing in mind they still meet operational or other environmental objectives);

- developing and maintaining a site closure plan, to demonstrate that, in its current state, the installation can be decommissioned to avoid any pollution risk and to return the site of operation to a satisfactory state. The plan should be kept updated as material changes occur. However, even at an early stage, the closure plan can include:
  - either the removal or the flushing out of pipelines and vessels where appropriate and their complete emptying for any potentially harmful contents;
  - plans of all underground pipes and vessels;
  - the method and resource necessary for the clearing of lagoons;
  - the method of ensuring that any on-site landfills can meet the equivalent of surrender conditions;
  - the removal of asbestos or other potentially harmful materials unless agreed that it is reasonable to leave such liabilities to future owners;
  - methods of dismantling buildings and other structures, for the protection of surface and groundwater at construction and demolition-sites;
  - testing of the soil to ascertain the degree of any pollution caused by the activities and the need for any remediation to return the site to a satisfactory state as defined by the initial site report.

Achieved environmental benefits
Prevents environmental issues during de-commissioning.

Technical considerations relevant to applicability
Techniques mentioned here are applicable throughout the installation's operational lifetime, during the design and building stage of the site and activities and immediately after the site closure.

Reference literature
[131, UK Environment Agency 2001]

3.2 Techniques to consider in the determination of BAT for foundries

3.2.1 Techniques to consider for all foundry types

3.2.1.1 Use of alternative substances which are non- or less hazardous in moulding and core-making

Description
Hazardous substances and substances of very high concern used in moulding and core-making are substituted by non-hazardous substances or – when this is not feasible – by less hazardous substances, by using for example:

- aliphatic organic (instead of aromatic) binders in moulding;
- non-aromatic solvents for cold-box core making;
- inorganic binders in moulding and core making;
- water-based coatings in moulding and core-making.

More information on the techniques
See Sections 3.2.1.9.10 (aliphatic organic binders), 3.2.1.9.8 (non-aromatic solvents), 3.2.1.9.11 (inorganic binders) and 3.2.1.5.5 (water-based coatings).

3.2.1.2 Monitoring of emissions to air and to water

3.2.1.2.1 Monitoring of emissions to air

Description
Regular monitoring of emissions to air.

Technical description
Monitoring of the relevant parameters can be accomplished by online measurements (which facilitate rapid intervention and control) or analytical results derived from air samples. Parameters to be monitored and the frequency of monitoring depend *inter alia* on the activities responsible for generating the emissions to air.

The monitoring of emissions is carried out in accordance with EN standards or, if EN standards are not available, ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality.

Achieved environmental benefits
Monitoring the waste gas of a foundry plant helps to maintain the proper operation of the plant and to detect accidental releases and thus helps to prevent any possible adverse environmental effects when the waste gas is emitted.

Environmental performance and operational data
Data for the common parameters monitored in foundry plants may be found in Section 2.3 (current consumption and emission levels for foundries). Some of the key parameters to be monitored are dust and metal compounds (such as Cd, Cr, Ni, Pb), NO_X, CO, amines, benzene, B[a]P, Cl_2, formaldehyde, HCL, HF, PCDD/Fs, phenol, TVOC.

Cross-media effects
Some equipment, ancillary materials and energy are required for carrying out monitoring.

Technical considerations relevant to applicability
Generally applicable to all foundries where there are channelled emissions to air.

Economics
The costs associated with monitoring the waste gas of a foundry plant relate to personnel and equipment used for sampling and measurement.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
See Section 2.3.

Reference literature
[169, TWG 2021], [174, COM 2018]

3.2.1.2.2 Monitoring of emissions to water

Description
Regular monitoring of emissions to water.

Technical description
Monitoring of the relevant parameters can be accomplished by online measurements (that facilitate rapid intervention and control of the waste water treatment plant – WWTP) or analytical results derived from waste water samples. Parameters to be monitored and the frequency of monitoring depend on the activities which are connected to the WWTP and to the destination of the treated effluent (direct discharge or indirect discharge after further treatment in another industrial WWTP or a municipal WWTP). Discharges may come from a WWTP that treats streams originating from one foundry installation only or from a common WWTP that treats waste water streams from several foundries and may also include streams from non-foundry activities.

The monitoring of emissions is carried out in accordance with EN standards or, if EN standards are not available, in accordance with ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality.

Achieved environmental benefits
Monitoring the waste water of a foundry plant helps to maintain the proper operation of the plant and to detect accidental releases and thus helps to prevent any possible adverse environmental effects upon discharge of waste waters.

Environmental performance and operational data
Data on monitored parameters are found in the Section 2.3 (current consumption and emission levels for foundries) and these parameters include AOX, BOD, COD, CN^-, HOI, metals/metalloids (As, Cd, Cr, Fe, Ni, Pb, Zn, Hg), phenol index, TOC and TSS.

Cross-media effects
Some equipment, ancillary materials and energy are required for carrying out monitoring. The COD measurement relies on the use of very toxic compounds (i.e. mercury and chromate).

Technical considerations relevant to applicability
Generally applicable to all plants from where there are emissions to water.

Economics
The costs associated with monitoring the effluent waste water of a waste water treatment plant relate to personnel and equipment used for sampling and measurement.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

See Section 2.3

Reference literature

[169, TWG 2021], [174, COM 2018]

3.2.1.3 Energy efficiency

Metal melting and the holding of molten metal in the molten state generally take up a significant part of a foundry's energy consumption. In many foundries more energy is used in holding the metal in the molten state than in the actual melting process. Furthermore, considerable energy is expended in areas other than that of metal supply. For example, foundries are generally large users of compressed air. Other large users of energy are likely to be items such as high-pressure die-casting machines, whose mainly hydraulic power units are also driven by electricity. Sand and gravity die foundries may employ hot core-making processes, such as shell or hot-box, using gas or electricity to heat the boxes. The heating of dies and ladle and furnace linings can amount to an appreciable fraction of the total energy used. The typical relative distribution of energy use in two foundry types is given in Table 3.3.
[26, ETSU 1997]

Table 3.3: Typical energy use in a non-ferrous foundry and an EAF steel foundry

Activity	Non-ferrous foundry (%)	EAF steel foundry (10000 t/yr good casting) (%)
Melting	30	44
Holding	30	
Plant actuation	15	
Air compression	14	10
Tool heating	3	
Heat treatment (gas)		7
Others *	8	39
(*) Includes all activities for which no values are given in the same column and activities which are not mentioned *Source*: [26, ETSU 1997], [100, TWG 2002]		

These data show that foundry processes~~services~~ (i.e. all but melting and holding) are responsible for up to half of foundry energy consumption. This includes activities using items such as motors and drives, compressed air, lighting, space heating and boiler plant. Energy efficiency measures should have regards to both the melting and the services field. [22, ETSU 1995]

Energy-efficient operation is brought about by applying good practice measures to reduce energy use in all of the mentioned steps. Improved energy efficiency is one of the main environmental benefits mentioned throughout the techniques discussions this chapter. The following sections focus on specific energy efficiency techniques ~~aimed at heat recovery and heat transfer to other parts of the foundry~~.

3.2.1.3.1 Selection of an energy-efficient type of furnace

Description
Furnace energy efficiency is taken into consideration in the furnace selection, e.g. furnaces that allow the preheating and drying of incoming charge prior to the melting zone.

Technical description
In foundries, one of the most important pieces of equipment is the melting furnace. A number of factors have to be considered when selecting a melting furnace including, e.g. the capital and operating costs, the type of metal, the production process used. Some of the key parameters to consider are described in Section 3.2.1.7.1. In addition, it is essential to consider the energy efficiency and potential melt losses of the different types of melting furnaces used in ferrous and non-ferrous metal melting.

Non-ferrous metal melting
Different types of melting furnaces may be used. Some of the advantages/disadvantages of the various furnaces are presented below.

a. *Crucible furnaces*: Most crucible furnaces are small-capacity furnaces used for melting or as holding furnaces. They present several advantages such as simple operation and maintenance and relatively low capital investment. In aluminium melting, crucible furnaces generally have a capacity of 1 000 kg (static type) or up to 1 500 kg (tiltable furnaces). The melting rate of electric crucible furnaces is typically about 250 kg Al/h whereas gas-fired furnaces can reach rates up to 400 kg Al/h. However, aluminum melting gas-fired crucible furnaces exhibit very low energy efficiency, ranging from 7 % to 19 % and a relatively high melt loss of 4-6 %. In this type of furnace, more than 60 % of the heat loss is due to radiation; the remaining heat losses are via hot exhaust gases leaving the furnace.
   - *Reverberatory furnaces:* There are three main types of fuel-fired reverberatory furnaces: i) dry hearth reverberatory furnaces where the metal is preheated prior to melting, ii) wet-bath reverberatory furnaces where the metal is directly charged to the molten bath without preheating, and iii) side-well reverberatory furnaces equipped with a number of burners inside the hearth with a charging well and pump that is usually placed outside the furnace. The energy efficiency of reverberatory furnaces is usually very low, ranging from 20 % to 25 %.
   - *Shaft furnaces*: Shaft furnaces present the highest thermal efficiency of all the gas-fired furnaces, typically within a range of 40 % to 45 %. This is mainly due to the special design of the furnace which allows the incoming metal to be charged through the exhaust stack. As a result, the heat from the flue-gases is used to preheat the metal prior to melting. Shaft furnaces have lower melt losses than reverberatory furnaces, typically within a range of 1 % to 2 %.

Cast iron melting
In cast iron melting, two types of induction furnaces may be used, the coreless induction furnaces and the channel induction furnaces. Coreless induction furnaces are marginally less efficient than channel induction furnaces but they are generally more flexible. Coreless induction furnaces can operate at low, medium or high frequencies and can be started cold and usually poured until fully empty, which simplifies alloy changes. Typically, electric induction furnaces can have a very high energy efficiency of 75 %.

Steel melting
Steel can be melted either in electric arc or induction furnaces. Typically, the coreless induction furnaces are found in newer installations compared to EAFs. Generally, the specific energy consumption of coreless induction furnaces is slightly lower than EAFs.

Achieved environmental benefits
Reduced energy consumption.

Environmental performance and operational data

- *Crucible furnaces*: As an alternative to gas-fired furnaces, electric resistance crucibles are less energy-intensive. Their energy consumption may range from 460 kWh/t to 570 kWh/t compared to 1 600 kWh/t to 2 600 kWh/t for gas-fired furnaces.

- *Reverberatory furnaces*: Dry hearth furnaces have a typical energy consumption of about 1 200 kWh/t. Wet-reverberatory furnaces exhibit lower melt losses (2-5 % for gas-fired and < 1 % for electric furnaces) and have a typical energy consumption of about 1 000 kWh/t. If metal circulation, metal preheating and regenerative burners are used, it is possible to reduce the energy consumption to about 650 kWh/t.

- *Shaft furnaces*: The replacement of reverberatory furnaces with shaft furnaces can lead to substantial savings in terms of energy consumption. Measurements carried out at two die-casting foundries in the US showed that the melting efficiency was 25 % for a reverberatory furnace and 44 % for a shaft furnace, both operated under the same conditions. In the second foundry equipped with both a reverberatory and a shaft furnace of equal capacity (1 360 kg/h) processing the same charge, the melt losses were 5.5 % using the reverberatory furnace but only 0.9 % for the shaft furnace. The energy consumption in the shaft furnace was 616 kWh/t but was significantly higher in the reverberatory furnace (1 275 kWh/t).

Cast iron melting

The energy consumption of a coreless induction furnace in cast iron melting for raising the metal temperature up to 1 450°C can be less than 600 kWh/t, but usually ranges from 600 kWh/t to 1 000 kWh/t.

Steel melting

In theory, the electrical energy consumption required to melt steel to a temperature of 1 600 °C is 342 kWh/tonne. However, the majority of steel foundries consume from 454 kWh/tonne to 726 kWh/tonne in melting due to heat losses.

Cross-media effects

Reverberatory furnaces can be built with large capacities while shaft furnaces have to be relatively high to achieve the preheating effect (typically about 6 m). The refractory lining at the bottom of the shaft furnaces can suffer from mechanical stress which results in a need for more frequent maintenance.

In shaft furnaces, the charge needs to be stacked properly, meaning that this type of furnace does not accept all shapes of aluminum scrap.

Technical considerations relevant to applicability

Only applicable to new plants and/or major plant upgrades.

Economics

No information provided.

Driving force for implementation

Legal requirements.

Example plants

Widely used.

Reference literature

[145, US EPA 2016], [194, Groteke et al. 1999], [195, Malpohl et al. 2010], [196, Butler 2006], [197, Biswas et al. 2012]

3.2.1.3.2 Techniques for maximising the thermal efficiency of furnaces

Description
Measures taken to maximise the efficiency of energy conversion in the furnace while minimising emissions (in particular of dust and CO). This is achieved by using furnace automation and control and by applying a series of process optimisation measures according to the furnace type.

Technical description
Cupola furnaces
In cupola furnaces, the amount of dust and exhaust gases resulting are directly related to the amount of coke charged per tonne of iron. Therefore, all measures that improve the thermal efficiency of the cupola will also reduce the emissions from the furnace.

Measures for maximising the thermal efficiency of cupola furnaces include the following:

- *Optimisation of operational regime*: ~~*Operating*~~ The furnace is operated in its optimum regime as much as possible. For any given cupola, the influence of the blast rate and the coke charge on the tapping temperature of the metal and the melting rate can be expressed in the form of a net diagram or Jungblüth diagram. A net diagram is only valid quantitatively for the cupola for which it was obtained. It displays how the metal temperature and melting rate behave upon changes in the blast rate and coke charge, and allows determination of the point (or line) of optimal thermal efficiency.
- *Avoidance of excess temperature*: Measures are taken to avoid excess temperatures of the melt and reduce the superheating temperatures ~~by taking measures~~ during the handling of tapped metal.
- *Uniform charging*: Care is taken during charging to get a uniform distribution of metal and coke.
- *Improving the control of the charge weight, the blast airflow and the metal temperature*.
- *Minimisation of air losses*: The correct supply of air is essential for efficient cupola operation. This is often hampered by air losses. Therefore, it is important to pay close attention to the prevention of all leaks to ensure efficient operation. Slag holes on intermittently tapped cupolas are often left open and are frequently oversized, resulting in considerable air losses. Air losses are particularly common for hot blast cupolas. They take place in the heat exchanger. The consequence is that oxygen must be injected in the tuyères instead of the air which is lost.
- *Avoiding 'bridging' in the cupola*: Bridging and scaffolding are the hanging or non-descent of cupola charges in the cupola shaft. This causes a loss of melting efficiency, and in severe instances melting can be completely stopped.
- *Good lining practice*: As melting proceeds, the diameter and the area of the melting zone increase due to lining erosion and wear. This affects the operation, moving it away from the optimum. Minimising the lining attack is therefore an energy saving measure. For satisfactory and economic cupola operation the melting zone needs to be efficiently repaired after each melt.

Coreless induction furnaces
Measures for maximising the thermal efficiency of a coreless induction furnace include techniques such as:

- *Optimisation of feedstock condition*: This involves avoiding rusty and dirty inputs, utilising optimum size and density input/scrap, and using cleaner carburisers. These measures shorten the melting time, reduce the specific energy needed for melting and/or reduce the amount of slag formed.
- *Closure of furnace lid*: Oxidation is reduced by avoiding badly fitting lids and unnecessary/prolonged openings, by quick charging, or by using a protective atmosphere over the melt (N_2). Opening times need to be minimised to prevent energy losses. The necessary opening times for charging, removing slag, temperature

measuring, sampling and pouring vary between 50 % and 25 % of the shift time. The latter figure applies for new furnaces, working in optimised conditions. A well-fitted closed lid limits the surface heat loss to about 1 % of the input power. When open, the heat loss can amount to up to 130 kWh/tonne for a 10-tonne-capacity unit. When melting under a closed lid, care should be taken not to overheat the furnace.

- *Restricting the holding time to a minimum*: Since melting is the first step in the foundry process chain, a shortening of the holding time can only be obtained by an integrated process optimisation for the whole foundry process and by minimising delays, problems and irregularities in any of the foundry departments. During holding, composition adjustment is performed based on the results of an analysis made on a chill cast sample. Optimisation of the sampling, testing and adjusting procedures is another measure for reducing the holding time.
- *Keeping a liquid heel in the furnace to reduce the duration of the melting cycle*: Maintaining a certain volume of liquid metal (a liquid heel) in the furnace reduces the amount of metal produced in one tap but reduces the melting cycle duration and and results in less fluctuation in melting operations. The use of a relatively large liquid heel (50-70 %) allows for a highly efficient melting process.
- *Addition of carburisers at the beginning of the melting cycle*: The addition of carburisers in the furnace has an influence on the energy consumption. Their addition at the beginning of the melting cycle along with the metallic load, instead of after melting, results in reduced energy consumption.
- *Operation at maximum power input level*: Furnaces are more efficient in their use of energy when they are being operated at maximum power input levels, and best results are obtained when the available power can be fully utilised for the largest proportion of the melting cycle. This also includes reducing cold start melts (optimise production programme), and allowing follow-up using monitoring and computer control.
- *Avoiding excessive temperature and unnecessary superheating*: It is important that the metal reaches the required temperature just at the time that the moulding department is in a position to receive it. Good co-operation between the melting and moulding shop is essential in order to minimise the electricity usage.
- *Optimising high temperature melts for slag removal* (good balance): Low melting point slag build-up can be reduced by heating the furnace up to elevated temperatures (1 580 ºC vs. 1 450 ºC normal). This results in a higher energy consumption, and can affect the metallurgical aspects of the melt. If the slag is allowed to build up on the furnace lining, this can affect the electrical efficiency of the furnace. Slag removal requires the opening of the furnace lid, and thus causes a thermal loss. A good balance needs to be found between increasing the melt temperature and the slag removal practice.
- *Preventing slag build up*: More common and more troublesome are instances where high melting point build-up is involved. This mainly results from charging sand and, in the case of iron melting, metallic aluminium into the melt. Some furnace operators have attempted flux additions and cleaning routines but prevention is better than cure in this respect. This involves minimising the presence of sand and Al in the raw materials.
- *Trickling the oxygen injection*: Instead of using conventional decarburisation.
- *Minimisation and control the refractory wall wearing:* The refractory life depends on the choice of materials as a function of the slag chemistry (acidic or basic), the operational temperature (steel, cast iron, non-ferrous), and the care taken upon relining (sintering). The lifetime may vary from 50 (steel, cast iron) to 200- 300 (cast iron) melts. Operational control measures are taken to follow the refractory wear. These include visual inspection, physical measurement and instrumental monitoring programmes. Good charging practice measures prevent the cumulative effects of physical chokes and mechanical stresses. These include the use of automatic charging systems, hot charging, avoiding high drops and the use of compact and dry scrap.

See also Section 3.2.1.3.2.1 for information on the optimisation of energy use (peak load management) in induction furnaces.

Rotary furnaces
Measures for maximising the thermal efficiency of rotary furnaces include techniques such as:

- use of anthracite and silicon for melt protection;
- adjustment of the continuous or discontinuous speed rotation of the furnace to achieve maximum heat transfer;
- adjustment of the power and angle of the burner to achieve maximum heat transfer.

Electric arc furnaces
- Measures for maximising the thermal efficiency of electric arc furnaces include techniques such asshorter metal melting and/or treatment times using advanced control methods for example for the composition and the weight of the charged materials, the temperature of the melt, as well as by efficient sampling and deslagging methods.

This consists more particularly of:

- closer control of the composition (e.g. C, S, P content) and the weight of the charged materials and slag-forming materials;
- reliable temperature control of the melt, which can improve the yield of the refining reactions and avoid overheating;
- more efficient methods for sampling and deslagging, which can reduce furnace downtime.

Secondary metallurgy, using AOD/VODC treatment, shortens the melting/treatment time in the EAF ~~time~~ and has a positive impact on energy conservation. The technique is discussed further in Section 3.2.3.2.1.

Shaft furnaces
Measures for maximising the thermal efficiency of shaft furnaces include techniques such as:

- independent control of the fuel/air ratio for each gas-fired burner;
- continuous CO or hydrogen monitoring for each row of burners;
- addition of oxygen above the melting zone to provide afterburning in the upper level of the shaft;
- preheating of the charge using waste heat recovered from the flue-gases.

Reverberatory furnaces
Measures for maximising the thermal efficiency of reverberatory furnaces include techniques such as:

- preheating of the charge in the case of dry hearth or side-well reverberatory furnaces;
- use of burners with automatic temperature control.

Crucible furnaces
Measures for maximising the thermal efficiency of crucible furnaces include techniques such as:

- preheating of the crucible prior charging;
- use of crucibles with high thermal conductivity and thermal shock resistance (e.g. graphite);
- cleaning of crucible walls immediately after emptying to remove slag or dross.

Achieved environmental benefits
- Increased furnace efficiency through shorter melting times and reduced downtime.
- Reduction of coke consumption and reduction of residues in cupola furnaces.

Environmental performance and operational data

Coreless induction furnaces

A typical coreless furnace can melt a tonne of iron and raise the temperature of the liquid metal to 1 450 ºC using under 600 kWh of electricity. However, in practice, only a few foundries can achieve this level of specific consumption on a week-by-week basis. Some foundries consume in the region of 1 000 kWh for every tonne of iron produced by their coreless furnaces. Prevailing circumstances in many foundries can restrict the scope for good energy management, but in fact almost all coreless melting operations could be improved in some way, in order to achieve a worthwhile saving in the quantity of electricity used per tonne of iron processed.

Rotary furnaces

An optimisation programme on a 3-tonne/h cast iron melting furnace suggested the following as good operational practice:

- Use of clean scrap and loading in the following order: (1) ingots and materials with low Si content; (2) internal return material and foundry scrap; (3) alloying elements and melt protection; (4) steel scrap.
- Melt protection: use of anthracite for melt protection (2 % of metal charge) and silicon (2 %).
- Rotation: in discontinuous phase, 1/3 of a rotation every minute with a total of 7.5 turns until the phase change. During continuous rotation: 1.7 rotations/minute.
- Power and angle of burner: use a parallel burner-head position for the lower injectors. Start at maximum power for 20 minutes, reducing 10 % every 20 minutes until change of phase (60 minutes after start).

Using these measures, a metal efficiency (molten metal/charged metal) of > 95 % could be maintained. The principles of the optimisation are generally valid for iron melting in rotary furnaces using oxygen burners. The operational data have been established for a 3-tonne/h furnace. For furnaces of other sizes, a site-specific optimisation is necessary.

Reverberatory furnaces

Preheating the hearth by using the heat from the flue-gases to heat scrap prior to charging into the furnace can reduce the energy use. For a furnace using 50 % new metal and 50 % scrap, preheating the metal for half an hour in the hearth prior charging can decrease the energy use by 10-12 %. [145, US EPA 2016]

Cross-media effects

None.

Technical considerations relevant to applicability

This technique applies to all new and exisiting cupola furnaces.

Driving force for implementation

- Optimisation of furnace operation.
- Legal requirements.

Example plants

Widely used.

Reference literature

[14, CAEF 1997], [20, ETSU 1993], [100, TWG 2002] [23, ETSU 1992], [38, VITO 2001], [51, Inductotherm 2002], [225, TWG 2003], [120, TWG 2003], [145, US EPA 2016]

3.2.1.3.2.1 Optimisation of energy use (peak load management) in induction furnaces

Description
When several induction furnaces are operated, the energy use is optimised through peak load management.

Technical description
When several furnaces are operated at the same time, peak load limitation is one way to reduce energy costs. In addition, modern energy management systems also reduce the specific energy requirement.

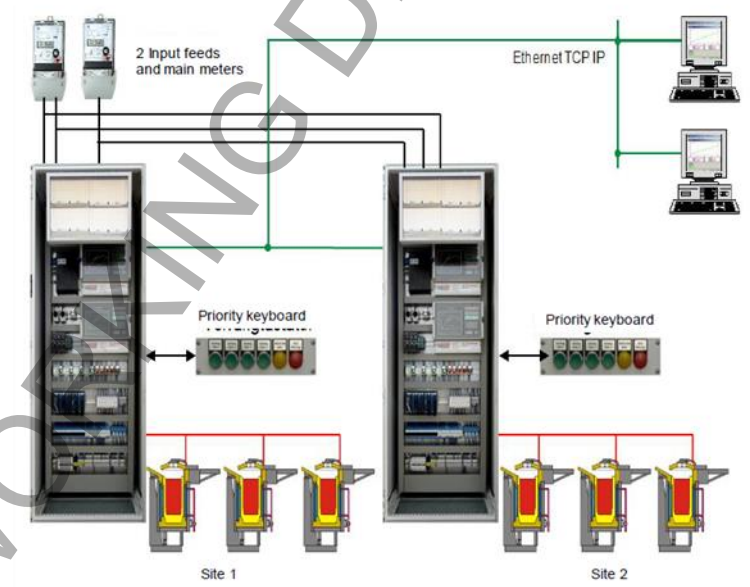
Energy-intensive companies pay, in addition to the energy rate, a demand charge that is based on the peak load. This is the highest measured power consumption in a given period.

Peak demands usually result from the simultaneous use of electrical energy by multiple consumers. The energy supplier must ensure availability of this maximum amount of electrical energy (peak) permanently due to its random occurrence.

With regard to the network load, peak loads are a crucial point. They cause additional supply costs to the energy supplier, which are invoiced to the purchaser of electrical energy. By reducing the peak demand, the energy costs can be reduced.

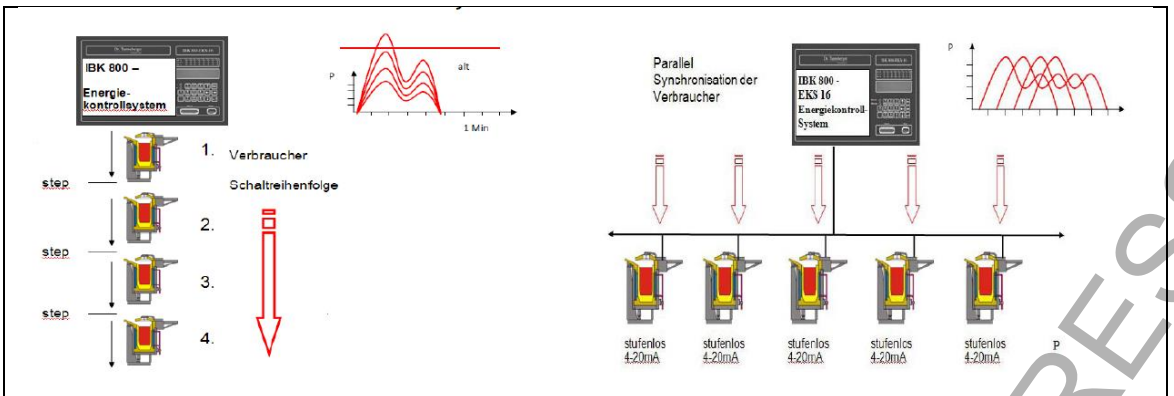
When peak loads are reached, modern load management systems do not cut the furnace off from the main supply but decrease the performance of individual furnaces for a certain time. This is achieved by an intelligent process technique.

Using multiple simultaneously operating melting aggregates results in characteristic data curves of the melting process. They represent the energy demand of the melting units in a given period. The processor attempts to coordinate the demands of the individual melting aggregates and thus to continuously improve the overall characteristic curve resulting from the energy demands of the sum of furnaces. The energy amount, resulting from the overall harmonisation and optimisation process, is then assigned to the individual furnaces. Priority can be given to individual furnaces manually.



Source: [133, DE UBA 2014]

Figure 3.2: Principle of control of electric furnaces



Source: [133, DE UBA 2014]

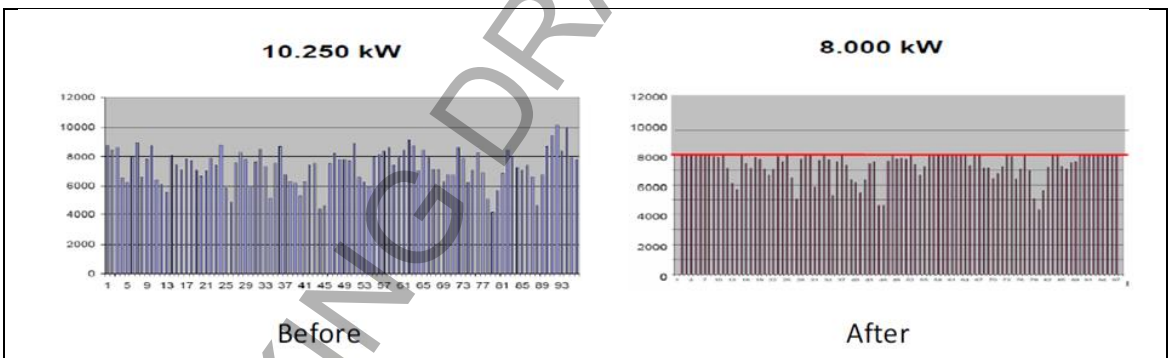
Figure 3.3: Serial load shedding following the trend calculation method (L) and parallel dedicated control for each furnace with its own load management (R)

Achieved environmental benefits

- By avoiding peak demands, provision of energy from the supplier can be balanced and use of a peak-load electricity generation plant – and with this environmental burden of starting such plants – can be avoided,
- Reduction of CO_2 emissions. Quantitative information about potential reduction of energy consumption is not available.

Environmental performance and operational data

In one foundry (Reinhard Tweer GmbH), the annual production volume of the foundry is 27 000 t of cast steel and cast iron with spheroid graphite. For melting, six medium-frequency furnaces are used, which have a significant influence on the energy costs of the foundry. The following illustration shows harmonisation of energy demands by reduction of peak demands. Without peak energy management, a peak demand as high as 10 250 kW was observed. After load optimisation, the maximum peak demand was reduced to 8 000 kW.



Source: [133, DE UBA 2014]

Figure 3.4: Effects of load optimisation on the peak demand of a German foundry (L: before load management optimisation; R: after load management optimisation)

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable in foundries with a significant number of electrically powered furnaces.

Economics
Reduced power purchase costs can be analysed by considering shift operations. The calculation below is based on electricity costs of:

- in 1-shift operation at 13.1 cents/kWh;
- in 2-shift operation at 12.4 cents/kWh;
- in 3-shift operation at 11.1 cents/kWh.

Table 3.4: Savings achieved from peak load management in several foundries

Installation	Savings (EUR/year)
Walzengießerei Coswig	160 000
Klaus Kuhn Edelstahl - Radevormwald	120 000
Jürgens Gießerei Emsdetten	60 000
Flender Siemens – Chemnitz	80 000
Affilips V.N. – Tienen / Belgium	100 000
Gießerei und Glasformenbau - Radeberg	80 000
KM Europa Metal AG - Osnabrück	90 000
Intermet / Sakthi - Neunkirchen	180 000
Eisenwerk Hasenclever & Sohn GmbH - Battenberg	130 000
Meuselwitzer Guss Eisengießerei GmbH	80 000
Technoguss Tangerhütte GmbH	50 000

Information about payback periods is not available.

Driving force for implementation
- Legal requirements and local conditions.
- Operational requirements:
  - Reduction of energy costs for electricity by between 5 % and 23 %.
  - Shorter holding times by just-in-time melting.

Example plants
See example plants in the Economics section above.

Reference literature
[133, DE UBA 2014]

3.2.1.3.3 Furnace automation and control

Description
The heating process is optimised by using a computer system controlling in real time key parameters such as furnace and feedstock temperature, the air to fuel ratio and the furnace pressure.

Technical description
Furnace automation takes care of the combustion, the energy consumption, material handling, temperature control of the feedstock and process safety continuously. In addition, it enables adjustment of the air to fuel ratio for optimum combustion, which in turn minimises NO_X emissions.

The furnace control system collects all the necessary data related to the operation of the furnace such as the equipment utilisation, the furnace temperature and pressure, the metal inputs and outputs and the energy consumption (fuel/electricity). The data can be visualised in real time by the plant operator and can be transferred for further analysis. Furnace logs including data on

operating modes, operating times, temperature curves and fuel consumption figures can be stored for quality assurance purposes.

Achieved environmental benefits
Optimised furnace operation.

Environmental performance and operational data
No information proided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
Increased efficiency of furnace operation and productivity.

Example plants
Widely used.

Reference literature
[195, Malpohl et al. 2010]

3.2.1.3.4 Use of clean scrap

Description
Melting clean scrap prevents the risk of non-metal compounds being taken up by the slag and/or degrading the furnace or ladle refractory linings.

Technical description
Melting clean scrap prevents the risk of non-metal compounds being taken up by the slag and/or attacking the furnace lining. These compounds are typically lime, iron oxides, manganese oxides, and basic oxides (e.g. MgO from nodular iron returns) in combination with silicon refractory (acid). If the amount of contamination is limited, this will reduce the amount of slag formed and will allow a longer lifetime of the furnace and ladle lining. For nodular iron production using a furnace with acid refractory, the adhering silica sand may have a beneficial effect, since it neutralises the MgO coming from foundry returns.

The presence of contaminants and oxides in the furnace load, will consume part of the melting energy. Furthermore, the removal of slags necessitates a higher bath temperature to keep the slags in a liquid state.

Internally recycled scrap consists of feeders systems and rejected casting. Feeder systems are knocked off after shake-out. In general they do not retain adhering sand, due to their geometry. Rejected castings are excluded upon quality control, which is carried out after the castings are cleaned using sand blasting or shot blasting to remove all adhering sand. The use of sand-free return material therefore, in general, necessitates no extra treatment.

Achieved environmental benefits
This technique reduces the amount of slags and dust that need disposal and limits VOC emissions. The energy consumption is reduced (by 10 % to 15 %) due to the reduced amount of slag. Additionally, the extracted airflow may be reduced.

Shot blasting of the scrap can be recommended for scrap where its contamination would lead to the production of excessive amounts of slag. The use of only shot-blasted scrap would actually require slag-forming additives to create the slag.

Environmental performance and operational data
An energy consumption to clean 30-40 kg of sand from 1 tonne of casting of 12-15 kWh has been reported for an operational foundry. The consumption level is dependent on the size and type of casting.

For a steel foundry using EAF melting, an increase in molten metal recovery (poured metal/charged metal) of 2 % to 3 % has been reported.

A typical metal charge for EAF is: 55 % foundry steel scrap; 40 % internal returns; 5 % metal correction additions.

Cross-media effects
If foundries only accept clean scrap, the overall recycling rate for dirty scrap will reduce. This will generate a need for additional cleaning operations and increase the disposal of scrap.

The use of cleaning techniques to remove sand from return material consumes energy. This is balanced however by the energy gained in the melting stage.

Technical considerations relevant to applicability
Generally applicable.

The removal of sand from internal scrap can be applied in all new and existing foundries. The use of clean scrap for melting can be applied in all foundry types, but the choice of the scrap grade should be related to the techniques installed for melting and gas cleaning. If the whole sector shifts to clean scrap, this will generate a problem for the recycling of dirty scrap.

The use of clean ferrous scrap (both steel and pig iron) will lead to increased purchase costs and will require investment in new cleaning equipment. There are no difficulties caused by scrap surface oxidation nor by using pig iron ingots during melting in cupola furnaces (reduction process). Electric furnaces will have difficulties only with contaminated scrap which does not comply with the parameters for steel scrap used in foundries.

Cupola furnaces can easily melt scrap which is not clean. There is little coke overconsumption and little environmental consequence, if the gases are correctly treated.

Limiting the slag is very important for good operation of the coreless induction furnace. The operation is more affected by the scrap cleanliness than the other furnace types.

The use of dirty scrap has no adverse effects on rotary furnace operation but is the main determining factor for dust emissions. There is little environmental consequence if the gases are correctly treated.

Economics
The price for clean scrap (i.e. class 1) is 20 % to 30 % higher than that for contaminated (i.e. class 2) scrap. Furthermore, disposal costs for slags and dust are reduced by applying this technique.

Driving force for implementation
- High disposal fees for residues and high prices for the refractory.
- Legal requirements.

Example plants
Widely used.

Reference literature
[36, Vereniging van Nederlandse Gemeenten 1998], [38, VITO 2001], [100, TWG 2002], [169, TWG 2021]

3.2.1.3.5 Improve casting yield and decrease scrap generation

More information on the technique
This technique provides environmental benefits both in terms of energy efficiency and material efficiency. It is fully described in Section 3.2.1.4.2.1.

3.2.1.3.6 Reduce energy losses/improve ladle preheating practises

Description
This includes all of the following elements:

- use of clean preheated ladles;
- keep the lid on ladles closed to preserve heat;
- use of energy-efficient techniques for ladle preheating (e.g. flameless microporous burners or oxy-fuel burners);
- use of large (as practically possible) ladles fitted with heat-retaining covers;
- minimise the molten metal transfer from one ladle to another;
- transfer the molten metal as quickly as possible.

Technical description
Energy is wasted if the molten metal transfer system allows an excessive loss of metal temperature between furnace tapping and mould pouring. Losses can be prevented by using good practice measures. These imply the following:

- the utilisation of clean ladles, preheated to bright red heat;
- using an energy-efficient method for ladle preheating (e.g. using porous burners or natural-gas/oxygen burners – see below);
- the utilisation of distribution and pouring ladles, which are as large as is practicable and are fitted with heat-retaining covers;
- keeping the covers on ladles which are standing empty or putting ladles upside down when not in use;
- minimising the need to transfer metal from one ladle to another;
- always conveying the metal as quickly as possible, while still complying with safety requirements.

Ladle preheating using porous burners
A modified gas-air burner technique is the so-called volume burner or gas porous burner. This process modification has been available for use in foundries since 2008.

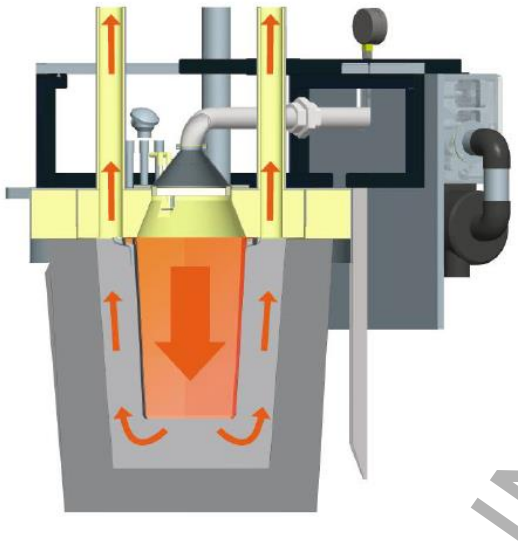
In a gas porous burner (volume burner), the combustion takes place in a porous high-temperature ceramic burner, the combustion reactor. The result is a flameless, volumetric combustion in the form of a glowing ceramic foam. This can be used as both a radiating surface and a homogeneous heat source. The combustion is limited to the numerous pores of the ceramic, which can be seen as small reactors. Porous burners can achieve power densities of more than 3 MW/m^2.

Serving as a combustion reactor, the ceramic foam body can be produced in almost any geometric shape. Adapted to the particular application, the round, square, or linear-shaped ceramic body provides the heat exactly where it is required in the process.

With a customised form and flameless combustion, more homogeneous heating can be achieved in particular for larger objects, such as transportation and casting ladles or crucibles of furnaces.

In principle, this technique could also be applied in other heating areas besides ladle preheating.

The following schematic and picture illustrate the ladle preheating process using porous burners.



Source: [133, DE UBA 2014]

Figure 3.5: Schematic of ladle preheating using porous burners

Source: [133, DE UBA 2014]

Figure 3.6: Ladle preheating using porous burners

<u>*Ladle preheating using natural gas and oxy-fuel diffusion burners*</u>

Oxy-fuel diffusion burners using natural gas as fuel can be used to warm up transport ladles for example. The warming of the transport ladle takes place with an open flame. The flame burner fires from the top into the ladles. In addition, these burners (Figure 3.7) are also used in foundries for special applications (Figure 3.8).

Source: [133, DE UBA 2014]

Figure 3.7: Control of the oxy-fuel diffusion burner

Source: [133, DE UBA 2014]

Figure 3.8: Oxy-fuel diffusion burner with cooling water, used here to heat the feeder during the casting of a ship propeller in a bronze alloy

Achieved environmental benefits

~~To reduce energy losses.~~

Reduction of energy losses and increase in energy efficiency.

Environmental performance and operational data

For ladle preheating using porous burners, the following environmental benefits were reported:

- Reduction in gas consumption of up to 60 %, In one example, gas consumption could be reduced by 60 000 m^3/y and related CO_2 emissions by 115 t. Excess heat could be used for heating of the production facilities.
- Increased energy efficiency.
- Substantial reduction in CO_2 and NO_X emissions.
- Reduction of noise emission by low-noise combustion.

For ladle preheating using natural-gas/oxygen diffusion burners, the following environmental benefits were reported:

- Using oxy-fuel diffusion burners, the gas to oxygen ratio is approximately 1:2. When using natural-gas-air diffusion burners, the gas to air ratio is approximately 1:10. Higher flow rates for the combustion result from the use of natural-gas-air diffusion burners compared to natural-gas/oxygen diffusion burners.
- The reduced nitrogen content from using oxy-fuel diffusion burners leads to a reduction in fuel consumption and reduction in the generation of NO_X emissions. Assuming that during the combustion of natural gas about 1.95 kg CO_2/m^3 is released, the total amounts of CO_2 emissions in the example described under Economics are:
  - 58.5 kg/h for one ladle, heating 3 ladles would equate to 175.5 kg/h;
  - 78.8 kg/h for one ladle, heating 3 ladles would equate to 263.3 kg/h.

Table 3.5: Operational data for ladle preheating using porous burners

Power density	Continuously adjustable from 150 kW/m^3 to 3 000 kW/m^3 with an adjustable burner size at a reactor depth of 15 mm .
Performance	From 2 kW to over 1 000 kW.
Flame free combustion	Heat source instead of open flame, i.e.: no contact of a product with the flame, no combustion interference by external convection, or outer atmosphere, no drafts or motion sensitivity. direct transfer of heat by hot gas and radiation heat.
Controllability	Control range up to 1:20 at lambda 1.3. Can quickly adapt to changing process conditions. Radiation and hot gas temperature controllable. Precise controllability of 900 °C to 1 400 °C to plus/minus 3 K in a few seconds.
Homogeneity	Targeted, flat heat input at any desired location. Gentle product treatment. Homogeneous temperature distribution.
Design/Form	Any shape as a line or surface burner.
Emissions	Minimal emissions of CO and NO_X in the entire power range.
Fuels	All gases according to EN 483. Oil vapour mixtures. Low calorific gase. Insensitive to varying gas pressure.
Source: [133, DE UBA 2014]	

Ladle preheating using natural gas-oxygen diffusion burners
Technically, the process of combustion of gaseous fuels with pure oxygen has the effect that, due to the reduced exhaust losses, the combustion temperature and gas radiation are increased.

With oxy-fuel diffusion burners, usually temperatures of 1 200-1 300 °C can be reached. By modifying a conventional oxy-fuel diffusion burner, for example with water cooling, temperatures around 1 500 °C can be reached. In addition to the heating of ladles, oxy-fuel diffusion burners are used for sintering and heating of:

- e-furnaces and for e-hearths;
- casting dies and converters;
- specific feeders; and
- slag emptying into the furnaces.

For ladle preheating using natural-gas/oxygen diffusion burners, the production and transport of oxygen is related to additional environmental burdens. Infrastructure for oxygen storage is required.

Cross-media effects
None.

Technical considerations relevant to applicability
Since ~~this~~ the general technique involves measures related to good practice, it is applicable to all new and existing foundries.

The 'ladle preheating using porous burners' technique is applicable in small and large foundries. The following factors may affect its applicability:

- When high temperatures are required, for example > 1 100 °C, the heating time can be longer than that of conventional burners. This is important to ensure the required power density of the burner (e.g. steel casting).

- If the burner can be moved manually and the geometry requires exact and careful handling, the burner can be damaged if handled carelessly.

Ladle preheating using natural-gas/oxygen diffusion burners is applicable to iron and steel foundries (mainly due to the achievable temperatures) but can also be used in non-ferrous metal foundries.

Economics
For the general technique, no economic data can be given.

For ladle preheating using porous burners, the following economic data were reported:

Cost savings of up to 60 % can be achieved by substituting conventional burners with porous burners due to the exact controllability and uniformity of the heat input. In conjunction with the high power modulation, the whole system improves in terms of efficiency and brings productivity gains of up to 50 %. In one example plant, ladle durability had been doubled.

The following investment costs, operating costs, maintenance costs and energy savings are based on information provided by an operator using porous burners:

- ladle size: 15 t.
- investment costs: EUR 70 000;
- operating costs: EUR 20 000/y in gas costs;
- maintenance costs: EUR 5 000/y;
- energy cost savings: EUR 8 000/y.

Information about the amortisation time is not available and depends on numerous individual factors. As an example, the following cost-benefit equation (reference values) has been made: 'With a saving of natural gas amounting to EUR 23 286 /y, a minimised ladle-lining abrasion of EUR 7 000 and an increase in productivity of approximately EUR 10 000, a static calculation states that a payback of capital results after 5.8 years'.

For ladle preheating using natural gas-oxygen diffusion burners, an exemplary case where three ladles of 8 tonnes per day are heated was reported. After about 1 hour, the ladle temperature reaches about 1 200 °C. The data are given below:

- natural gas demand is about 30 m^3/h per plant + oxygen demand 60 m^3/h per plant;
- cost of natural gas: EUR 0.35/m^3;
- cost of oxygen: EUR 0.20/m^3;
- total direct cost for natural gas: EUR 0.35/m^3 x 30 m^3 = EUR 10.50;
- total direct costs for oxygen: EUR 0.20/m^3 x 60 m^3 = EUR 12.00;
- total direct cost: EUR 22.50;
- total cost per day: EUR 22.50 x 3 ladles = EUR 67.50

To compare the economic differences between natural gas-air diffusion burners and gas-oxygen diffusion burners, an example is provided below:

Per day (single layer), the heating of three ladles with 8 tonnes takes place. Three natural gas-air burners are used, which also run constantly to keep the temperature. After about 1 hour, a ladle temperature of about 800 °C to 900 °C is reached. The data are given below:

- natural gas demand is about 45 m^3/h per plant + air requirements (fan) is about 450 m^3/h per plant;
- costs for heating of a ladle: natural gas demand is about 45 m^3/h x 1 h results in 45 m^3 + air consumption (fan) is approximately 450 m^3;
- costs for natural gas: EUR 0.35/m^3;

- costs for providing air: EUR 0.04/m^3;
- total direct costs for natural gas: EUR 0.35/m^3 x 45 m^3 = EUR 15.75;
- total direct costs for air (fan) EUR 0.04/m^3 x 450 m^3 = EUR 18;
- total cost: EUR 33.75;
- the cost of continuous operation to preheat the ladles must be added, exemplary set with EUR 80; after all, in many foundries the ladles are under continuous heating to keep them in case of need immediately ready for use;
- total cost per day: EUR 33.75 x 3 ladles/d = EUR 101.25/d + EUR 80/d = EUR 181.25/d.
- yearly cost: EUR 181.25/d x 22 d/month = EUR 3 987.5/month x 12 months = EUR 47 850/y.

Driving force for implementation
Energy savings and reduction in energy cost. ~~efficient foundry management.~~

In addition, ladle preheating using porous burners contributes to a longer life of the lining and therefore to reduction of refractory material consumption and reduction of waste refractory material generation.

Ladle preheating using natural-gas/oxygen burners increases the availability of melting units and transport ladles and improves product quality by reducing the temperature difference between the melt and the transport ladle.

Example plants
These general measures are used to a varying extent in European foundries.

Ladle preheating using porous burners was reported for the following plants:
- HegerFerrit GmbH, 67681 Sembach
- Stahlwerke Bochum GmbH, 44791 Bochum
- Edelstahlwerke Schmees GmbH, 40764 Langenfeld

Ladle preheating using natural gas-oxygen burners:
- Mecklenburger Metallguss GmbH – MMG, Waren/Müritz, Germany

Reference literature
[20, ETSU 1993], [133, DE UBA 2014]

3.2.1.3.7 Oxy-fuel combustion

Description
Combustion air is replaced fully or partially with pure oxygen. Oxy-fuel combustion can be used in combination with flameless combustion.

Technical description
Flame temperatures are increased by the application of pure oxygen instead of air in the burners used for melting or preheating the pouring ladles. This enables a more efficient heat transfer to the melt and reduces the energy use.

If the air supply is blocked by a tight closure of the recipient, no NO_X can be formed through the oxidation of atmospheric nitrogen. Additionally, the total flow of flue-gases from ~~an oxyburner~~ oxy-fuel combustion is smaller due to the absence of nitrogen ballast. This allows the application of a smaller dedusting installation.

Achieved environmental benefits
The techniques reduce energy consumption and lower the emissions of NO_X and CO_2 through higher combustion temperatures.

Environmental performance and operational data
The following table gives, for ~~the "oxygas"~~ melting of cast iron and various furnace capacities using oxy-fuel combustion, the theoretical consumption of several fuels and of oxygen per tonne melted:

Table 3.6: Table of energy consumptions (minimum melt)

Energy source	Units	Furnace capacity (tonnes)				
		3	5	8	12	20
Light fuel oil	kg/tonne	33 – 38	33 – 38	33 – 38	32 – 37	32 – 37
Natural gas	Nm^3/tonne	38 – 43	38 – 43	38 – 43	38 – 42	38 – 42
Propane	Nm^3/tonne	15 – 17	15 – 17	15 – 17	14 – 16	14 – 16
Oxygen	Nm^3/tonne	130 – 150	130 – 150	130 – 150	130 – 145	130 – 145
Source: [52, Eurofine 2002]						

Oxygen enrichment used in conjunction with a recuperator generally achieves a 30 % energy saving. Additionally, the higher combustion temperature assists in reducing the overall emissions. The exhaust gas volume is also reduced. Full oxy-fuel combustion ~~firing~~ may offer energy savings of up to 50 %, and can reduce the exhaust gas volume by up to 72 %.

A German installation's change from oil-air firing to gas-oxygen firing caused a reduction in noise emissions of 15-18 dB(A) in the immediate vicinity of the furnace, dependent on the point of analysis. At the installation border, a value of 48 dB(A) was measured. With the application of energy recuperation for charge preheating, a total energy saving of 53 % was reported.

The use of oxy-fuel combustion has been reported in a cupola furnace in Germany. In total, six oxy-fuel combustion burners were installed at the foundry Fritz Winter Eissen Giesserei GmBH producing mainly grey iron using a hot blast cupola furnace (capacity 24 t/h). The use of oxy-fuel combustion resulted in an increase of 20 % of the melt rate together with a reduction of 6 % in coke consumption, based on long-term results. [188, Niehoff, T. et al. 2004]

Oxy-fuel combustion, sometimes in combination with flameless combustion, is often used in ladle preheating. In this case, the replacement of conventional burners with oxy-fuel burners can lead to a decrease in operational costs by about 50 % due to quicker heating (1 hour instead of 2.5 hours) and lower natural gas consumption. Because ladle preheating takes a long time, ladles are frequently kept running continuously to ensure operational readiness. Oxy-fuel burners enable a quicker heating process, meaning that continuous operation might not be always required. [145, US EPA 2016]

Cross-media effects
The production, storage and use of oxygen increases the safety risks. Oxygen production is done through cryogenic distillation or Vacuum (Pressure) Swing Adsorption, which both involve electricity consumption. The consumption of the latter technique is 0.35-0.38 kWh/Nm^3 O_2. Oxygen production is often done by an external supplier, who deliver the oxygen to a storage tank or directly through a pipeline.

Fuel or heavy oil gives rise to SO_2 or NO_X emissions, depending on their S or N content. The use of cleaner carburants such as natural gas and propane will not cause any additional pollution, except for CO_2, as is the case for all combustion processes.

Technical considerations relevant to applicability
Applicability to existing plants may be restricted by furnace design and the need for a minimum waste gas flow.

Economics
No information provided.

Driving force for implementation

- Optimisation of furnace operation and ~~to~~ increased melting efficiency.
- Legal requirements.

Example plants

This technique finds wide application in ferrous foundries using rotary furnaces and for ladle preheating.

Reference literature

[11, Brettschneider et al. 1992], [14, CAEF 1997], [38, VITO 2001], [36, Vereniging van Nederlandse Gemeenten 1998], [52, Eurofine 2002], [64, UK Environment Agency 2002], [127, Novem 2000], [145, US EPA 2016], [188, Niehoff, T. et al. 2004]

3.2.1.3.8 Use of medium-frequency power in induction furnaces

Description

Use of medium-frequency (250 Hz) induction furnaces instead of mains-frequency (50 Hz) furnaces.

Technical description

Medium-frequency (250 Hz) furnaces have a higher power density (up to 1 000 kW/tonne) than mains-frequency (50 Hz) furnaces (300 kW/tonne). This allows the use of a smaller crucible (up to a factor of three smaller) which results in a smaller total heat loss. The thermal efficiency of medium-frequency furnaces is 10 % higher than for the mains-frequency types. Additionally, mains-frequency units need to be operated with a molten heel of up to two thirds of the crucible capacity to optimise specific energy consumption and also require specific starter-blocks for cold start-up. Medium-frequency furnaces can readily be started with a cold charge and can be emptied at the end of each working shift or melting batch. Medium-frequency furnaces are typical in foundries if there are little changes of casting materials or in holding processes.

When a foundry converts from mains-frequency melting to operating a medium-frequency installation, it is important that the furnace personnel undertake some retraining. Operating techniques formally used to date will have to be abandoned, and new specific procedures designed to give good specific energy consumption will have to be adapted. If retraining is overlooked, the available improvements in energy usage may not be fully realised.

Economics

A change of furnace type constitutes a considerable investment.

Achieved environmental benefits

Increased energy efficiency of the melting operation.

Environmental performance and operational data

~~Operational data are given in Section~~

Upgrading a mains-frequency furnace to medium-frequency leads to energy savings of 12-15 % in batch mode. Furthermore, medium-frequency furnaces present the advantage of improved electric coupling which enables a cold start. Medium-frequency furnaces provide a much higher power input density (three times higher compared to a mains-frequency furnace), which increases productivity and efficiency.

Cross-media effects

None. ~~No cross-media effects apply.~~

Technical considerations relevant to applicability

This technique applies to new installations and for major refurbishments of existing installations

Driving force for implementation
To increase the efficiency of the foundry operation.

Example plants
The technique is commonly applied in foundries installing a new furnace.

Reference literature
[23, ETSU 1992] [145, US EPA 2016]

3.2.1.3.9 Compressed air system optimisation

Description
This includes all of the following measures:

- applying an appropriate maintenance system to reduce leaks;
- efficient monitoring of operating parameters such as flow, temperature, and pressure;
- minimising the pressure drops;
- applying efficient load management;
- reducing inlet air temperature;
- using efficient compressor control systems.

Technical description
Foundries use compressed air in numerous applications including powering tools, filling core boxes, transporting sand, blowing of moulds and core boxes and others. Best practices for energy-efficient compressed air systems include all the following measures:

- *Applying an appropriate maintenance system to reduce leaks*: A plant which is not well maintained can have a leak rate ranging from 20 % to 50 % of the total compressed air capacity. The areas where leaks may occur include couplings, hoses, tubes, fittings, pressure regulators, open condensate traps and shut-off valves, pipe joints, disconnects and thread sealants. Effective monitoring of these areas as part of a leak detection and correction program is key to reduce to a minimum the number and severity of leaks.
- *Efficient monitoring of operating parameters such as flow, temperature, and pressure*: Monitoring systems are in place across the site including pressure gauges on each receiver and differential gauges for dryers and filters, temperature gauges to detect fouling or blockages in compressors, flow meters to control the quantity of air used, and dew point temperature gauges to monitor the efficiency of air dryers.
- *Minimising the pressure drops*: Excessive pressure drops result in an increase in energy consumption. Flow restrictions (e.g. obstructions) can result in higher operating pressures. Such pressure drops are often observed at the points of use, e.g. leaking hoses, tubes, disconnects, dryers, filters, regulators, valves, nozzles or moisture separators. Pressure drops can be minimised or prevented by good design of the system and good maintenance of the equipment.
- *Applying efficient load management*: Improving the load management can be achieved by avoiding partial load operation. The use of multi-stage compressors which operate more efficiently than single-stage compressors can save energy.
- *Reducing inlet air temperature*: When the inlet air temperature is reduced, the energy used by the compressor is also reduced. It is often possible to draw cold air from outside the buiding to reduce the inlet air temperature of compressors.
- *Using efficient compressor control systems*: Control systems are in place to ensure that unneeded compressors are shut off and to delay the start of additional compressors until needed. This is achieved using the following control systems:
    - start/stop (on/off): the compressor is turned on or off depending on the discharge pressure of the machine;
    - load/unload: use of constant speed controls allowing the motor to run continuously but to unload when the discharge pressure is adequate;

- modulating or throttling controls: the output of the compressor is modulated to meet the flow requirements;
- single master sequencing control: individual compressors are taken on-line or off-line in response to the measured system pressure demand;
- multi-master controls: four or more compressors are handled at the same time using an advanced compressor control system, each compressor is working at a level that produces the most efficient operation.

Achieved environmental benefits
Increased energy efficiency.

Environmental performance and operational data
The implementation of a leak maintenance programme can reduce leak rates down to less than 10 %.

The use of compressor control systems which shut off unneeded compressors can save up to 12 % in energy costs per year.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
Energy savings.

Example plants
Widely used.

Reference literature
[145, US EPA 2016]

3.2.1.3.10 Microwave drying of cores for water-based coatings

Description
Use of microwave drying ovens (e.g. with a frequency of 2 450 Hz) for drying cores coated with water-based coatings, resulting in rapid and homogeneous drying of the entire core surface.

Technical description
Water-based coatings require a drying treatment. The application of microwave furnaces for this purpose gives operational advantages over the use of ambient or heated air drying. Microwaves of 2 450 MHz frequency are used, and have the following properties:

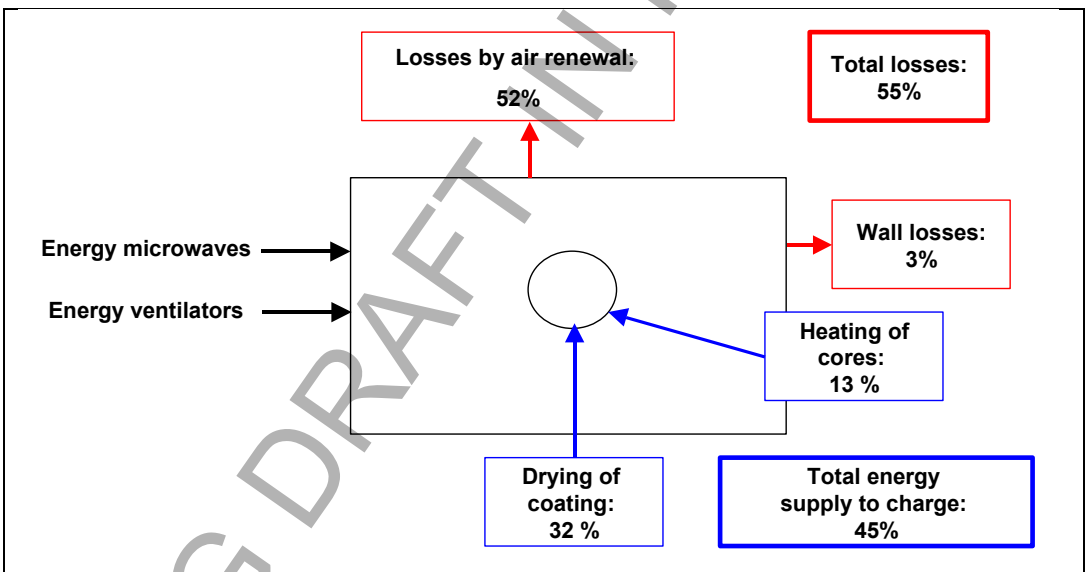
- Good selectivity of energy transfer: The microwave energy is transferred preferentially to the water molecules, rather than the sand material. This implies a preferential and homogeneous drying of the surface, even for complex cores.
- Self-adaptive coupling: The drying mechanism provides a self-controlling homogenisation of the humidity of the material.
- Quick drying: The speed of drying depends on the applied power. The high drying velocity results in a limitation of the water-core contact time. This results in a good mechanical stability of the cores.

The application of microwave drying presents difficulties in the following cases:

- heterogeneous loading of the furnace (with a range of core masses and volumes);
- use of cores or inserts with iron;
- inhomogeneous drying of thicker parts of the coating;
- risk of deformation of complex cores.

Achieved environmental benefits
Increased energy efficiency of the drying process.

Environmental performance and operational data
The use of microwave drying has not been implemented on an industrial scale, although large-scale industrial tests have been performed. The results of these tests are given below. One test campaign has been run using a 50 kW microwave furnace. The stove was loaded to 50 % of its capacity with a charge of 800 kg of cores. Cores are placed on plastic trays, which are not heated by the microwaves. The thermal balance is given in the following figure. It shows that more than 30 % of the energy input is used for drying. Additionally, the cores are only slightly heated up (temperature at exit = 40 ºC), which allows immediate handling. The data from two measurement campaigns are given in Table 3.7, and compared to analogous campaigns on hot air furnaces (as discussed in Section 3.2.1.9.12).



Source: [49, Inasmet and CTIF 2002]

Figure 3.9: Thermal balance for the microwave drying of cores for a 50 kW furnace working at 50 % capacity

Table 3.7: Results of test campaigns on core drying, using hot air and microwave furnaces

	Foundry A	Foundry B	Foundry B	Foundry C
Furnace type	**Hot air**	**Hot air**	**Microwave**	**Microwave**
Core load	156 kg/h	270 kg/h	800 kg/h	500 – 900 kg/h
Humidity	5.5 %	2.7 %	2.7 %	2 – 3.2 %
Thermal energy supply	73 kW	70 kW	50 kW	40 kW
Duration	48 min	113 min	8 min	8 min
Specific consumption per kg evaporated water	8.5 kWh	9.3 kWh	2.3 kWh	2 kWh
Specific consumption per tonne wet cores	465 kWh	280 kWh	63 kWh	-
Source: [49, Inasmet and CTIF 2002]				

The data show that the drying time is considerably reduced from 1-2 h to less than 10 minutes. Additionally, the energy consumption is reduced by a factor of 4-5, and the throughput is increased.

Cross-media effects
Microwave drying also brings polymerisation reactions to a further completion. This reduces the gaseous emissions in the proceeding stages of the foundry process (i.e. pouring, cooling, shake-out).

Technical considerations relevant to applicability
This technique is applicable for the drying of all water-based coatings. Furthermore, it allows the greater applicability of water-based coatings to more complex core shapes and smaller series.

Economics
Microwave drying represents high investment costs. The actual investment is proportional to the power requirement, which corresponds to the amount of water to be evaporated. The high investment is partially counterbalanced by:

- higher energy efficiency, though the technique uses electricity rather than gas in the hot air furnace;
- reduced solvent cost for water-based vs. solvent-based;
- reduced maintenance costs due to a more compact installation compared to the use of (hot) air drying or a cooling line.

Driving force for implementation
- Pressure from authorities, with increasing attention being paid to the emissions of organics, combined with the need for higher energy efficiency.
- Legal requirements.

Example plants
The technique is reported to be applied in foundries in France and Spain.

Reference literature
[49, Inasmet and CTIF 2002], [120, TWG 2003]

3.2.1.3.11 Scrap preheating

Description
Scrap is preheated by blowing hot flue-gases directly onto it.

Technical description
The high temperature from hot flue-gases can be used to preheat scrap. For example, in steel foundries, the hot flue-gases from melting in the EAF, typically from the fourth hole, can be used to preheat the scrap to temperatures ranging from 450 °C to 600 °C. An additional benefit of this technique is the complete removal of moisture from the scrap.

In non-ferrous metal foundries, shaft furnaces are a typical example of scrap preheating. In a shaft furnace used for example in an aluminium foundry, cold aluminium scrap and ingots are charged at the top of the furnace through a charging door. The hot gases from the melting burners make their way up to the stack and enters into contact with the charge, resulting in both complete drying and preheating of the charge. In this respect, shaft furnaces have significantly higher energy efficiency than reverberatory furnaces, in particular.

Achieved environmental benefits
Increased energy efficiency.

Environmental performance and operational data
Energy use can decrease by up to 50-75 kWh/tonnes when scrap is preheated.

In non-ferrous metal foundries, the energy efficiency of shaft furnaces ranges from 40 % to 50 %, compared to only 15 % to 40 % for reverberatory furnaces, as a result of scrap preheating. It is reported that energy consumption can be reduced by 135 kWh/tonnes in the case of a single shaft furnace.

Cross-media effects
In some cases, the delays caused by scrap preheating may reduce the productivity.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
Reduced energy consumption – energy savings..

Example plants
No information provided.

Reference literature
[145, US EPA 2016], [189, BCS Incorporated 2005]

3.2.1.3.12 Heat recovery from off-gases generated in furnaces ~~Excess heat utilisation~~

Description
Waste heat from hot off-gases is recovered (e.g. through heat exchangers) and reused on site or off site (e.g. in thermal oil / hot water / heating circuits, for steam generation or for preheating of combustion air (see technique (n)). This may include:

- excess heat from cupola hot off-gases is used for example for steam production, thermal oil heating, water heating;
- excess heat from the furnace cooling system is used for example for drying of raw material, space heating, water heating;
- in fuel-fired furnaces in aluminium foundries, excess heat is used for example for heating the premises and/or the water for the casting cleaning facility;
- low-grade heat is converted into electricity using high-molecular-weight fluids by using the Organic Rankine Cycle (ORC).

Technical description
The need to cool ~~cupola~~ off-gases before they enter the air emissions abatement system (e.g. bag filter) leads to the possibility of attaching to a secondary user and applying waste heat utilisation. The secondary user may be for example:

- a steam boiler;
- a thermal oil circuit;
- a heating circuit;
- a hot water circuit.

In the case of low-grade heat, an additional option is electricity generation using high-molecular-weight fluids through the Organic Rankine Cycle system.

Examples of in-situ waste heat utilisation are:

- power generation using steam turbines (reported by Plants AT016, CZ024, DE049 and DE050) [169, TWG 2021];
- power generation using the Organic Rankine Cycle (ORC) process;
- space heating and/or heating the water for the casting cleaning facility (see example plant below);
- heating circuit, e.g. in the case of elevated energy consumption for drying, when water-based coatings are used instead of solvent-based ones.

An option for off-site waste heat utilisation is when this can be used for steam generation in a nearby installation using a thermal oil circuit for heat transfer.

Organic Rankine Cycle
In an Organic Rankine Cycle (ORC), high-molecular-mass organic fluids are used instead of water as the working fluid. In general, the types of working fluids used are siloxanes or hydrocarbons. These fluids exhibit much lower boiling points than water. The working fluid is vaporised in a heat exchanger using the heat from waste flue-gases. The working fluid changes into a gaseous state and expands in a turbine directly connected to a generator to produce electricity. The working fluid is condensed in a water-cooled condenser and pumped back to the heat exchanger. The ORC is used to generate electrical power using low- to medium-temperature heat sources (e.g. low-grade heat), typically in the range of 80 ºC to 350 ºC.

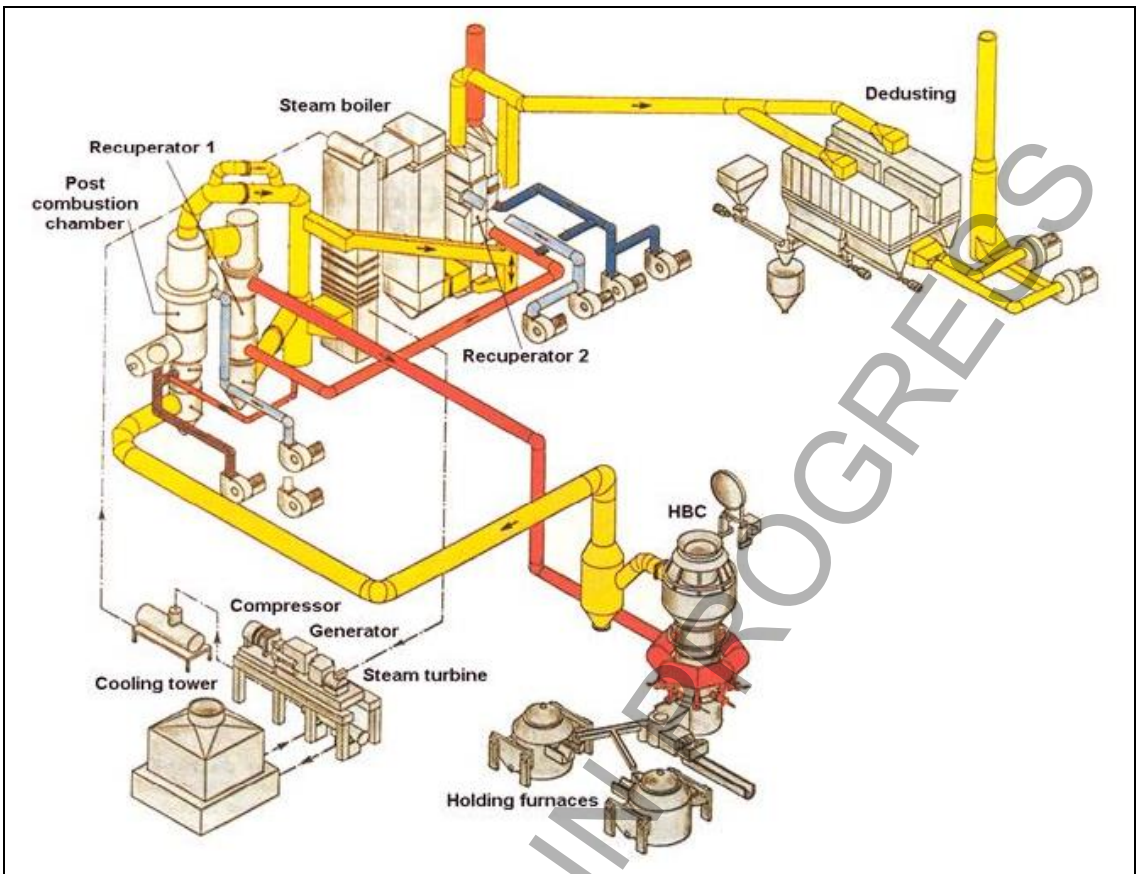
Achieved environmental benefits
Recovery of waste heat, which otherwise would be lost to the outside, allowing a reduction in fuel (or other sources of energy) consumption.

In the case of the Georg Fischer Automotive AG plant (off-site waste heat utilisation – see example plants below), the calculated reduction in primary energy consumption of the end user of the waste heat is around 50 000 MWh/yr which corresponds to a reduction of CO_2 emissions of around 11 000 tonnes.

Environmental performance and operational data

Steam boiler for electricity production
For the two example plants described in Section 3.2.2.1.9, which are equipped with a waste heat utilisation system, a short description and basic elements are presented in the following paragraphs. Plant data have been given in Table 3.53.

Plant G (example plant described in Section 3.2.2.1.9, plant data have been given in Table 3.53) uses cupola waste heat for electricity production. Part of the off-gas flow is fed to a steam boiler, which drives a turbine, coupled to a generator or compressor. A schematic representation of the installation is given in Figure 3.10. In total 29 % of the introduced cokes heat is converted into additional utilisation. Around 2.9 MW of electrical energy are generated. This means that the plant generates an electrical power of 75 kWh/tonne liquid iron.

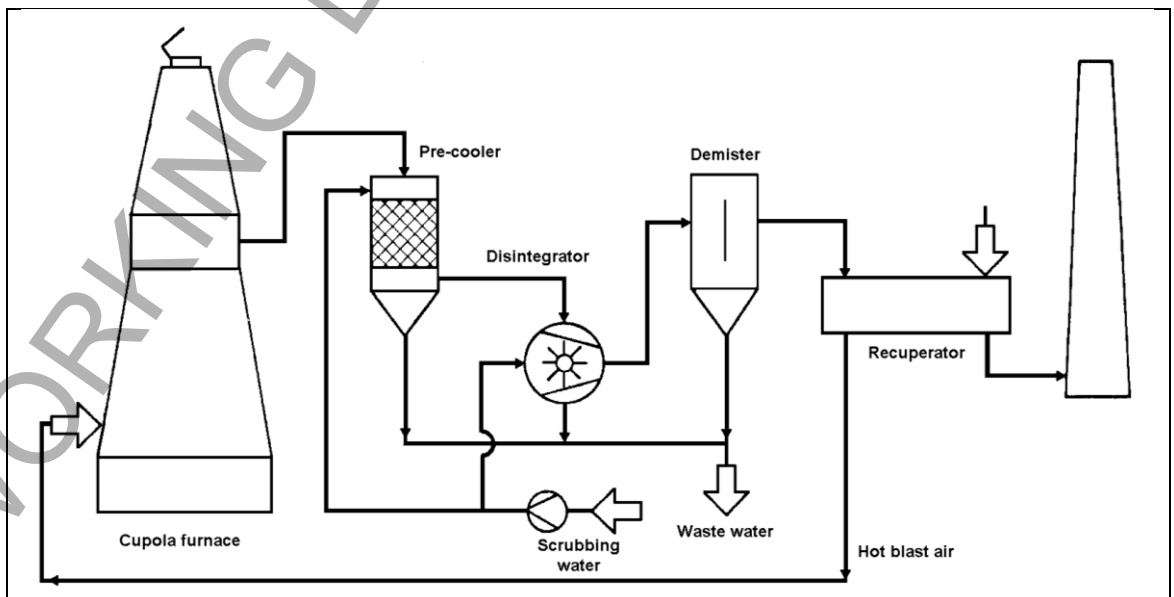


Source: [12, Kran, H.-P. et al. 1995]

Figure 3.10: Schematic representation of a hot blast cupola with a steam boiler, turbine and generator

Thermal oil circuit

Plant H (example plant described in Section 3.2.2.1.9, plant data have been given in Table 3.53) uses cupola waste heat in a thermal oil circuit. After heat exchange for blast preheating, the off-gas passes a gasoil heat exchanger. The heated oil is used for core drying. A maximum heat recovery of 21 MW can be attained. A process flow diagram is given in Figure 3.11.



Source: [7, Strauß 1983]

Figure 3.11: Process flow diagram of a hot blast cupola with heat recovery

In another example plant (Gießerei Heunisch GmbH, DE), substitution of solvent-based coatings with water-based ones made the recovery and utilisation of excess waste heat economically advantageous. In 2009, a thermal oil heat system to recover excessive heat from the stack gas was installed at the cupola furnace. To use the waste heat, a secondary circuit (recovery circuit) was constructed between the upper end of the zero-pressure collector of the primary circuit (cooling circuit at the cupola furnace) and by a cycle line (DN-125 mm) and - via the roof – to the drying area of plant. In the event that there might be additional consumption points for the waste heat, additional sockets could be integrated in the circuit. The hot oil in the secondary circuit reaches a temperature of about 210 °C. To use some of this waste heat for a paint shop, five thermal oil heat exchangers were installed in the drying tunnel. The basic characteristics of the new system are presented in the table below.

Table 3.8: Basic characteristics of the new waste heat recovery system

Start date of operation	4th Quarter of 2009 (actual system) 2nd Quarter of 2010 (extension waste heat utilization)
Operation time	Monday to Friday in a three-shift operation
Area requirements	1 700 m^3
Performance - flow rate castings	6 500 kg/h
Installed electric power	335 kW
Installed capacity of natural gas burner	2 250 kW
Power consumption	1 728 028 kWh in 2010
Gas consumption	118 078 m^3/y compared to 1 315 400 kWh in 2010
Source: [133, DE UBA 2014]	

Gas consumption for drying is reduced by around 30 % from about 25.5 m^3/h to 18.2 m^3/h. It is noted that the cupola operated in two shifts while the paint shop in three shifts. In the case of operating the cupola in three shifts, the period of waste heat recovery is longer and the heat recovery potential rises.

Space heating and/or heating the water for the casting cleaning facility

In an aluminium foundry, the fuel-fired furnaces are connected to a heat exchanger system, which heats the premises and the water for the casting cleaning facility. When closing the direct line to the chimney, the exhaust gases flow through a bypass to the heat exchanger, which transfers the process heat to the water circuit.

In this furnace, high resource efficiency and good insulation were realised to be able to make use of as much melt heat as possible. At the same time, low amounts of exhaust gas are generated due to the special design of the combustion chamber. The principle of reverse airflow is used, hence gases formed during the melting process are not directly discharged through the chimney, but remain longer in the oven (Figure 3.12).

At the example plant JURA CAST GmbH (see example plants below), the annual production capacity of the aluminium foundry is about 300 000 castings parts mainly for automobile and truck manufacturers, international engineering as well as for medical technology. This medium-sized company currently employs around 200 staff.

Source: [133, DE UBA 2014]

Figure 3.12: Exhaust systems of four furnaces connected with heat exchangers to transmit the heat of the hot gases from the melting process to the heating circuit

With two heat exchangers, one for the large melting furnace and one for the three small systems, a 30 000-litre storage reservoir is heated, which supplies 80 % of the company building area with heat. In addition, the washhouse system for finished castings is heated from this reservoir. The large melting furnace has two burners, each with 1 000 kW power, the flow of heat energy after the melting process is about 35 % to 40 % to the heat exchanger. The heat exchanger is able to transfer about 75 % of the incoming heat into the reservoir.

Source: [133, DE UBA 2014]

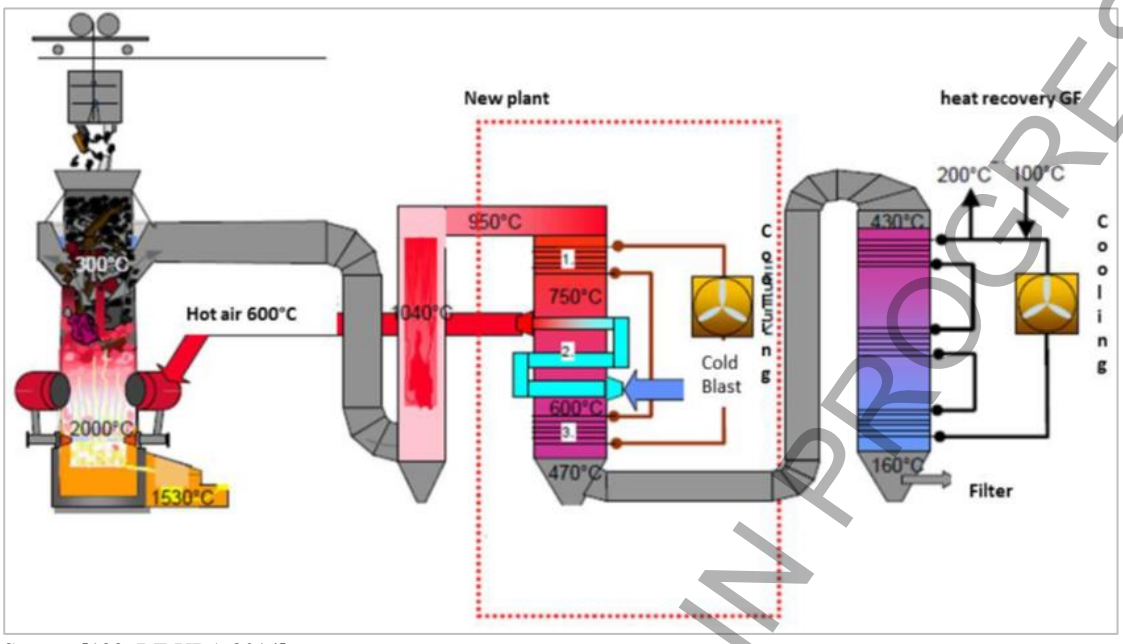
Figure 3.13: Largest furnace lowered into the ground

In addition, in the concrete case of the example plant the cleaning system was simplified. Since the furnace is embedded about 70 cm deep in the ground, it is easy to clean without pedestals, and other resources from both sides (see Figure 3.13). All areas are reachable over the large holes while cleaning. To empty all the melt, the furnace tilts into a recess in the floor, in which there is a transport ladle. This is moved subsequently hydraulically upwards.

Off-site waste heat utilisation

The Georg Fischer Automotive AG in Singen produces ductile iron castings for cars and trucks. A total of 200 000 tonnes of metals are cast per year from a hot blast cupola furnace. The CO-rich off-gas is post-combusted and temperatures up to 900 °C are achieved. The off-gas must be cooled before entering the cleaning system.

Waste heat is discharged to a nearby food processing plant using a thermal oil circuit. The thermal oil is pumped through a 400-metre-long pipeline system in the boiler house of the food processing plant. The 280 °C hot thermal oil is used there in a heat exchanger to produce a food-grade steam. The food processing plant expects to have about 67 % savings in natural gas consumption previously used to produce food-grade steam.



Source: [133, DE UBA 2014]

Figure 3.14: Heat exchanger

Table 3.9: Comparison of potentially usable energy with actually used energy

	Situation before reconstruction	Situation after reconstruction
Maximum energy for recovery	25 MW	30 MW
Used energy		
Hot blast	7 MW	7 MW
Hot water	6 MW	6 MW
External use	0 MW	10-14 MW
Total	13 MW	23-27MW
Source: [133, DE UBA 2014]		

ORC applications

Several applications of ORC in foundries have been reported (see the Example plants section below).

Cross-media effects

None. ~~No cross-media effects apply.~~

Technical considerations relevant to applicability

This technique applies to new installations and should be taken into account when designing the process. For existing plants, the technique canh be applied during major refurbishment of the plant, however, small add-on units can generally be accomodated in existing plants.

It is necessary for the excess energy of the foundry furnace to meet the needs of the end user. A short distance between production and use of heat is crucial. The maximum distance must be determined case by case.

Economics
The first two stated examples (for Plants G and H) were installed as part of a major rebuilding of the ~~considered~~ installation. It is therefore not possible to extract specific cost data.

For the third example (Gießerei Heunisch GmbH, DE, on-site waste heat utilisation), the following figures were reported:

- The additional investment costs for the integration of waste heat to the drying area were approximately EUR 1.4 million (2013 data). These costs have been considered only on a pro rata basis.
- By using waste heat for the paint drying process, the production costs can be reduced compared to the paint drying process using exclusively natural gas burners by approximately 20-25 %.
- Maintenance and repair costs are in the order of EUR 20 000/y (2013 data).

For the example of off-site waste heat utilisation (Georg Fischer Automotive AG):

- capital expenditures for the foundry plant were about EUR 3.5 million (2013 data);
- the food processing plant investment was around EUR 1.5 million.

In the theoretical case of costs for primary energy of 5 cents/kWh, the amortisation time of the overall investments will be less than 3 years.

For the example plant JURA CAST GmbH (space heating and/or heating the water for the casting cleaning facility), the investment costs for heat exchangers, piping, structural interventions, connection to the central heating system were about EUR 100 000.

Driving force for implementation
- Increasing energy efficiency of industrial processes.
- Economic and environmental benefits.

Example plants
- Widely used. In the SF data collection, 20 plants reported heat recovery from induction furnaces and 11 plants reported heat recovery from cupola furnaces.
- The first two example plants mentioned (Plants G and H) are located in Germany.
- Thermal oil circuit: Gießerei Heunisch GmbH, http://www.heunisch-guss.com, Germany.
- Off-site waste heat utilisation: Georg Fischer Automotive AG, Germany.
- Space heating and/or heating the water for the casting cleaning facility: JURA CAST GmbH, Germany
- ORC applications:
  - Schulte and Schmidt, Brasov, Romania [192, Pocola et al. 2017]
  - FMGC foundry, France [187, Baret 2014]
  - German foundry: [207, J. Lechner 2016]
  - DE049

Reference literature
[7, Strauß 1983], [12, Kran, H.-P. et al. 1995], [100, TWG 2002], [133, DE UBA 2014], [169, TWG 2021], [187, Baret 2014], [192, Pocola et al. 2017], [207, J. Lechner 2016]

3.2.1.3.13 Preheating of combustion air

Description
Reuse of part of the heat recovered from the combustion flue-gas to preheat the air used in combustion. This may be achieved for example by using regenerative or recuperative burners

(see below). A balance has to be achieved between maximising heat recovery from the flue-gas and minimising NO_X emissions.

Technical description
To improve the thermal efficiency of furnaces, the exhaust gases from the furnace may be used to preheat the combustion air. Thermal efficiency increases with increasing preheated air temperature and decreasing waste gas temperature. Potential fuel savings achieved by combustion air preheating may be case-specific.

In general, two systems exist: the regenerative and the recuperative burner.

Regenerative burners
Regenerative systems use two sets of heat exchangers, containing for example brick chequer material or ceramic balls. When one burner is fired, the furnace gases are channelled via the other burner. The exhaust gases pass through a regenerator which contains a bed of refractory or ceramic materials. The refractory materials are heated by the exhaust gases and store the energy, which is then used to preheat the combustion air. When the refractory materials are fully heated, the firing burner is turned off and the regenerated burner is put into operation. Typical reversal times are in the range of 20 s to 100 s.

New regenerative low-NO_X burners have been developed, combining the regeneration with coupled gas and air staging, internal POC (products of combustion) recirculation and flameless technologies.

A special type of regenerative burner is the integral bed burner which has a more compact design as the regenerative bed is incorporated in the body of the burner. These types of burners are especially suitable for retrofitting furnaces where space constraints may be a problem and for small furnaces.

Recuperative burners
A recuperator is a heat exchanger fitted in the exhaust gas outlet, which allows heat to be transferred continuously through the heating surfaces to the incoming combustion air. Various equipment designs are available. Self-recuperative burners have integral heat exchangers for preheating combustion air.

More information on regenerative and recuperative burners can be found in the BREF for the Ferrous Metal Processing Industry [168, COM 2021]

Achieved environmental benefits
Reduction of energy consumption.

Environmental performance and operational data
See [168, COM 2021].

Cross-media effects
[168, COM 2021].

Technical considerations relevant to applicability
Generally applicable.

Economics
[168, COM 2021].

Driving force for implementation
Reduction of energy consumption.

Example plants
TWG, please provide information on plants using this technique

Reference literature
[168, COM 2021], [169, TWG 2021], [177, COM 2009]

3.2.1.4 Material efficiency

3.2.1.4.1 Storage and handling of residues, packaging and unused process chemicals

3.2.1.4.1.1 Appropriate storage of various residue types

Description
Fabric filter dust is stored on impermeable surfaces, in enclosed areas and in closed containers/bags.

Other residue types (e.g. slag, dross, spent furnace refractory linings) are stored separately from each other on impermeable surfaces in covered areas protected from surface run-off water.

Technical description
The storage area for the various residue types is structured and managed according to the residue/waste type in order to avoid their potential mixing and to facilitate the subsequent management processes, e.g. recovery, reuse, recycling, disposal.

Achieved environmental benefits
- facilitation of subsequent residues management,
- reduction of groundwater and soil contamination.
- in addition, reduction of diffuse emissions to air (see Section 3.2.1.5).

Environmental performance and operational data
No information provided

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[169, TWG 2021]

3.2.1.4.1.2 Reuse of internal scrap

Description
Reuse of internal scrap directly or after treatment. The degree of reuse of internal scrap depends on its content of impurities.

Technical description

Ferrous metal foundries
Internal scrap is produced from the knock-off of feeders and runners, in quality control and in finishing operations. The relative amount of internal scrap produced can be calculated from the metal yield as defined and described in Section 3.2.1.4.2. In order to minimise residue production, internal scrap is returned to the scrap metal feed of the furnace.

For steel foundries, 100 % use of return metal is uncommon, due to the amount of dissolved gas. Operators consider 60 % to be the maximum amount of return metal (feeders, scrap castings, etc.) in the charge metal. Swarf and turnings may cause excessive molten metal oxidation.

Internal scrap recycling/reuse may also be limited in the case of nodular base iron melting, as a high amount of silicon (about 1 % in most cases) is added in the liquid iron during the metal treatment. In some cases remelting the whole internal scrap is not possible because the final silicon would be too high (typically 2.5-3 % in the castings).

In the case of grey or nodular iron, lead or bismuth are very noxious for the properties of the metal after solidification. If there has been a pollution incident the returns (internal scrap) must not be recycled.

Magnesium foundries
The two main techniques for internal recycling of metal in magnesium casting foundries are as follows:

'In cell' recycling
Clean feeders can be directly melted in the melting furnaces. Because of oxides and other inclusions, the possible amount of recycling is limited. Specialised equipment for exact analytical and metallographical control is necessary.

'In house recycling'
Here the scrap is treated and recycled at a separate recycling-plant on-site at the foundry. Two techniques may be applied:

- *Fluxless remelting:* Remelting of Mg scrap under a covering gas in a hearth type furnace; applicable only to class 1 scrap. Advantages are the low additional investment and low energy consumption.
- *Salt remelting:* Remelting of Mg scrap under a salt cover. Is applicable to the processing of all scrap classes except used fluxes and sludge (not treated). If only class 1-2 scrap is used, HP (high purity) magnesium alloys may be produced.

Both techniques can be used to produce Mg ingots or molten metal for liquid charging.

Both in fluxless and salt-covered remelting, dross (the floatings on the melt) and sludge (the sinkings in the melt) are generated, as well as residues retaining a residual metal content (70-80 % Mg for sludge, 60-90 % Mg for dross). For recovery of the metal content, three options exist:

- salt remelting (in the same or a separate furnace);
- remelting in the aluminium industry;
- utilisation in the desulphurisation of iron or steel.

If the scrap is re-melted in a fluxless melting furnace, the salt remelting of dross and sludge involves the operation of a separate furnace.

The remelting of mixed class scraps is performed using salt remelting. The mixed scrap needs pretreatment. Table 3.10 gives a survey of the input-outputs of a pretreatment installation.

Table 3.10: Inputs and outputs for a magnesium scrap treatment plant

Inputs	Equipment	Outputs	End-of-pipe technology
- Oily or wet Mg-turnings (> 2 % oil/water) - Electricity	**Centrifuge**	- Mg-turnings (< 2 % oil/water) - Oil/water-emulsion	
- Centrifuged and all other turnings - Electricity	**Turning–press (T = 400 °C)**	- Pressed turning - Exhaust air	Particle separator for the vaporised oil
- Feeders, bad castings - Dross (without salt, from the foundry process) - Electricity	**Shredder (if necessary)**	- Shredded material - Dust	
Source: [100, TWG 2002]			

The recovery of metal from the remelting salt residue is done using dry crushing and screening with magnetic separation or by using a wet washing system. The wet system produces a magnesium fraction and a sludge, which, after dewatering, may be used in fertiliser industry.

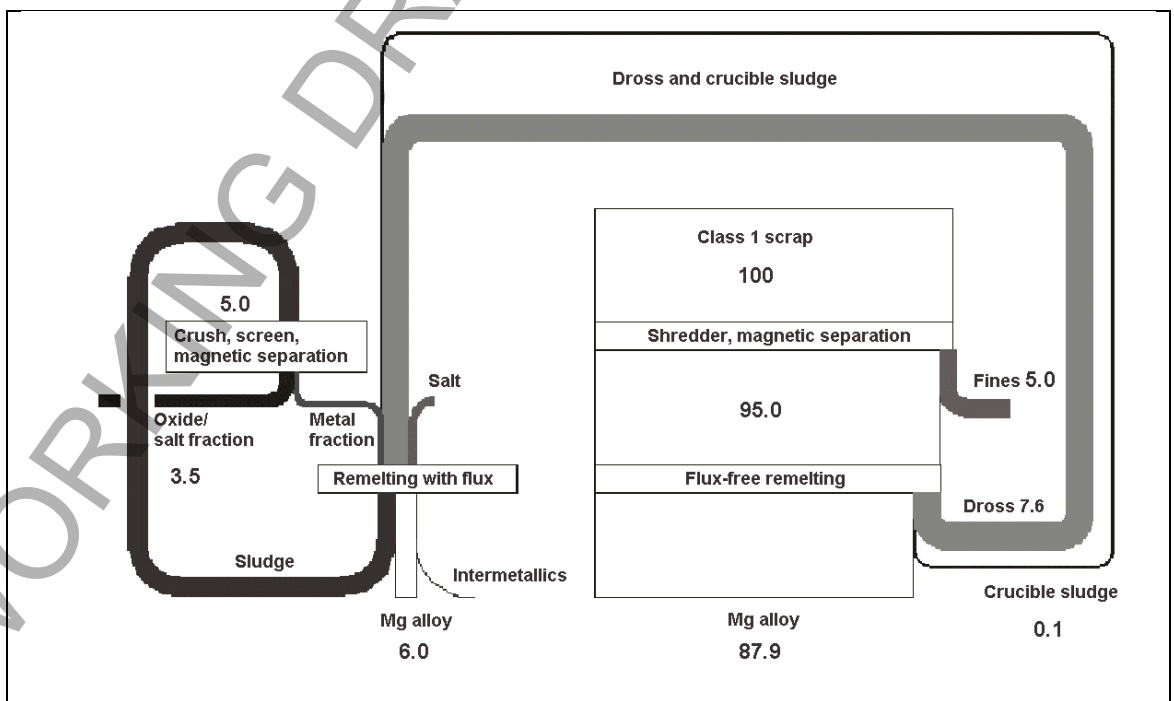
Achieved environmental benefits

- The main benefit is the optimised recycling of metal.
- Minimisation of residues through recycling of raw materials.
- Internal recycling has the added benefit of eliminating transport to an external recycling plant. The metal efficiency of the recycling is increased by type-specific melting.

Environmental performance and operational data

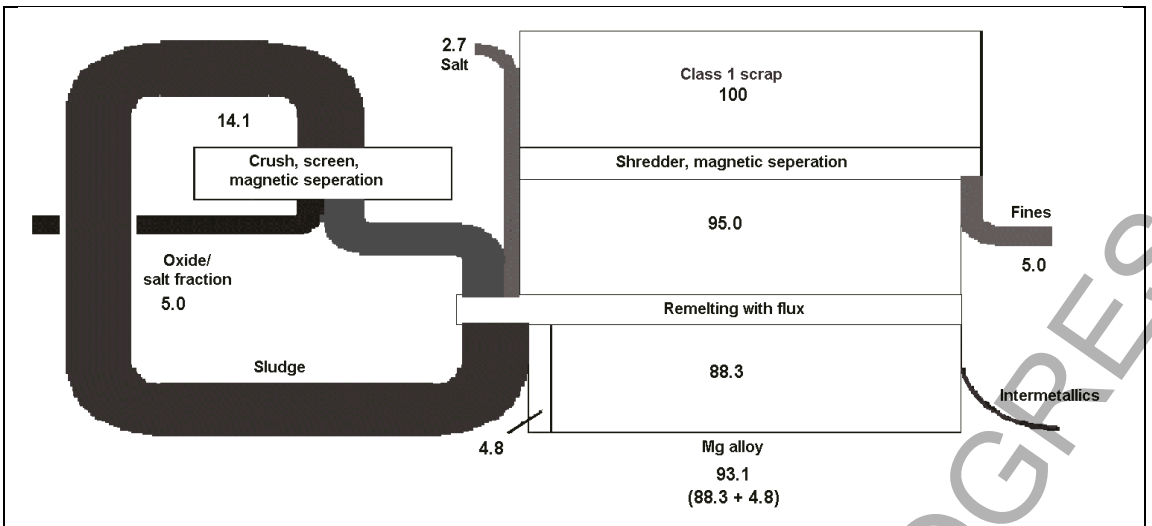
Magnesium foundries

Experimental mass flow diagrams for the remelting of class 1 scrap are given in Figure 3.15 and Figure 3.16. These include the internal remelting of sludge and dross.



Source: [104, Ditze et al. 2000]

Figure 3.15: Mass flow diagram for the fluxless remelting of magnesium class 1 scrap



Source: [104, Ditze et al. 2000]

Figure 3.16: Mass flow diagram for the salt remelting of class 1 magnesium scrap

Operational data from a 2 000 tonne/yr salt remelting plant for mixed treated scrap (3 furnaces with a capacity of 600 kg each) give consumption levels of salt: of 3.4 kg/tonne scrap and natural gas: of 26.5 Nm^3/tonne scrap.

The wet treatment of the salt fraction produces a magnesium fraction (43 %) and a sludge (57 %). The sludge is dewatered using a membrane filter press and the water is re-circulated into the process.

Cross-media effects
In the case of ferrous metal foundries None.

For magnesium foundries, fluxless re-melting involves the use of sulphur containing protective gases.

Technical considerations relevant to applicability
This technique applies to all new and existing installations.

Economics
In the case of ferrous metal foundries, the technique does not involve any additional costs.

In the case of magnesium foundries, the following information is available.

TWG, please provide up-to-date economic information
Costs for external recycling are estimated to be approximately EUR 1 200/tonne, depending on the type of transport used, the transport distance and the local market. The costs for in-house recycling are EUR 500/tonne, a difference of EUR 700/tonne. For a single plant with 1 500 tonnes/yr recycling material this means a potential saving of more than one million euros per year.

The given data are general and have to be adapted individually for each enterprise. Depending on the products and the processes used, the expenses needed for separation of the waste have to be taken into account. The waste has to be collected specifically for every alloy and every procedure.

Further factors of major influence are:

- depreciation (approximately 10 % in a depreciation period of 5 years);

- personnel costs (35-40 %);
- cost for new material (approximately 30 %) to substitute the material loss (estimated 7 %);
- costs for energy, maintenance, spare parts, salt, disposal (20-25 %).

The amortisation of a flux-based facility with two furnaces is in the range of 8 to 11 months. The amortisation of a continuous facility with 500 kg magnesium per hour will likely take a few months more.

Driving force for implementation

- Minimisation of residues, optimal use of metal.
- Legal requirements.

Example plants

The technique is applied in all European ferrous metal foundries.
For magnesium foundries: TCG Unitech, Kirchdorf/Krems (A) uses an in-house recycling facility.
No fluxless remelting plants have been reported in Europe, although the melting technology is available on the market.

Reference literature

[100, TWG 2002], [104, Ditze et al. 2000], [118, Rauch et al. 2003], [169, TWG 2021]

3.2.1.4.1.3 Reuse/recycling of packaging

Description

Process chemicals packaging is selected to facilitate its complete emptying (e.g. considering the size of the packaging aperture or the nature of the packaging material). After emptying, the packaging is reused, returned to the supplier or sent for material recycling. Preferably, process chemicals are stored in large-size containers.

Technical description

The packaging types used for process chemicals include intermediary bulk containers (IBCs), big bags, containers (1 000 l), metal recipients (50 kg), plastic or paper bags (up to 25 kg).

<u>IBCs, buckets, containers and recipients</u>

Packaging for chemicals like IBCs, buckets, containers and recipients for ready-to-use solutions, mixtures of active substances is emptied without the use of water: by gravity and by scraping the inner surface when possible.

Thereafter, the emptied packaging is stored in an appropriate manner in a dedicated storage area, until it is taken over by a qualified processing company or by the chemicals supplier.

<u>Sacks and big bags</u>

Sacks or big bags with chemicals in powder form are emptied under negative pressure. Thereafter, emptied sacks and big bags are stored in an appropriate manner, until they are taken over by a qualified processing company or by the chemicals supplier. Emptied sacks are packed in polyethylene sacks and sacks and big bags are stored in enclosed conditions.

In addition, purchased chemicals and additives are stored in large containers. Used containers are returned to chemicals/additives suppliers.

Achieved environmental benefits

Prevents waste generation, reduced emissions to soil and ground water and further stimulates recycling/reusing.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Savings in chemical purchase.
- Reduction of waste generated.

Example plants
This technique is commonly applied in European foundries.

Reference literature
[38,VITO 2001], [169, TWG 2021]

3.2.1.4.1.4 Return of unused process chemicals

Description
Unused process chemicals (i.e. which remain in their original containers) are returned to their suppliers.

Technical description
The unused chemicals (in their original packaging) are preferably returned to the supplier before their expiration date, for possible resale and use. This is achieved especially by using innovative business models like chemical leasing, closed-loop chemicals management, etc.

Achieved environmental benefits
Reduction of the generation of waste chemicals.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
Cost savings.

Example plants
Widely used.

Reference literature
[169, TWG 2021]

3.2.1.4.2 Operational material efficiency in the casting process

Metal yield (or operational material efficiency – OME) is defined as the ratio of good casting to the total metal melted and calculated as the total yearly amount (expressed in t) of final castings without defects divided by the total yearly amount of liquid metal output.

3.2.1.4.2.1 Improving casting yield and decreasing scrap generation

Description
Measures are taken to maximise the efficiency of the casting process and to decrease the generation of scrap, e.g.:

- applying best practices in melting and pouring operations to reduce for example melting losses, excessive pigging, scrap generation rates;
- applying best practices in moulding and core-making to reduce scrap generation resulting from deficiencies in moulds and cores;
- optimising gating and rising systems;
- using insulated exothermic feeders;
- introducing more efficient casting technology (e.g. by using computer-aided simulation) to reduce the number of faulty castings generated.

Technical description
Metal yield (or operational material efficiency - OME) is defined as the ratio of good casting to the total metal melted ~~to the weight of finished castings~~. The difference between the two values is due to metal losses (e.g. melting losses, spilt metal, grinding losses) and return metal (e.g. pigged metal, runners, scrap castings). An improvement of the metal yield involves reducing the metal loss and amount of return metal.

Improving metal yield is possible using one or more of the following measures:

- Applying an efficient method: proper design of runners, risers, ingates, pouring basin and optimised box yield (castings/metal poured in a mould). A valuable tool in designing ~~on efficient method~~ is the use of computer aided simulation of casting, pouring and solidification (see also Section 3.2.1.4.2.2).
- Applying good procedures in melting and pouring operations: in order to reduce melting losses, excessive pigging, scrap rates, etc.
- Applying good practice in the moulding and core-making departments: in order to reduce scrap due to deficiencies in the mould- and core-making operations.
- Applying direct remelting and or avoiding sprue materials [169, TWG 2021]

Achieved environmental benefits
Increasing the metal yield results in a lower consumption of energy, sand and additives per unit of good casting. The overall efficiency of the process is increased.

Environmental performance and operational data
A statistical analysis of the data reported for OME is presented in the following table.

Table 3.11: Statistical analysis of the data reported for OME (expressed in %)

	Iron foundries	Steel foundries	NFM foundries
Average	51	53	56
Median	58	57	60
20th percentile	5	41	39
80th percentile	80	69	85
Number of values	73	23	45
Source: [169, TWG 2021]			

The following table provides a guide to the typical yields obtained for different types of iron casting production. ~~It is not possible to recommend a target yield Figure which can usefully be adopted by a particular foundry, as so much~~

It is noted that OME depends on the type of metal, type of casting, the production facilities and the market which has to be served. ~~It is therefore necessary that a foundry sets individual targets, based on an analysis of its own current performance.~~

Table 3.12: Typical metal yields for different iron casting types

Casting type	Yield (%)
Heavy grey iron, simple shape	85 – 95
Medium sized grey iron jobbing or small batch	65 – 75
Mechanised repetition, general quality small to medium sized grey iron engineering and municipal castings	65 – 75
Mechanised repetition, high quality small to medium sized grey iron engineering castings, relatively simple design	60 – 65
Mechanised repetition, high quality small to medium sized grey iron engineering castings, complicated heavy cored design	55 – 60
Medium sized nodular iron jobbing or small batch	50 – 60
Small or very small grey iron repetition	45 – 55
Mechanised repetition of malleable iron and small nodular iron castings	40 – 50
Source: [21, ETSU 1990]	

~~In response to a questionnaire, 82 UK foundries reported their metal yield performances for the period 1981 - 1987. The improvement in yield per metal type (weighted average) is given in.~~

	~~Yield in 1981 (%)~~	~~Yield in 1987 (%)~~	~~Improvement in yield (%)~~
~~Grey iron~~	~~60.5~~	~~63.0~~	~~2.5~~
~~Nodular iron~~	~~51.8~~	~~55.7~~	~~3.9~~
~~Malleable iron~~	~~36.4~~	~~39.2~~	~~2.8~~

~~**Weighted average of yield performances in 82 UK ferrous foundries, 1981 - 1987 [21, ETSU 1990]**~~

Cross-media effects
No cross-media aspects apply to this technique.

Technical considerations relevant to applicability
The technique is applicable in all existing ferrous and non-ferrous foundries.

Economics
Improving the metal yield is possible through simple low-cost practical measures and controls. The benefits may be high since every percentage improvement results in a corresponding reduction of melting energy consumption and a reduction in the consumption of sand and chemicals.

The introduction of a computer-aided simulation for pouring and solidification requires investment and training costs.

Driving force for implementation
Optimisation of process efficiency.
Legal requirements.

Example plants
Metal yield considerations are part of good operational practice in the majority of European foundries.

Reference literature
[21, ETSU 1990], [47, EU Thematic Network Foundry Wastes 2001], [169, TWG 2021]

3.2.1.4.2.2 Use of computer-aided simulation for casting, pouring and solidification

Description
A computer simulation system is used to optimise the casting, pouring and solidification process, to minimise the number of defective castings and increase foundry productivity.

Technical description
The simulation of mould filling improves the quality, the recovery and productivity. The yield during a manufacturing process is the net weight generated, based on the spent gross casting weight.

As an example, the use of the new casting process simulation technique, compared with the previous model, leads to an improvement in yield of about 18.5 %. The example case refers to the manufacturing of a front wheel fork in light alloy, which is manufactured by tilted die-casting.

Achieved environmental benefits
- Reduced consumption of metallic materials.
- Reduced dust and gaseous emissions from melting, casting / cooling / emptying and casting treatment from reduced use of material.
- Less energy consumption and related CO_2 emissions, particularly during the melting.

Environmental performance and operational data
Both hardware and software for the simulation of cooling characteristics and properties of cast iron or cast parts are needed.

Cross-media effects
None.

Technical considerations relevant to applicability
Applicable for all industrial casting materials and casting processes.

Economics
Licence fees for the annual use of standard software is approximately EUR 25 000. The software is material-specific or process-dependent and can be extended with additional modules. Alternatively, it is possible to use casting simulation as a service.

Economic benefits are:

- the increase in yield and reduction of rejection rate and the moulding cycle time can result in a reduction of the melting and material costs in the sum of EUR 28 000 in the first year (example), leading to a return of investment in approximately 1 year;
- an increase in the metal yield results in less consumption of energy, sand and additives per tonne of good casting.

Other exemplary cases for the application of simulations [133, DE UBA 2014]**:**

- The equipment manufacturer John Deere, Moline III. has reduced the scrap rate of the grey-iron part from 10.3 % to 1.4 % and saved USD 66 936/year by modifying the part and gating system. The company also boosted its casting yield from 58 % to 64 % for an additional saving of USD 66 600/y.
- Simulation results led pump manufacturer Otto Junker in Germany to cast a steel pump housing that had direct-pour top risers instead of the typical side risers. This lowered the

amount of liquid metal needed by 81 %, reduced the moulding time by 79 % and minimised the time needed to burn off the risers by 87 %. The company reduced its total production costs for the part by 12 %.

- A South American iron foundry increased its casting yield for a ductile-iron differential case housing from 62 % to 67 % by using simulation to develop a non-traditional gating system. The design lowered the overall scrap rate from 17 % to 7 %, saved 700 000 kWh/yr to produce 24 000 parts and reduced total costs by USD 500 000.
- Heidelberger Druck (Germany) relocated a mould gate based on simulation results and thereby significantly reduced the amounts of repair welding to perform on a cover. Temperature losses in the original part had let to incomplete filling of a rib. Simulation enabled the engineers to visualise how the material flow was affected by moving the gate to different locations.

Driving force for implementation

- Increase in the ability to process and avoid casting defects.
- Increase the yield by reducing the amount of recycled material.
- Reduction in wall thickness and therefore reduction of the setting time and the moulding cycle time by 10 %.

Example plants

In Germany, about 180 simulation systems from various providers are in use.

Reference literature

[133, DE UBA 2014]

3.2.1.4.2.3 Production of lightweight castings using topology optimisation

Description

Use of topology optimisation (i.e. casting simulation by means of algorithms and computer programs) to reduce the product mass while meeting the product performance requirements.

Technical description

Topology optimisation uses the principles of the ‘bionic’ concept. The term ‘bionics’ is a composition of the words biology and technology, and describes the implementation of requirements from nature to technology. The central goal is the production of components such as castings with a minimum mass of material.

With the help of the bionic concept, typically implemented by computer programs for topology optimisation, the castings can be improved for all applications like castings for automotive, engineering and many more.
An example is the manufacturing of machining tools, which is subject to the highest design and manufacturing challenges. By using advanced optimisation algorithms and computer programs, more lightweight castings can be produced having even better mechanical properties compared to their predecessors.

The specified design goal, high stiffness combined with low manufacturing costs, can be taken into account with natural growth structures (for example, the growth patterns of trees). For the development of a bionic product, the German VDI guideline 2221 (‘Methodology for Developing and Designing Technical Systems and Products’) may be used and this can find applications in die-casting, particularly in lightweight design. [198, Beismann et al., 2018]

Achieved environmental benefits

- Reduced flows of metallic feedstock in the total production process including raw material storage, melting, casting / cooling / emptying and in casting treatment.
- Reduced dust and gaseous emissions in these manufacturing sectors (at constant number of castings).

- Less energy use and CO_2 emissions, especially during melting and transport.

Environmental performance and operational data
A case example of topology optimisation is using a special calculation tool - the 'finite element method' (FEM). The FEM software allows the user to find weaknesses in a constructive computer-aided design and an objective evaluation of design variants. So far, designers used it only as a tool to improve functionality in an iterative approach by repeated modifications of the CAD model, which was very time-consuming. By combining FEM software with advanced optimisation algorithms, it became possible to generate functionally convincing design proposals automatically by masking areas during the topology optimisation of the work piece which are not or only minimal stressed. Output is a structure, which provides minimal distortion with a given weight.

The software improves and accelerates finding of convincing workpiece designs which is seen as even more important due to increasing deadline constraints.

After the detailed design of the workpiece, the mould can be optimised. Analogous to growth processes in nature, it eliminates strength-related vulnerabilities by automatically applying some material in heavily used areas.

Cross-media effects
None.

Technical considerations relevant to applicability
Applicable to all cast components - regardless of casting materials and casting processes. Close communication with the customers is advised especially when low mass castings will be developed.

Economics
- Reduced raw part costs by saving material.
- Reduced melting costs.
- Reduced cost for core and mould production.
- Increased value of components in cases where value of components depends on weight and or costs per piece.
- Competitive advantages over competing materials and manufacturing processes (welding, forging, polymer concrete).

Driving force for implementation
- Reduction in weight of castings. In general a range of reduction between 10 % and 35 % is expected.
- Maximum component stiffness by minimum material use.
- Accelerated finding of concepts for design of workpieces.
- Reductions of unit costs.

Example plants
- CLAAS GUSS is using the software Hyperworks.
- Under the trade name BIOCAST®, Heidenreich and Harbeck AG is developing material-efficient premium cast parts with the help of bionic optimisation tools.
- GF Automotive is producing mechanically highly stressed components for the automotive industries with bionic guidelines that are based on the principle of growth of trees.

Reference literature
[133, DE UBA 2014], [198, Beismann et al., 2018]

3.2.1.4.3 Reduction of material consumption

3.2.1.4.3.1 Separate spraying of release agent and water in high-pressure die-casting

[This technique has been moved here from Section 4.2 of the old BREF (Emerging Techniques for Foundries)]

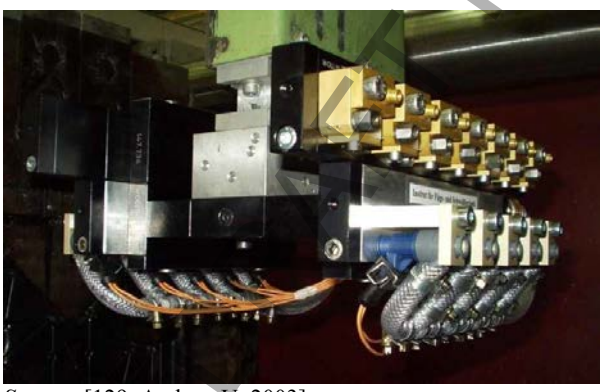
Description

Water and release agents are applied separately to the mould using an additional row of nozzles mounted on the spray head. Water is sprayed first, leading to a significant cooling of the mould before the application of the release agent, which results in reduced emissions and consumption of release agents and water.

Technical description

In aluminium high-pressure die-casting, the permanent moulds are cooled and sprayed with release agent prior to casting to prevent the casting adhering to the mould. The conventional technique for release agent use is that a mixture of release agent and water is applied to the hot mould in one go, by means of several linearly arranged nozzles. Some of the water evaporates, cooling the mould and leaving the release agent in place, whilst another part of the mixture runs off the mould, leading to a loss of release agent and water. The evaporation may also cause the formation of a mist.

In an alternative process, water and release agent are applied separately. For this purpose, a row of nozzles was added to the spray head for the separate application of release agent. These nozzles can be actuated individually via a computer (see the figure below).



Source: [129, Anders, U. 2003]

Figure 3.17: Spray head with separate nozzles for water and release agent

Water is sprayed on first, cooling the mould by approximately 20 ºC, followed by spray application of the release agent. The preliminary cooling causes less release agent to evaporate and improves its adhesion to the mould. This reduces the consumption of release agent by some 25 %. Thermographic measurements showed that the technique cools moulds more strongly and more evenly. Tests proved that it involves no leakage of release agent which otherwise would have had to be collected and disposed of.

Release agent is applied only to those parts of the mould which come into contact with the molten aluminium. This can reduce the consumption of release agent by another 30 %.

The use of computer-assisted actuation of the nozzles for the release agent has made the previously used existing array of nozzles for compressed air redundant. This function is now taken over by the nozzles for the release agent.

An advantage with small series and frequent mould changes is that the spraying programme can be saved on the computer and can thus be reproduced quickly after a mould change.

Achieved environmental benefits
The consumption of release agent can be reduced by 25 % by the separate application of water and release agent. Separate actuation of the nozzles makes it possible to achieve a further saving of up to 30 %, depending on the geometry of the casting, as the release agent is applied only to those parts of the mould which come into contact with the casting.

Water consumption can be reduced by about 15 %. There are no losses of water or release agent to be disposed of. No gaseous emissions due to evaporation of release agent are generated.

Environmental performance and operational data
No information provided.

Cross-media effects
None. No increase in energy costs is expected.

Technical considerations relevant to applicability
Generally applicable.
~~Previous tests were carried out in aluminium die-casting. The technique can also be applied in zinc die-casting and in the injection moulding of plastics. Modifications are necessary when the spray head is used at higher temperatures. These have not yet been tested.~~

Economics
Economic advantages result from the considerable savings in release agent and water, and from the elimination of disposal costs.

Further advantages result from the major time savings achieved in the mould change, due to the fact that spraying programmes can be saved and re-run.

The investment costs for this technique are higher than those of the conventional process. On the plus side, different moulds can be sprayed individually with the same spray head.

Driving force for implementation
- Considerable saving of material and water.
- The loss of release agent-water mixture, which needs to be collected, is avoided.
- Short time-scales required for machine set up and adaptation.
- High reproducibility of the results (consistent quality).

Example plants
~~The spray heads are produced and sold by a German producer from the end of 2003. Enquiries from the industry have already been received. Industrial use is expected to start by the end of 2003.~~
CZ025, DE031, FR114, FR115, PT142, SE148.

Reference literature
[129, Anders, U. 2003] [169, TWG 2021]

3.2.1.4.3.2 Minimisation of release agent and water consumption

Description
Measures to minimise the consumption of release agent and water include:

- use of an automated spraying system;
- optimisation of the release agent's dilution factor;
- application of in-die cooling;
- closed-mould application of release agent.

Technical description
A water-based solution of release agent is sprayed on the open HPDC die before closing it. This allows cooling and coating of the die. Some simple process measures allow the minimisation of the release agent and water consumption. These will also prevent the formation of a mist. These measures ~~are~~ include the following:

- *Automated spraying process*: Robotisation of the spraying process allows a careful control of the amount of release agent used and adaptation of the amount used to the local needs of the cast piece.
- *Optimise dilution factor*: The release agent dilution factor should be chosen such that the spraying action has the required balance between coating and cooling of the die.
- *Apply in-die cooling*: The cooling action may be partially taken over by internal cooling using an integrated water circuit.
- *Closed-mould application of release agent*: A release agent is applied to the closed die-casting mould in a vaporised form. The high temperature results in a condensation and deposition of a release agent film. This technique is an alternative to the spraying of a water-based solution of the release agent onto the open die. It allows the water usage to be reduced and also reduces the consumption of release agents. The active substances for the process, i.e. getting the casting out of the die, are very similar to the open-mould technique: paraffin wax, aliphatic carbons, polysiloxanes, polyglycol. Water spraying, however, also causes the necessary cooling of the die surface. The alternative technique therefore requires enhanced temperature management (mainly by a cooling effect), by means of an internal die cooling system. This may be obtained by reducing the thermal oil temperature. Combined water spraying and closed-mould release agent application is possible in places where the moulds cannot achieve complete thermal equilibrium by means of internal cooling systems alone.

Achieved environmental benefits
- Minimisation of water and chemicals consumption.
- Prevention and/or reduction of (diffuse) emissions.
- Reduction of generated waste water and reduced emissions of steam containing oily particles.

Environmental performance and operational data
For the closed-mould application of release agent, some operational examples in aluminium foundries have been reported. ~~These result in~~ A 50-80 % reduction in the spraying time was reported as well as ~~, and a~~ an 80 % reduction in sleeve-parting agent consumption. [202, TWG, 2002]

Cross-media effects
Generally no cross-media effects were reported for most of the techniques. For the closed-mould application of released agent, ~~The technique requires~~ an increased effort to cool the dies is required. In simple cases, this may involve a lowering of the thermal oil temperature, but for more complex dies, it may involve the application of an additional cooling circuit.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Foundry strategy to reduce waste water production and to reduce the consumption of water and chemicals.
- Legal requirements.

Example plants
Most of the techniques are applied in major HPDC plants, e.g. in the manufacture of car parts. For the closed-mould application of released agent, some operational examples in aluminium foundries have been reported.

Reference literature
[189, Hüttenes-Albertus, 2002], [202, TWG, 2002]

3.2.1.4.3.3 Minimisation of binder and resin consumption

Description
Measures to minimise binder and resin consumption include:

- use of a sand quality which is consistent with the binder system;
- good management of sand storage and sand testing (purity, grain size, shape, moisture);
- temperature control;
- mixer maintenance and cleaning;
- checking mould quality (to prevent and if necessary repair moulding defects);
- optimising binder addition;
- optimising mixer operation.

Technical description
The minimisation of chemicals consumption can be achieved through optimisation of the process controls and material handling. ~~The latter category is dealt with in Section~~. In this section process measures are discussed.

Overuse to compensate for poor process control is the most common way in which binder chemicals are wasted. For instance, key parameters that relate to good binder management include:

- *Sand consistency*: Use of a sand quality which is consistent with the binder system. Good management of sand storage and sand testing (purity, grain size, shape, moisture) are of the main importance. A low content of fines and maximum amount of re-used sand will reduce the amount of resin needed.
- *Temperature control*: The sand temperature must be maintained in a narrow range, with regular checks and adjustment of the amount of hardener addition. Positioning the sand heater just before the mixer allows close temperature control.
- *Mixer maintenance and cleaning*.
- *Mould quality*: Checking, solving and preventing moulding defects.
- *Addition rates*: The appropriate binder addition depends on the binder type, the surface area of the sand and the size of the casting.
- *Mixer operation*: Optimisation of the mixer performance involves monitoring and control of its operation.

The following table lists the mixing process variables that are easy to measure using readily available instrumentation. Interfacing the controls with an alarm system allows the operator to be alerted to any 'out-of-specification' condition. This needs to be corrected by cleaning, maintenance and recalibration before a major problem develops.

Table 3.13: Process variables and how they indicate mixer performance

Process variables	Comments	Instrumentation
Sand flow	Can vary as a result of obstructions at the discharge gate that reduce/stop the sand flow or worn/loose stop nuts that produce a faster flow	Impact plate flowmeters
Sand temperature	Determines the speed of hardening and the amount/type of hardener required	A process control instrument can be used to adjust hardener additions to compensate for changes in sand temperature
Power consumption	Provides an indicator of mixer cleanliness	Motor load monitor
Resin and hardener flowrate	Can vary as a result of worn pumps, viscosity changes with temperature, blockages or leaks in pipework and nozzles, sticking of non-return valves, etc.	Positive displacement, electromagnetic or coreolis flowmeters
Operating hours	Useful for assessing performance against capital and maintenance costs	
Source: [28, ETSU 1998]		

For foundries that require greater sophistication, a range of fully automated mixer control systems are available. These systems use microprocessor technology to provide automatic corrective control of mixed sand production and need only limited operator involvement. The additional benefits achievable with automated control systems are mainly due to the much reduced dependence on the operator and the more rapid correction of variations in conditions. The latter is also performed without having to stop production.

Achieved environmental benefits
Optimisation of the binder and resin use results in a minimisation of the consumption of chemical additives.

Volatile organic compounds make up to 50-60 % by weight of the binder components. The amount depends on the binder system type. Most are emitted during sand mixing and metal pouring. A reduction in the use of binder results in a corresponding reduction of VOC emissions.

Environmental performance and operational data
In most cases, reductions of 5 % in binder levels and 1 % in scrap moulds are easily achieved using modern mixer control systems. Many foundries have realised savings that have been considerably higher. Reductions in binder addition of 5 % to 25 % have been reported for various foundries, as well as almost eliminating scrap moulds production.

The installation of an automated mixer control system in an iron foundry using cold-setting resins allowed the foundry to reduce the resin addition rate from 10 kg/minute (1.22 % resin to sand weight) to 8.89 kg/minute (1.09 %), which correspondingly resulted in a 10 % saving in the amount of catalyst used. The number of defective moulds fell by over 60 % and cost savings of over GBP 37 000/year (1995 UK prices) were achieved.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable. This technique applies to all new and existing foundries using chemically bonded sands. Mixing monitoring control equipment can be retrofitted to existing plants.

Economics
TWG, please provide more up-to-date economic data to revise this section.

For a tonne of mixed sand, the binder addition is typically only 1-3 % by weight, but in terms of cost, the binders account for 30-60 % of the total raw material cost. It is estimated that cost savings of 5-10 % could be achieved through better management of binder materials.

Incorporating all the equipment suggested in Table 3.13 in a mixer system costs around GBP 10 000 (1997 UK prices). However, due to the significant improvement in process control, this capital investment will have a relatively short payback time. Although the cost of installing an automated control system is approximately twice that for simple on-line monitoring, substantial cost savings are possible.

Some example economic data are given in Table 3.14. These refer to the iron foundry described under Operational data.

Table 3.14: Annual savings, cost and payback for example plant mixer control (1995 prices)

Cost type	EUR
Saving due to 60 % reduction in defective moulds	6416
Saving due to 10 % reduction in resin use	29966
Saving due to 10 % reduction in catalyst use	9050
Total saving in material cost	**45433**
Annual running cost	320
Estimated annual maintenance cost	24
Net cost saving	**45088**
Purchase cost of unit	24166
Payback period	7 months
Source: [31, ETSU 1996]	

Driving force for implementation
- Optimisation of operational costs and minimisation of VOC emissions.
- Legal requirements.

Example plants
Good binder management measures are used in the vast majority of the foundries using bonded sand.

Reference literature
[28, ETSU 1998], [31, ETSU 1996], [100, TWG 2002], [120, TWG 2003]

3.2.1.4.3.4 Minimisation of mould and core sand losses

Description
Production parameters of the various product types are stored in an electronic database that allows easy changeover to new products with minimised losses in time and materials.

Technical description
Modern mould and core-making machines allow the production parameters of the various product types to be saved in an electronic database. This allows easy change-over to new products, without the loss of time and materials from finding the right parameters by simply using trial and error. For new products, the settings for similar products may be used to shorten the optimisation time.

Achieved environmental benefits
Reduction of the amount of waste sand and energy, through minimisation of the test run period.

Environmental performance and operational data
This technique is especially useful for the production of small series with high production throughput. An errorless change-over requires good control and continuity of the sand quality.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
The investment cost for a core shooting machine depends on the core volume, and range from EUR 150 000 (5 l) to EUR 400 000 (100 l). Operational costs are 5-10 % of investment costs per year (2001 data).

Driving force for implementation
Optimisation of processes that require frequent change of core or mould type.

Example plants
This technique is applied in several foundries around Europe.

Reference literature
[38, VITO 2001]

3.2.1.4.3.5 Use of best practices for cold-setting processes

Description
Practices include the following (depending on the binding system used):

- Temperature control: the temperature of the sand is kept as constant as possible and low enough to prevent emissions caused by evaporation. For phenolic- and furan-acid catalysed, polyurethane and ester silicate systems, the optimum temperature range is between 15 ºC and 25 ºC. For resol-ester systems, the optimum temperature range is between 15 ºC and 35 ºC.
- for furan-acid catalysed systems:
  - minimise the content of free (monomer) furfuryl alcohol in the resin (e.g. less than 25 wt-%); and
  - reduce the sulphur content of the acid catalyst by substituting a portion of the sulphonic acid with a strong sulphur-free organic acid.

Technical description
In cold-setting processes, temperature control of the sand should be kept as constant as possible and the optimum temperature ranges should be selected. This is summarised below together with additional parameters to consider for all the main cold-setting systems:

- *Phenolic*: The temperature of the sand is kept as constant as possible, i.e. at around 15-25 ºC, which is low enough in order to prevent emissions caused by evaporation. Direct contact between the resin and catalyst has to be avoided as the reaction is exothermic and can be violent.
- *Furan*: The temperature of the sand is very important for this process and is kept as constant as possible, around 15-25 ºC; in order to control the setting time of the binder and to minimise catalytic additions. Direct contact between the resin and catalyst needs to be avoided as the reaction is exothermic and can be violent.
- *Polyurethane (phenolic isocyanate):* The sand temperature is kept between 15 and 25 ºC, to maintain process control and to minimise emissions. Best practice is to

work with three pumps and to mix the catalyst and the phenolic resin with isocyanate and sand directly in the mixer [100, TWG 2002].

- *Resol-ester* (alkaline phenolic ester hardened): The temperature of the sand is controlled and kept at an optimal level of 15-35 ºC. The process is less sensitive to temperature fluctuations than other self-hardened systems. The velocity of hardening is managed by the choice of the hardener type [120, TWG 2003].
- *Ester silicate:* The sand temperature is controlled within the range 15-25 ºC. As moulds and cores pick up moisture, they need to be used as quickly as possible after achieving full strength. Prolonged storage can only be done in dry conditions.

Specific measures for furan-acid catalysed systems

Furan resins are made from furfuryl alcohol and can be modified with urea, formaldehyde or phenol. Generally, the higher the content of furfuryl alcohol in the resin, the lower the viscosity of the resin. Since the classification of furfuryl alcohol as a carcinogenic compound in Regulation EC No 1272/2008, the content of free (monomer) furfuryl alcohol in resin should be limited theoretically to less than 25 wt-%.

In order to limit the emissions of sulphur compounds during pouring, new types of acid catalysts have been developed. Essentially, sulphur is introduced into the moulds via the acid catalyst (paratoluenesulphonic acid) employed in furan-acid catalysed systems. The most efficient way to reduce sulphur inputs into the mould consists of reducing the amount of paratoluenesulphonic acid added or partially replacing it with other compounds (e.g. sulphur-free organic acids).

Achieved environmental benefits

Reduction of VOC and sulphur emissions during pouring.

Environmental performance and operational data

Historically, the furfuryl alcohol content in furan resins used in the foundry process ranged from 50 wt-% to 95 wt-%. New resins have been developed where the furfuryl alcohol content has been limited to slightly above 50 wt-%. [191, M.Holtzer et al., 2015], [199, M.Holtzer et al., 2013]

More recently, furan resins with low formaldehyde content (percentages of formaldehyde of less than 0.1 wt-%, based on the weight of the resin) and low furfuryl alcohol content (less than 25 wt-%.) have also been developed. [200, Zennaro et al. 2019]

Binders developed by different manufacturers for foundries using low-sulphur catalysts composed of a mixture of non-sulphur strong organic acids and aliphatic or aromatic toluenesulphonic acid, and H_2SO_4 are effective (possibility of reducing the sulphur content of the acid catalyst by about 50 %).

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

The price of using low-sulphur catalysts in furan binders is higher than using paratoluenesulphonic acid only.

Driving force for implementation

Legal requirements.

Example plants

Widely used.

Reference literature
[100, TWG 2002], [120, TWG 2003], [191, M.Holtzer et al. 2015], [199, M.Holtzer et al. 2013], [200, Zennaro et al. 2019]

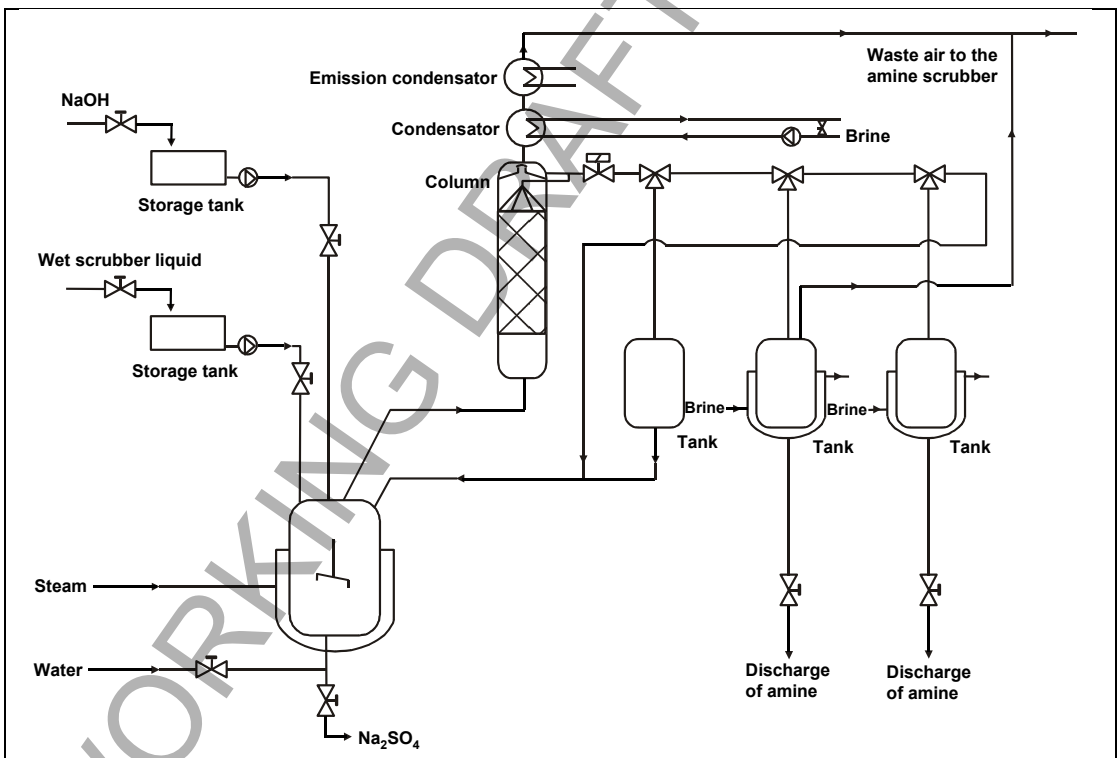
3.2.1.4.3.6 Recovery of amines from acid scrubbing water

Description
When acid washing is used (e.g. using sulphuric acid) to treat the cold-box off-gases, amine sulphate is formed. The amines are recovered from the treatment of amine sulphate using sodium. This may take place on site of off site.

Technical description
When acid washing the cold-box exhaust gas, amine sulphate is formed (see Section 3.2.1.4.3.6). This amine may be recovered through neutralisation with sodium hydroxide, followed by distillation.

As shown in Figure 3.18 the salt that is formed from tertiary amine (e.g. DMEA, DMIPA and triethanolamine (TEA)) in the acid scrubber, and the scrubbing acid (e.g. sulphuric acid) are retransformed by reaction with a strong base (e.g. caustic soda solution), thereby forming free amine and e.g. sodium sulphate. The amine is expelled with water vapour and is then cleaned and concentrated in a column, to an extent that allows it to be re-used. The sodium sulphate solution (together with polluted scrubbing solution) can be recovered or may be disposed of.

If the amine is not recycled, the scrubbing concentrates can be treated in a biological waste water treatment plant with nitrogen elimination.



Source: [93, UBA 2003]

Figure 3.18: Amine recycling plant

Achieved environmental benefits
Recovery of a chemical compound, which may be reused.

Environmental performance and operational data
This technique is applicable to all amine-containing scrubber liquors from core-making exhaust. The implementation is ~~limited by~~ associated with economic factors (e.g. transport costs), since sufficient quantities of amine scrubber liquid need to be available. In general, the treatment is applied in a centralised location, treating the effluents of several foundries. Since the operation is subject to an explosion hazard, any necessary measures to prevent explosion risks should be taken (see also Technical considerations relevant to applicability below).

Cross-media effects
If the operation is performed in a centralised plant, it involves transport of the scrubber liquid to the treatment unit.

Technical considerations relevant to applicability
Applicability may be limited due to safety considerations (explosion hazard).

Economics
No information provided.

Driving force for implementation
- Recovery of chemical compounds.
- Disposal costs for industrial waste.

Example plants
- Centralised recycling plants: Voerde (DE).
- Centralised plant for group of automotive foundries: Poitou (FR).

Reference literature
[93, UBA 2003]

3.2.1.4.3.7 Use of best practices for gas-hardening processes

Description
Practices includethe following (depending on the hardening process used):

For phenolic urethane resins (cold-box process):
- The consumption of amines is minimised by optimising the diffusion process within the core, typically through simulation and optimisation of the gas flow.
- The sand temperature is maintained as constant as possible, between 20 ºC and 25 ºC, to minimise gassing time and amine consumption.
- The moisture of the sand is maintained below 0.1 % and the gassing and purging air is dried.
- Core boxes are well sealed to allow the amine catalyst gas to be extracted and the cores are thoroughly purged to prevent amine releases during the storage of cores.

For resol-ester resins:
- The sand temperature is maintained as constant as possible, between 15 ºC and 30 ºC.
- Curing of the alkaline phenolic resin is achieved using methyl formate that is gasified by air typically heated up to 80 ºC.
- Core boxes and gassing heads are sealed correctly and the venting of the core box designed to give a slight backpressure so that the curing vapour is held long enough for the reaction to take place.

For CO_2-hardened resins (e.g. alkaline phenolic, silicate):
- The exact volume of CO_2 gas necessary for curing the resins is used by employing a flow controller and a timer to achieve the best strength and storage time.

- For silicate resins, liquid breakdown agents are employed (e.g. soluble carbohydrates) to increase gassing speed.

For SO_2-hardened resins (e.g. phenolic, epoxy/acrylic):

- The gassing period is followed by purging with the same inert gas (e.g. nitrogen) used for curing to remove the unreacted excess sulphuric dioxide from the sand.
- Core boxes are well sealed and the cores are thoroughly purged to prevent gas releases during the storage of cores.

Technical description

- *Cold-box:* Amine vapours need to be captured at the core-making machine. Any excess amine is captured through the core box. Additionally, it may also be necessary to ventilate the core storage area. When possible, hoods are placed over the moulding or coring machines as well as over the temporary core storage area.

  Amine consumption can be minimised to the extent that its consumption matches the production needs of the sand cores, since the cost of the raw material and its treatment is high. Minimisation of amine consumption is helped by optimising the amine distribution process within the core, typically through a simulation and optimisation of the gas flow [100, TWG 2002].

  The sand temperature has to be maintained as constant as possible, between 20 ºC and 25 ºC, otherwise a too low temperature will involve a longer gassing time, thus resulting in a larger amine consumption. A too high temperature drastically reduces the lifetime of the prepared sand.

  Water is detrimental to this process. The moisture of the sand has to be maintained below 0.1 %, and the gassing and purging air must be dried.

  Note: Amines are flammable and explosive in some proportions with air. Considerable care is required in their storage and handling, and the supplier's instructions need to be observed at all times.

- *Resol (alkaline phenolics methyl formate hardened):* It is advisable to ventilate the working area, at least in order to prevent any danger of fire. Methylformate consumption needs to be minimised to such an extent that its consumption matches the production needs of the sand cores. The sand temperature has to be maintained higher than 20 ºC, in order to prevent the condensation of methylformate. Methylformate vapours are heavier than air; this should be kept in mind when designing the exhaust system.

  Note: Methylformate is flammable when its concentration in air reaches 6 to 20 % and explosive in some proportions with air. Considerable care is required in storage and handling, and the supplier's instructions need to be observed at all times.

- *Resol-CO_2:* The resin has low contents of unreacted phenol and formaldehyde, and their emission levels, even during the gassing and purging periods, are very low. It is advisable to ventilate the working area. [120, TWG 2003]

- *SO_2 hardened phenolic or furan:* The working area has to be ventilated, and the emissions collected at the emission point by totally hooding the moulding or coring machines and by applying venting.

  These collected gases must be treated before emission. This is easily completed by a scrubber containing a sodium hydroxide solution. The pH and the concentration of the scrubbing solution have to be continuously supervised. The scrubbing solution needs to

be occasionally replaced to remove concentrated salts, it then requires disposal as a hazardous waste.

Sulphur dioxide consumption needs to be minimised to the extent that its consumption matches the production needs of the sand cores.

Normally, the purging cycle lasts 10 times longer than the gassing cycle.

- *SO_2 hardened epoxy/acrylic (free radical curing)*. As for gassing and purging, collection and treatment are described in the SO_2 hardened furan resins section. The best gassing conditions for achieving cores with good characteristics require:
  - the sand to be dry before use;
  - the blowing or shooting air to be dried too;
  - the concentration of sulphur dioxide in CO_2 or nitrogen to be from 5 % to 100 %, depending on the resin used (minimal for acrylic, maximal for epoxy/acrylic);
  - the purging cycle to last 10 times longer than the gassing cycle.

Achieved environmental benefits
Reduction of consumption of resins and of associated emissions.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Reduction of resins consumption and associated emissions.
- Legal requirements.

Example plants
Widely used.

Reference literature
[120, TWG 2003]

3.2.1.4.3.8 Use of alternative moulding/core-making processes

Description
Alternative moulding/core-making processes include:

- lost foam casting process;
- ceramic shell moulding.

See more information on the Lost Foam casting technique in Section 3.2.1.4.3.9 and on the post-combustion of off-gases from the Lost Foam process in Section 3.2.1.11.2.1.

More information on the ceramic shell moulding technique is available in Section 3.2.1.4.3.10.

3.2.1.4.3.9 Lost Foam casting

Description
The Lost Foam process starts with the 3D-CAD design and production of a precision moulded foam pattern, made from expanded polystyrene (EPS) or PMMA, produced by automated injection moulding machines.

Technical description
The general principles of Lost Foam casting have been described in Section 2.2.5.9.1. Due to the absence of binders, the technique produces a reduced amount of solid waste and emissions compared to sand casting methods.

The technique allows the production of pieces with tighter tolerances, less feeder and riser channels and better as-cast features. This all results in less machining and clean-up time.

Lost foam foundries include a foam workshop, a melting shop and a casting shop. They do not have an extensive core-making shop and finishing shop. The foam shop involves foaming machines, steam generators and coolers and ambient air dryers.

The Lost Foam models are made of polystyrene (EPS) or PMMA, with small amounts of pentane, glue and a mineral coating. Since both EPS and pentane are pure hydrocarbons, organic carbons are formed upon pyrolysis of the model. In order to minimise emissions of the organic decomposition products of EPS, post combustion of the off-gases is performed.

The technique uses unbonded sand, which results in no binder–related emissions upon pouring and shake-out and which may be internally re-used without major treatment. EPS pyrolysis results in a slow build-up of organic material in the sand. This may be prevented by de-dusting and partial renewal of the circulating sand. A 5 % renewal is sufficient to maintain sand quality. The evacuated sand may be thermally regenerated for internal re-use.

Achieved environmental benefits
Since unbonded sand is used, the technique shows no binder-related emissions upon pouring. However pyrolysis of the EPS or PMMA results in organic decomposition products, which necessitate post combustion.

The use of energy in the Lost Foam process is significantly lower than in conventional casting methods. This is mainly due to the reduced energy uses for post casting operations, melting and sand preparation. The production of cores for conventional moulding methods is relatively more energy intensive than the production of the foamed model.

LCA analysis has confirmed that the environmental benefit as stated above, can be extended to an overall better environmental performance of the Lost Foam process over sand casting, in as far as the casting of core-intensive castings are concerned. For simple castings (e.g. lids), the life cycle approach shows that there is no overall better performing process.

Environmental performance and operational data
This technique applies to the serial production of small and medium sized products in ferrous and non-ferrous metal. Maximum casting sizes are 1 000 x 1 000 x 550 mm. The technique finds most of its implementation in aluminium foundries and has a 2 % share of aluminium casting.

Emission data and data on residue production have been given in Section 2.2.5.9.1. The technique results in lower residue production compared to a sand foundry of equal capacity. Flue-gases need more intensive cleaning (post-combustion) and (after cleaning) result in higher organic compound (BTEX, formaldehyde) stack emissions.

Comparative consumption levels for the production of a comparable compressor casing using sand casting and Lost Foam casting are given in Table 3.15. This shows the higher amount of return material in the melt and the lower weight of the casting. For the Lost Foam method, the total amount of moulding-sand is greatly increased, while no cores are used.

Table 3.15: Operational data for the production of a similar cast iron compressor casing, using various methods

Input material	Green sand	Chemically bonded sand	Lost Foam
Cast iron	98.0	98.0	96.1
Foundry returns	30.0	30.0	38.1
Weight casting	68.0	68.0	58.0
Moulding-sand	256.8	233.0	1101.4
Core sand	122.0	150.7	n.a.
Weight foam model + feeder	n.a.	n.a.	0.212
All data in kg n.a: not applicable *Source:* [44, de Wilde et al. 1999]			

An LCA-based assessment of the Lost Foam process (also taking into account processes outside the foundry borders) shows a lower overall environmental impact for the production of core-intensive castings. The technique produces a reduced amount of residual sand and dust and the sand may be more easily regenerated (shortened thermal treatment).

Cross-media effects

The technique represents a reduction in energy consumption and a decrease in mould making and casting finishing operations (see Environmental performance above). The off-gases show increased values of BTEX and formaldehyde, but emissions only occur during pouring and they can be more easily captured and treated (see Section 3.2.1.11.2.1).

Technical considerations relevant to applicability

Applicability of the Lost Foam casting process to existing plants may be limited due to the required infrastructure modifications.

Since the technique implies a basic change in the mould making procedure and infrastructure, it applies primarily to new installations. Application in existing foundries requires a conversion of the foundry process with regard to the moulding, pouring and finishing operations and a review of these stages for each of the castings produced. To introduce Lost Foam for a given casting requires funds, manpower and the necessary time and flexibility, as well as the co-operation of the customer.

Economics

Economic data for an aluminium Lost Foam installation are given in Table 3.16. Investment costs include equipment, installation, start-up and training.

Table 3.16: Economic data for an aluminium Lost Foam foundry

Investment costs	Description	EUR
Model making equipment	Model making machine Steam generator Coating installation	1 300 000
Casting equipment	Automatic casting machine	2 540 000
Off-gas cleaning	Dry dedusting Thermal regenerative treatment	608 000
Sand preparation	Sieving, cooling, transport	160 000
Total	*Investment, installation, start-up, training*	*4 608 000*
Operational cost		**EUR/tonne good casting**
Consumption	EPS-granules, glue, coating, steam, combustibles	202
Foundry details: aluminium castings, 5 500 tonne/y production good castings, 6 864 tonne/y production molten metal, 1997 data. *Source*: [35, Spillner, A. 1997]		

Driving force for implementation

- To reduce wastes from sand casting and to reduce energy consumption.
- Legal requirements.

Example plants

~~Several example plants are reported in Germany and France.~~
Plants DE078, IT129 and IT130.

Reference literature

Cast iron: [44, de Wilde et al. 1999]
Aluminium: [35, Spillner, A. 1997], [49, Inasmet and CTIF 2002]
[169, TWG 2021]

3.2.1.4.3.10 Ceramic shell moulding

Description

A polystyrene model is covered with a thin ceramic shell made of ethyl silicate and refractory sand. The shell is hardened using ammonia and sintered burning away the polystyrene model. The metal is then poured into the shell.

Technical description

This kind of ceramic shell moulding is a patented process (Replicast®) in which a polystyrene model is covered with a ceramic shell (2-3 mm thickness), based on ethyl silicate and refractory sand. The shell is hardened using ammonia and sintered at 1 000 ºC. The sintering cures the shell and burns away the polystyrene model. The metal is then poured into the shell.

The sintering furnace is equipped with post-combustion to reduce emissions.

The technique allows a casting design with no parting lines, cores and draft angles and reduced feed metal. This reduces the need for finishing and machining operations.

Achieved environmental benefits

The technique results in a minimisation of dust emissions from moulding and finishing, as compared to sand moulding. The emissions of VOC are eliminated as no gas is emitted for the inert ceramic mould. Additionally the amount of waste (dust, metal) is reduced. The reduction of feeder systems results in a higher yield of castings per melt.

Environmental performance and operational data

Operational data from the owner of the technique are reported in Table 3.17 for the casting of valves, as compared to sand casting.

Table 3.17: Relative weight reduction for ceramic shell casting of valves as compared to sand casting

Property	Relative weight reduction (%)
Finished weight of castings	20 – 26
Feed metal	24 – 60
Poured metal	24 – 50
Source: [117, Castings Technology International 2003]	

Cross-media effects

None.

Technical considerations relevant to applicability
Applicability of ceramic shell moulding may be restricted by product specifications (e.g. high surface finish).

The technique applies for the fabrication of castings which need a high surface finish, in low-carbon alloys such as ultra low carbon stainless steel and nickel-based alloys with a finished weight of up to 550 kg. This patented type of ceramic shell process may only be used in accordance with the terms and conditions of the licence granted ~~to the licensee~~.

Driving force for implementation
Regulation of VOC emissions and high disposal costs for residual wastes.
Legal requirements.

Example plants
- CMS srl, Urbisaglia (IT): 2 automated shelling lines, producing steel valves up to 150 kg finished weight.
- Saint-Gobain SEVA, Chalons-sur-Saone (FR): steel and super alloy components for glass industry.

Reference literature
[38, VITO 2001], [117, Castings Technology International 2003]

3.2.1.4.4 Sand reconditioning and regeneration

3.2.1.4.4.1 Optimised reconditioning of green sand (breaking, separation, cooling)

Description
Various techniques can be used for breaking the sand into its original grain size and for removing the fines, e.g. vibrator, drum, shot blasting. For cooling of reclaimed sand, techniques such as evaporative cooling or fluidised bed cooling can be used.

Technical description
One of the major advantages in using green sand moulding is that the sand from the moulds can be reconditioned after pouring for multiple re-use. The addition of a minimum percentage of new sand is performed in order to maintain the quality of the moulding-sand. The amount of new sand added is determined by the input of core sand and the losses in the process. For coreless moulding, the average sand renewal ratio is 2-5 %. In casting processes using cores, sand renewal occurs through the introduction of the core sand into the loop. In any case, surplus sand is removed from the sand circuit after the shake-out screen or from the storage silos. The general treatment is depicted in Figure 2.32. This internal recirculation of green sand with minimal treatment is referred to as primary regeneration. This regeneration basically has three aims: (1) to break the sand into its original grain size or small particles, (2) to remove the fines, and (3) to cool the sand before blending with new sand.

Various techniques are applied for the breaking and separation:

- *Vibration*: The vibratory grid, or screen equipment, is the most widely used technique for primary reclamation purposes. The sieved sand is removed for subsequent treatment, e.g. for cooling, size classification, and thermal reclamation, and the residual material is collected for disposal.
- *Drum*: Sand from the knock-out operation is loaded into a rotating drum fitted with both lifting and travelling bars. As the sand travels along the drum, the rotating and lifting action causes the sand particles to grind against each other and break down to individual grains. The sand grains fall through screens at the end of the drum, while oversize and tramp materials are removed for landfill disposal.

- *Shot blast*: The mould and casting is loaded directly into the shot blast machine. The action of the shot blast results in the complete disintegration of the mould and also cleans the surface of the casting. The sand and shot are subsequently separated. However, this technique is not very common.

During cooling of the castings, the sand gets heated-up. In order to reach good sand mixing conditions, the sand needs to be cooled down to 40 – 45 ºC. Evaporative coolers are used with turbulent and fluidised beds, as well as heat-exchangers. If shake-out is done using the vibrating transporters of revolving drums, the cooling can occur at the same time.

If a fluidised bed cooler is used, the drying air may be heated using gas or electricity. The average treatment time in the bed is 10 minutes. In general, the sand enters the fluidised bed with a humidity of 2-3 % and a temperature of 250-300 ºC. Temperature and humidity control may be performed before the fluidised bed cooler with a subsequent addition of controlled amounts of water. This allows minimisation of the amount of fines that are removed during the fluidised bed drying. The fines contain bentonite that may be re-activated. The level of humidity of the return sand needs to be kept between 2 % and 2.2 % at 35 ºC. Consequently, during storage, the bentonite contained in the cooled and wet sand starts to activate and, during the mixing, the water and bentonite that need to be added are reduced, as is the cycle time.

A good homogenisation of the sand allows a constant sand quality and better and easier sand preparation. Homogenisation systems consist of the use of a few small silos instead of one big one, or in the re-circulation of the sand in the silo.

In systems using chemically bonded cores, the mixing of the core sand may have a negative effect on the sand quality, depending on the binder type and the amount of core sand mixed. The negative effects are more significant with acidic and alkaline cores, than compared to neutral systems (SO_2-epoxy, PUR-cold-box). During shake-out, core sand and moulding sand will inevitably get mixed. Uncured cores and non-broken cores, however, may be left out or taken out of the sand before feeding back to the primary regeneration.

Achieved environmental benefits
Reduced usage of primary materials (sand and bentonite), reduced amount of material for disposal.

Environmental performance and operational data
While the level of new sand addition is governed by a number of factors, the usual range is 10-20 % of the poured metal weight. However, it is more convenient to consider new sand additions as a percentage of sand throughput. For most foundry processes, a 5 % addition is considered sufficient, but many foundries work at lower rates.

For a green sand monosystem, regeneration ratios of 98 % may be achieved. Systems with a high degree of incompatible cores, may achieve a regeneration ratio of 90-94 %.

Cross-media effects
Sand regeneration uses electricity, therefore it increases the overall electric energy consumption of the installation. Since mechanical techniques are mainly applied, this increase is low.

Sand cooling and the separation of fines leads to dust-laden exhaust gas. The exhaust needs to be filtered to prevent dust emissions. The collected dust is sent to disposal or reused (see Section 3.2.1.4.4.14).

Technical considerations relevant to applicability
Generally applicable. This technique is applicable to all green sand foundries, in new and existing installations.

Economics
The potential cost benefit of reclamation for a foundry that does not currently reclaim its sand is summarised in Table 3.18.

Table 3.18: Cost benefits from primary reclamation

Description	Cost (EUR/tonne of sand)
Average price of silica sand	32.64
Average cost of waste sand disposal	14.56
Total cost of sand purchase and disposal	**47.2**
Estimated depreciation cost to recoup equipment expenditure in one year	18.24
Average operating cost	7.76
Anticipated cost saving in first year	**21.2**
Anticipated cost saving in subsequent years	**39.44**
(UK estimation 1995)	

The investment for a mixer, dosing unit and process control unit is in the range of EUR 0.05-1 million. The investment for the size reduction of core-breaks is EUR 0.1 million, although this is only applied if the size reduction cannot be done in an available mechanical or pneumatic regeneration unit. Operational costs (on a yearly basis) can be estimated at 5-10 % of the investment cost.

Driving force for implementation
- Many foundry operators state the reduction in costs as the sole reason for starting various sand reclamation programmes. Regulations encourage a reduction in the amount of dumped material, through an increase in disposal costs.
- Legal requirements.
- Local conditions.

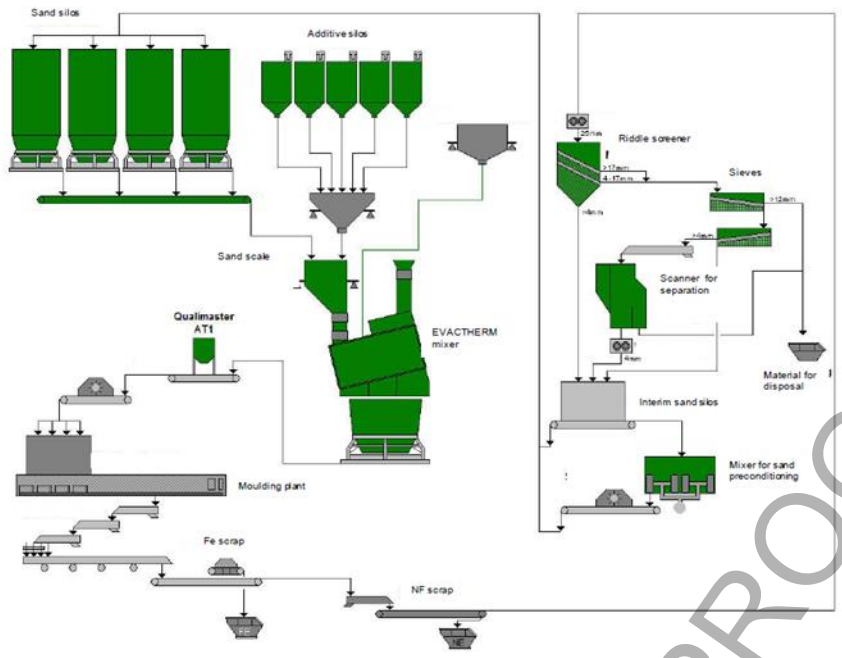
Example plants
Primary reclamation is used by virtually all green sand foundries, though the degree of sophistication of the reclamation plant varies widely; from a simple manual operation to one fully automated with computer-controlled equipment.

Reference literature
[29, ETSU 1995], [30, ETSU 1995], [37, FEAF 1999], [38, VITO 2001], [42, IHOBE 1998], [47, EU Thematic Network Foundry Wastes 2001], [49, Inasmet and CTIF 2002] [169, TWG 2021]

3.2.1.4.4.2 Low-waste green sand reconditioning

Description
Green sand reconditioning in aluminium foundries is carried out using a scanner for identifying impurities in green sand based on brightness/colour. These impurities are separated from green sand using an air blast pulse.

Technical description
In foundries, process-related factors cause an accumulation of impurities in the moulding material in sand casting. In standard sand regeneration systems these impurities (core sand, insulating material, metal scrap) cannot be separated sufficiently from the moulding material. Significant agglomeration of impurities creates a necessity to dispose of comparatively high amounts of moulding material and refresh the system with new silica sand and clay binder. A new sand regeneration technique achieves a more complete separation of impurities from the moulding material (Figure 3.19).



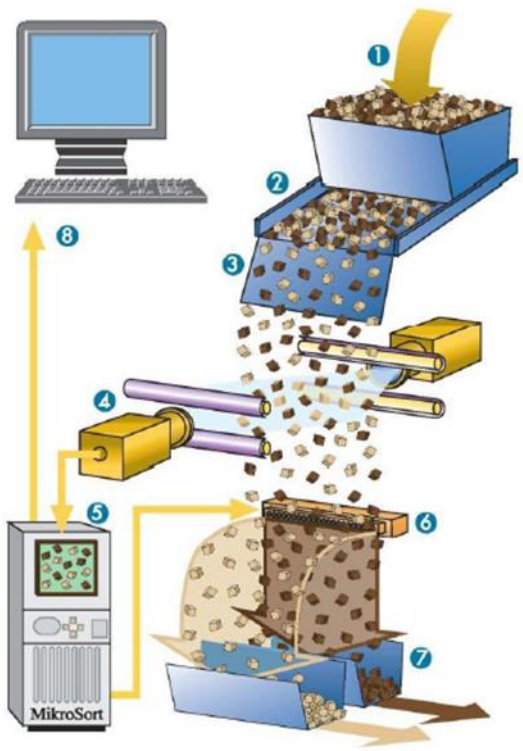
Source: [133, DE UBA 2014]

Figure 3.19: New green sand regeneration plant at an aluminium foundry (key components in green)

Key components are mixers, silos, riddle screeners and a scanner for separating impurities from green sand based on the brightness/colour of the material (Figure 3.20).

Source: [133, DE UBA 2014]

Figure 3.20: Device for optical detection and separation of impurities from green sand



Legend:
1: Input feed (mixture).
2: Vibration chute to widen input material.
3: Falling distance.
4: Camera system for identification of components.
5: Computer system for image processing and steering of separation process.
6: Blast pipe band for separation of detected component via blast impulse.
7: Separation boxes.
8: Visualisation.

Source: [133, DE UBA 2014]

Figure 3.21: Process scheme of the device for optical detection and separation of impurities

Organic bonded sands are kept separately from inorganic bonded sands.

Achieved environmental benefits

- Minimisation of waste sand.
- Reduction of raw material consumption (resource conservation for silica sand and bonding clay).
- Significant reduction of heavy-duty transport.

Table 3.19: Reduction potential using low-waste green sand reconditioning

Parameter	Potential in case of full capacity operation for the example plant
Reduction of used sand for disposal	12 650 t/y
Reduction of raw material consumption: silica sand	13 800 t/y
Reduction of raw material consumption: clay binder	92 t/y
Reduction of CO_2 emissions due to reduction of transport	140 t/y
Source: [133, DE UBA 2014]	

The following operational data were reported.

Table 3.20: Operational data (in case of full capacity operation for the example plant)

Maximum licensed operating hours:		8 760 h
Operating hours:		6 570 h
Capacity sand preparation plant:	70 t/h	460 000 t/y
Without new technique:		
- amount of new sand:	ca. 3 %	13 800 t/y
- amount of disposed sand:	ca. 3 %	13 800 t/y
With new technique:		
- amount of new sand:	0.25 %	1 150 t/y
- amount of recycling sand (no disposal):	0.25 %	1 150 t/y
Reduction of new sand consumption:		12 650 t/y
Reduction of disposal of contaminated sand:		13 800 t/y
Source: [133, DE UBA 2014]		

Environmental performance and operational data
See Achieved environmental benefits above.

Cross-media effects
None.

Technical considerations relevant to applicability
Applicable at all aluminium foundries with a green sand system and moulding plant.

Economics
The following economic data were reported.

Table 3.21: Economic aspects of green sand preparation

Total investment:			4.44 Mio €
Cost reduction per year: ca.			1.18 Mio €:
- New sand costs	12 650 t	45 €/t	569 250 €/y
- Disposal sand costs:	13 800 t	43 €/t	593 400 €/y
- Total sand costs:			1 162 650 €/y*
- Bentonite costs:	92 t	228 €/t	21 000 €*
Source: [133, DE UBA 2014]			

Driving force for implementation
- In addition to resource efficiency improvement, technical advantages were also achieved by means of the new sand preparation system, which are of great importance in foundry production:
  - significant reduction in the consumption of bentonite binders and water in the moulding material;
  - fine-grained moulding sand composition achieved, resulting in smooth surfaces in the castings.
- Reduction of surface defects from impurities accumulated in the moulding material.

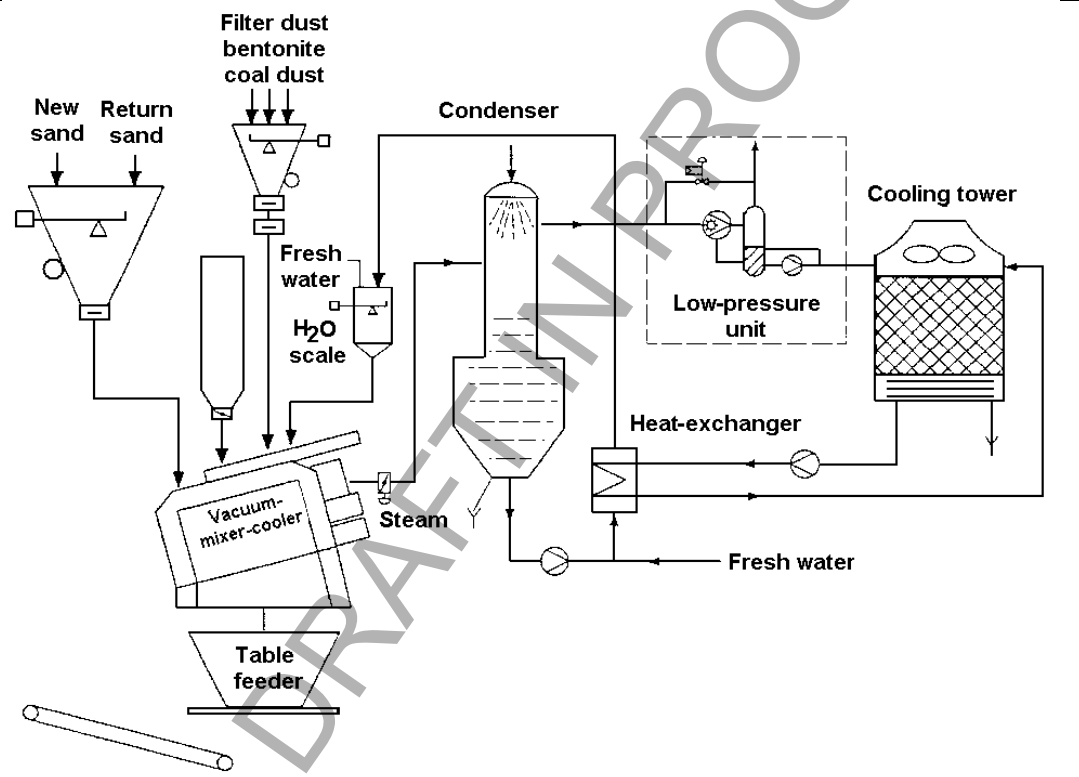
Example plants
Ohm&Häner Metallwerk GmbH & Co KG, Drolshagen, DE.

Reference literature
[133, DE UBA 2014]

3.2.1.4.4.3 Preparation of clay-bonded sand by vacuum mixing and cooling

Description
Mixing and cooling processes are combined into a single process step by operating the sand mixer under reduced pressure, which results in cooling by the controlled vaporisation of the water.

Technical description
The mixing and cooling process are combined into a single process step. This is achieved by operating the sand mixer under reduced pressure, which results in cooling by the controlled vaporisation of the water. The special mixer needs to be hermetically closed. It has a pressure casing and is connected to a vacuum system. The layout of the system is given in the following figure.



Source: [105, Drews, B. 1996]

Figure 3.22: Moulding-sand preparation plant with vacuum mixer-cooler

As compared to a normal mixing plant (Figure 2.32), this technique does not require a separate cooler and associated equipment. The vacuum plant therefore is a more compact size. Since the total airflow is reduced, the vacuum installation has a smaller central dust extraction filter. The size and energy consumption of the filter are 50 % of that of a conventional plant. The reduction of the airflow, results in a reduced removal of active bentonite and thus in an overall reduction of additive consumption. Due to the enclosed operation, the technique is not affected by outside climatic conditions.

The use of steam in the absence of air leads to a quick activation of the bentonite, resulting in a very quick attainment of the optimal compressive strength for the bonded sand.

Water is added in two separate stages:

- water to moisten the return sand to the prepared sand moisture content;
- water to cool the sand by vaporisation to the required temperature of 38-40 ºC.

The disadvantage of the system is the operation and management of the vacuum system. The process also affects the sand technical properties (e.g. compressive and tensile strength, permeability), which diminish after 72 h ('the 72 h effect'). This can be prevented by re-mixing for about 90 s.

Achieved environmental benefits
Reduction of the total airflow results in a reduced off-gas volume and amount of dust for disposal, as well as a reduced consumption of binder as compared to conventional cooling and mixing plants (although this also depends on the efficiency of the regeneration plant). Additionally, the system uses less energy.

Environmental performance and operational data
See Technical description above.

Cross-media effects
None.

Technical considerations relevant to applicability
May not be applicable to existing green sand plants due to technical constraints (sand properties).

Economics
The commercial limits of application appear to be processes where sand cooling is required and which have a capacity of > 60 tonnes of sand per hour.

Driving force for implementation
- Reduction of dust for disposal and minimisation of additives consumption. Limitation of space.
- Legal requirements.
- Local conditions.

Example plants
In Japan, a vacuum mixing and cooling plant has been in operation since 1993, with a prepared sand throughput of 100 m^3/h.
Various installations are also currently running in Italy, France, Germany and England.

Reference literature
[49, Inasmet and CTIF 2002], [105, Drews, B. 1996], [112, Gerl, S. 2003]

3.2.1.4.4.4 Mechanical regeneration of cold-setting sand

Description
Mechanical techniques (e.g. breaking of lumps, segregation of sand fractions) using crushers or mills are used to regenerate cold-setting sand.

Technical description
Simple mechanical techniques are used for the regeneration of cold setting monosands (e.g. furan sand) and uncured core sand. These techniques include the breaking of lumps, segregation of the sand grains and cleaning by intergranular friction, with consequent dedusting and cooling down to operational temperature. Various types of crushers and mills are used, e.g. impact crusher, jaw crusher, ball mill.

Achieved environmental benefits
A reduction of the amount of sand for disposal and of the consumption of new primary sand.

Environmental performance and operational data
For furan cold setting monosands, regeneration ratios ~~around 78~~ of more than 90 % are reported. The technique can be used for all cold-setting sand, excluding silicate sand. The regenerated sand can be reused in the same moulding cycle, with small additions of new sand to level off quality losses.

Cross-media effects
The regeneration of sand requires additional energy and causes additional dust emissions and residual dust for disposal.

Technical considerations relevant to applicability
May not be applicable to silicate sand.

Economics
No information provided.

Driving force for implementation
- Avoidance of costs associated with the disposal of residues.
- Legal requirements.
- Local conditions.

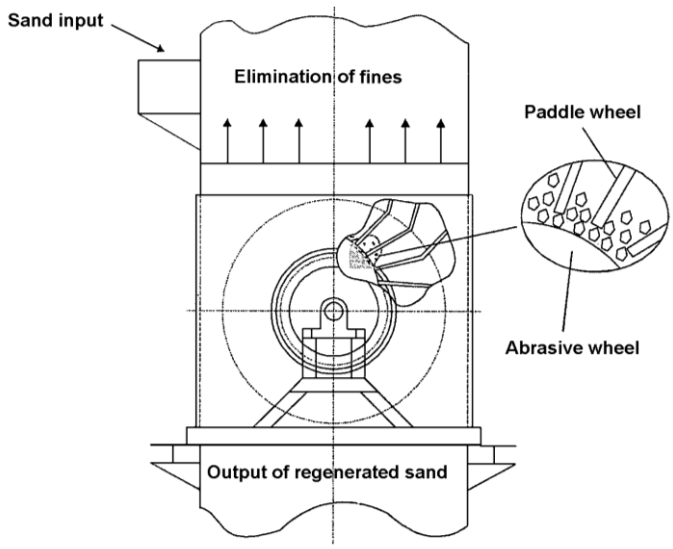
Example plants
Simple mechanical regeneration of furan sand is applied in many foundries around Europe, reported by the following plants: AT009, CZ156, DE032, DE042, DE052, DE057, DE067, FI102, FR107, FR117, IT128, IT131, IT134, PT140, PT141 and SE144~~and is specifically widespread in Germany and Finland~~.

Reference literature
[57, Umweltbundesamt 2002], [100, TWG 2002], [169, TWG 2021]

3.2.1.4.4.5 Cold mechanical regeneration of clay-bonded or chemically bonded sand using a grinding wheel

Description
Use of a rotating grinding wheel to remove clay layers and chemical binders from used sand grains.

Technical description
This is a widely applied commercial grinding system (see Figure 3.23). The system was originally developed to regenerate mixed bentonite-organic sands. In this system, a horizontally rotating grinding wheel is used to remove the hard oolitic bentonite layer from the sand. The grinding can also remove chemical binders from sand grains. Around the grinding wheel is a slowly rotating paddle wheel, which continuously moves the sand onto the grinding wheel. Above this, a dedusting unit extracts the dusts and the fines. To be fit for processing, the sand must be dry. A pre-drying step, using a fluid bed or other dryer, is required to bring the moisture content down to below 0.2 %.



Source: [42, IHOBE 1998]

Figure 3.23: Cold mechanical regeneration using grinding

The off-gas stream of the regenerator is dedusted using a cyclone and a bag filter. The filter dust contains residual active bentonite and coal dust. It may be recirculated into the core-making, thereby allowing a reduction in the use of lustrous carbon. Furthermore, the moulds demonstrate better technical quality (wet tensile strength, flowability), due to the remaining bentonite content, which furthermore leads to a reduction in the amount of scrap moulds and a reduction in finning on the castings.

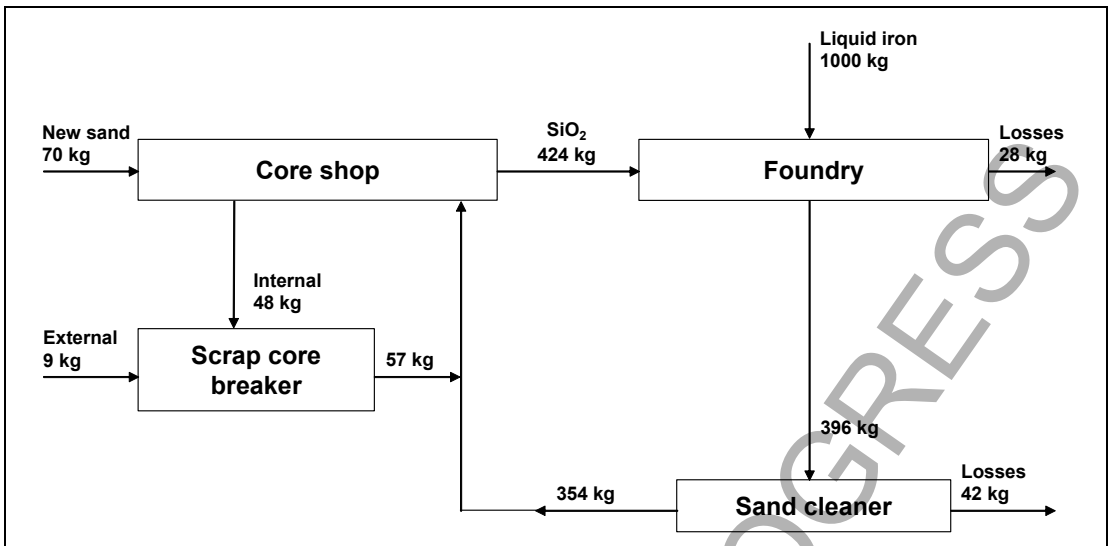
Achieved environmental benefits

- A reduction of the amount of sand for disposal and of the consumption of new primary sand.
- A reduction in the consumption of lustrous carbon, in the case of green sand.
- An increase in moulding sand properties, resulting in a reduction in the number of scrap moulds and in the number of rejects in finished castings.

Environmental performance and operational data

For clay-bonded sand, the maximum regeneration rate is 65-75 %. This corresponds to the quartz grain content of the material. For a chemically bonded sand, the amount of recyclable quartz sand is 90-95 %.

The total sand circuit flow and the need for new sand depends on the amount of cores (and core sand) used. Therefore, data on the sand circuit are very process-specific. Figure 3.24 gives data for a plant in the Netherlands.



Source: [47, EU Thematic Network Foundry Wastes 2001]

Figure 3.24: Operational data on the sand circuit of a Dutch green sand foundry

In general, waste green sand consists of about 80 % quartz sand grains and about 20 % fines (bentonite, coal dust, etc,). Out of 100 % waste sand, about 70 % is transferred back to the core-making as reclaimed sand. The degree of efficiency with regard to quartz is about 88 %.

The filter dust contains approximately 40 % active bentonite, which has a loss of ignition (LOI) of 17 % and contains 43 % fines. Reuse of the dust in the sand plant results in a reduced requirement for lustrous carbon by up to 30 %. Results of the improved sand quality at the example foundry show the amount of scrap moulds were practically halved.

The cyclone dust (20 % of regenerated green sand weight) contains 25-30 % bentonite and high levels of organics, but its chemical composition falls outside the required specification to allow its re-use as a secondary construction material. In the Netherlands, a specific application in cover layers on disposal sites is allowed. In other regions, this fraction will need disposal of. However, legislation limiting the organic content of material for disposal, may limit the disposal options.

The grinding of the sand causes accelerated wearing of the sand grains. This and the recirculation of the filter dust cause shifts in the grain size distribution of the sand. The overall sand composition therefore needs good control and follow-up.

Cold mechanical regeneration is mainly applied for removing bentonite layers from green sand and for removing chemical binders in no-bake systems. The grinding technique is the most widely applied cold mechanical treatment. Vibration and impact systems are also used for chemically bonded sands but produce sand of only low or average quality. These techniques are more appropriate for the conventional sand loop (primary regeneration). The secondary regeneration of green sand has limited implementation.

Cross-media effects
The regeneration of sand requires additional energy and causes additional dust emissions and residual dust for disposal. However, the use of regenerated sand in the moulding process allows a reduction in the amounts of lustrous carbon used.

Technical considerations relevant to applicability
Generally applicable.

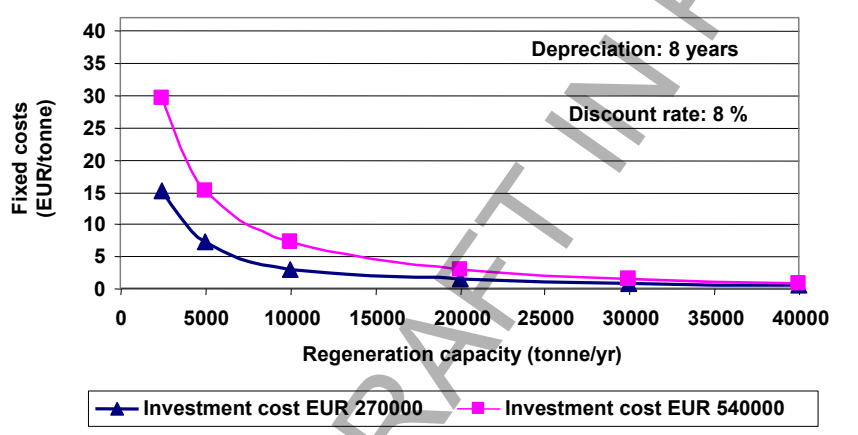
Economics

The investment cost for a 50-tonne/day unit, including drying, cooling, regeneration unit, cyclone and bag filter is around EUR 1 135 000. Data from Germany (1996) state an investment cost of EUR 600 000 for a 1.5 tonne/h unit.

The consumption levels are as follows (based on yearly average figures):

Electricity:	39	kWh/tonne;
Natural gas:	3	Nm^3/tonne (depending on the moist input of the sand);
Compressed air:	36	Nm^3/tonne;
Wear parts:	1.18	EUR/tonne;
Manning level:	0 %;	
Maintenance:	routine.	

Cost curves for the mechanical regeneration of organic bounded sand are given in Figure 3.25. Fixed costs vary according to the total capacity and investment. Variable costs can be up to around EUR 11/tonne, although the actual costs depend on the specific installation and local conditions. The total costs (fixed plus variables) range from EUR 12-40/tonne of regenerated sand, depending on the size and type of equipment.



Source: [34, IfG 1996]

Figure 3.25: Fixed costs in euros per tonne of regenerated sand, for the mechanical regeneration of sand with cold-setting binders

Driving force for implementation

- ~~Legislation using~~ hHigh disposal fees aiming to reduce the amount of residues for disposal.
- Legal requirements.
- Local conditions.

Example plants

- De Globe, Weert, the Netherlands, 60 tonnes per day plant using two lines, in operation since 1995
- Eisenwerk Brühl, Brühl; D (1.5 tonne/h), 1999
- Giesserei Fritz Winter GmbH & Co KG, Stadtallendorf, D (9.5 tonne/h)
- Mercedez-Benz AG, Mannheim, D (9 tonne/h)
- Reported in the SF data collection by plants: DE054, DE055, DE067, DE068, DE073, DE074, IT1125, IT126, IT128, IT130, IT131, IT132, IT134, IT157, PL135 and PT140.

Reference literature

[34, IfG 1996], [38, VITO 2001], [42, IHOBE 1998], [45, De Globe B.V. 1999], [47, EU Thematic Network Foundry Wastes 2001], [55, Gemco 1999], [169, TWG 2021]

3.2.1.4.4.6 Cold mechanical regeneration using an impact drum

Description
Use of an impact drum with a spinning internal axis, equipped with small blades, for abrasive cleaning of sand grains.

Technical description
This mechanical regeneration technique is based on intergranular grinding of the sand and gives the best results for chemically bonded monosand. The sand is fed into a drum with a spinning internal axis, equipped with small blades. Sand grains are impacted against the drum wall and against each other. This impact produces a mechanical abrasive cleaning action. Fines are removed with the exhaust gas. The impact drum operates in a batch wise regime. The installation of two units allows continuous operation.

When applied on a mixed bentonite-organic sand, the regeneration is preceded by a magnetic separator, to remove green sand. Due to the presence of unreacted bentonite, the green sand shows a very weak magnetism, which allows a magnetic separation to be carried out. The regeneration system allows the introduction of a limited amount (15 %) of uncured core sand (core breaks from production). The combination of magnetic separation and impact drum cleaning allows an optimised chemically bonded sand regeneration from a mixed sand flow, with re-use of the regenerated sand in core-making.

Achieved environmental benefits
Internal re-use of core sand, therefore limiting the amount of material for disposal and the need for raw materials.

Environmental performance and operational data
The regeneration drum has a batch wise regime, with a 20 minute treatment time for each 1.5 tonne sand charge. The energy consumption of the full installation (including magnetic separation, exhaust treatment, sand transport) is 55 kWh/tonne of treated sand, of which 35 % may be attributed to sand transport and feeding. The installation uses compressed air at 48 Nm^3/tonne sand.

The regenerated sand is of the following quality:

- average grain size: 0.30-0.33 mm;
- share of fines: 0.4-1 %;
- pH: 8.7;
- loss on ignition: 0.25-0.5 %.

Cores made with 100 % regenerated sand have acceptable properties. In practice, 10-70 % of regenerated sand is used for new cores, the actual amount depending on the core type.

Dust generation in the installation is 10 % of the regenerator input. This dust is collected using a cyclone (90 %) and a bag filter (10 %).

The combined separation-regeneration technique can be applied for the treatment of mixed green sand and chemically bonded sand. Regeneration is performed on the chemically bonded sand flow and may include uncured core sand. The technique may be applied in new and existing installations.

Cross-media effects
The regeneration of sand requires additional energy, and causes additional dust emissions and residual dust for disposal.

Technical considerations relevant to applicability
Generally applicable.

Economics
Investment costs for a 3 tonne/h unit with 1 impact drum, magnetic separation, exhaust gas dedusting and transport and a feeding system are EUR 1.3 million. Operational costs for this unit are EUR 10/tonne. These include energy consumption, wear and tear of parts, maintenance and disposal of residues. This represents a net benefit of EUR 37/tonne, compared to the costs of new sand purchase and used sand disposal (both incl. transport) (2002 data).

For a 380 tonne/day unit in France, an operational cost of EUR 15/tonne was quoted. For this plant this represents a net benefit of EUR 18/tonne, compared to the costs of new sand purchase and used sand disposal (both including transport) (2002 data).

Driving force for implementation
- ~~Legislation using~~ ~~h~~High disposal fees aiming to reduce the amount of residues for disposal.
- Legal requirements.
- Local conditions.

Example plants
This technique is used in the following plants:

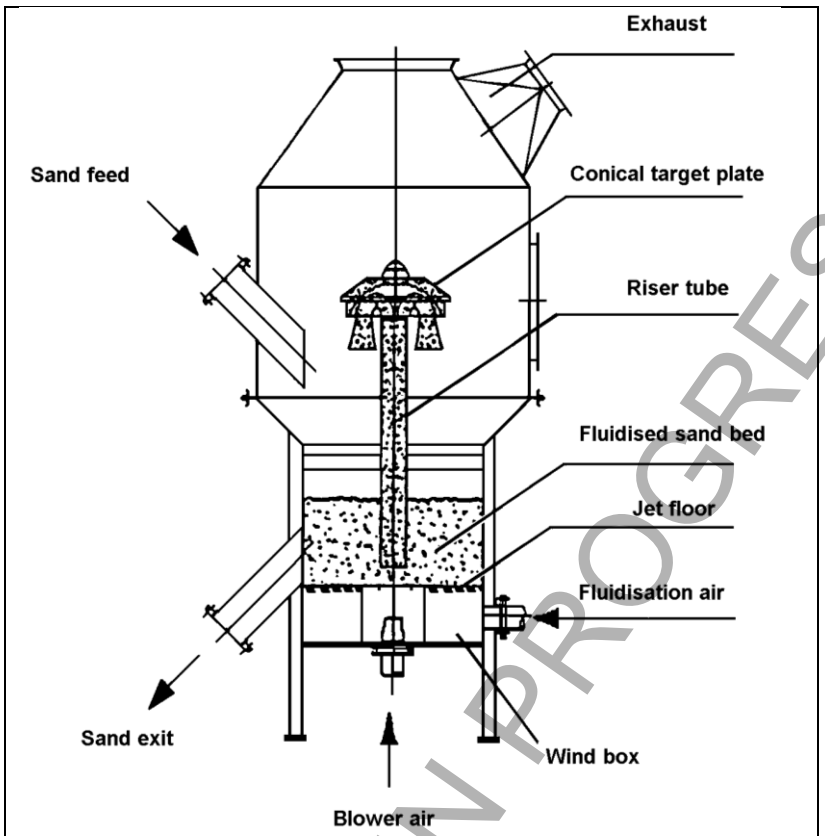
- PSA, Sept-Fons (FR): 6 magnetic separators and 2 grinders, working alternatively.
- GF, Leipzig (DE): 2 magnetic separators and 1 grinder.
- Döktas – Turkey: 5 magnetic separators and 2 grinders.
- Reported in the SF data collection by plants: AT013, AT016, BE019, BE022, BE023,CZ024, DE036, DE037, DE060, DE072, ES088, FI103, FR105, IT124 and IT130.

Reference literature
[84, Spitz et al. 2002], [40, Kirst, J. 1999], [57, Umweltbundesamt 2002], [169, TWG 2021]

3.2.1.4.4.7 Cold regeneration using a pneumatic system

Description
Removal of binders from the sand grains using abrasion and impact. The kinetic energy is provided by a compressed air stream.

Technical description
In a pneumatic system, binders are removed from the sand grains using abrasion and impact. The kinetic energy is provided by a compressed air stream. This results in a simultaneous dedusting. The advantage of this type of system is that the direction and velocity of the sand can be controlled. Due to the low energetic efficiency of air compression, the energy consumption is higher compared to the purely mechanical treatment. The principle of the reactor is depicted in Figure 3.26.



Source: [40, Kirst, J. 1999]

Figure 3.26: Cold mechanical regeneration using a pneumatic system

The reactor uses a fluidised bed with a central raiser tube. The sand is blown into the tube using compressed air and impacts on either a rubber deflector plate or a conical target plate. From there, the sand falls down again and the cycle starts over again. The cleaning happens through intergranular abrasion, abrasion against the impact plate and through 'pure' impact. The shape of the plate determines the main cleaning mechanism: impact (bell-shape) or abrasion (conus). The generated dust is removed with the airflow over a bag filter. Treatment is performed as a batch system or through a series of coupled pneumatic units. In this case, the cleaned sand is sucked out of the reactor through a deflector below the impact plate.

Achieved environmental benefits
Reduction of the amount of sand for disposal and of the consumption of new primary sand.

Environmental performance and operational data
A waste sand mix of green sand with chemically bound core sand having the following characteristics: 8-12 % fines content, 3-5 % LOI, < 2 % humidity; produces a regenerate with the following characteristics:

- regenerate yield, based on SiO_2 content of waste sand: 70-80 %;
- ultra fines content (< 0.063 mm): max. 2 % ;
- fines content: < 2 %;
- loss on ignition: < 0.5 %;
- average grain size: unaltered.

The technique uses a modular installation build-up, using 0.8-1.2 t/h basic units. The supplier mentions an electric energy consumption of 15-20 kWh/t (excluding dedusting equipment). German operational data give an electric energy consumption of 41 kWh/t for a 8 t/h unit and 62 kWh/t for a 0.75 t/h unit. Reported sand regeneration efficiencies based on sand input range from 65 % to 85 %. Spanish data give a total energy consumption of 120 kWh/t of regenerated sand for a 1.2 t/h unit.

The pneumatic system can be used for the regeneration of organic mixed and monosands and mixed sand containing bentonite. It also finds application as a pre- or post-treatment in combined mechanical-thermal-mechanical treatment Here, the main use is the removal of residual dust from the sand grains and cooling. The regenerated sand from simple mechanical regeneration may be used in mould making (using 100 % regenerated sand) or mixed with new sand in core-making (using 40-60 % regenerated sand).

Furthermore, the technique may be applied for the regeneration of core sand of the CO_2-water glass type from aluminium foundries. This is discussed separately below.

Cross-media effects
The regeneration of sand requires additional energy and causes additional dust emissions and residual dust for disposal.

The general evaluation of internal regeneration versus external re-use and the corresponding cross-media effects are discussed separately below.

Technical considerations relevant to applicability
Generally applicable.

Economics
Investment costs for a single 0.8-1.2 tonne/h unit are EUR 330 000. Operational costs are estimated at EUR 22/tonne, which gives a total regeneration cost of EUR 36.5/tonne of sand (1998 data).

Driving force for implementation
- ~~Legislation using~~ ~~h~~High disposal fees aiming to reduce the amount of residues for disposal.
- Legal requirements.
- Local conditions.

Example plants
This type of equipment is built by various suppliers: e.g. KGT Jet Reclaimer, Künkel-Wagner GmbH Turbo Dry, Kernfest Webac AB. The technique is used in several plants in Western Europe and China. Reported in the SF data collection by plants: AT017, AT018, DE038, DE044, DE056, DE058, DE068, DE069, DE077, ES088, ES095, ES098, FI103, FR104, IT121, IT126, IT128, IT129 and SE153.

Reference literature
[14, CAEF 1997], [34, IfG 1996], [37, FEAF 1999], [38, VITO 2001], [40, Kirst, J. 1999], [42, IHOBE 1998], [169, TWG 2021]

3.2.1.4.4.8 Thermal regeneration

Description
Use of heat to burn binders and contaminants contained in chemically bonded and mixed sand. This is combined with an initial mechanical pretreatment to bring the sand to the correct grain size and remove any metallic contaminant. In the case of mixed sand, the share of chemically bonded sand should be high enough.

Technical description
Thermal regeneration uses heat to combust binders and contaminants. All thermal processes need an initial mechanical step in order to bring the sand to the correct grain size and to screen out any metallic contaminants. This pretreatment may also involve a (partial) abrasion of bentonite and dust removal. The heating of the sand is usually achieved by means of a fluidised bed furnace, operating at temperatures mostly between 700 ºC and 800 ºC. Rotary kilns or multiple-hearth furnaces are also used. Heat may be provided by gas combustion, electric

heaters or by short wave infra-red emitters. The throughput of these systems ranges from 250 kg/h to more than 5 t/h.

The emerging gases are combusted in order to eliminate carbon monoxide and any VOCs that may be present. This may be done in the freeboard of the furnace, if it is large enough, by adding complementary air or by gas-fired afterburners. If the temperature of the combustion gases is not high enough or if the time during which the gases are at a high temperature is not sufficient, a separate afterburning device is added. In all cases, emissions can be considered as insignificant.

The exhaust gases are filtered, mostly by means of fabric filters. Therefore cooling is needed, which may be done using water injection, heat exchange/recovery or by mixing with air naturally entering through openings/slits etc. The cooling may incorporate a preheating of the fluidisation air.

Achieved environmental benefits
Reduction of the amount of sand for disposal and a reduction in the consumption of new primary sand.

Environmental performance and operational data
The sand is usually heated to temperatures of 700-850 ºC. Theoretically, this requires 200 kWh/t. In practice, energy uses of 150-350 kWh/t are reported, depending on the energy recuperation and the calorific value of the sand.

Operational data from three thermal regeneration plants, treating various types of sand and of various capacities are given in Table 3.22.

Table 3.22: Operational data of 3 German reference foundries applying thermal sand regeneration

Property	Units	Plant		
Reference plants		**Foundry K**	**Foundry L**	**Foundry M**
Type of sand		Cold-box core units	Green sand moulding, Cold-box cores	Handforming in furan bonded sand
Regeneration unit supplier		CEC/VAW	Richards	Siempelkamp
Technique		Multiple hearth furnace (500 ºC) with sieving and classification	Fluidised bed furnace (780 ºC), mechanical size reduction and dedusting	Fluidising combustion chamber with magnetic pre- separation, simultaneous processing of sand and dust from mechanical furan sand regeneration
Sand throughput	t/h	12 – 16	1.0	2.0 used sand, 0.5 dust
Capacity	t/yr	28600	3840	5000
Regeneration ratio, based on used sand throughput	%	95	95 (99 (1))	95
Application of regenerated sand		Core-making	Core-making	Mould and core-making
Quality criteria for regenerated sand		Dust <1 % AFS 60 – 70 LOI <0.1 %	Identical to new sand F33	LOI <0.5 % pH 6.0 – 6.5 Mould strength upon addition of 1 % binder and 0.3 % harder: 350 N/cm² after 24 h
Consumption of electrical energy	kWh/t	119	65	
Consumption of natural gas	m³/t	24.5	38	
Residue production	t/year	660	Dust: 10 Bentonite sand: 1700	200
Final destination of residues		Mining cavities	Cement production	Construction industry/disposal site
Waste gas flow	Nm³/h	7000	16509	6560
Waste gas temperature	ºC	75	60	35

Type of filter		Post combustion and fabric filter	Fabric filter	Lime injection + fabric filter
Emission levels (2)				
- dust	mg/Nm³	0.1	4.9	0.4
- C_{total}		2.2	5.7	10
- CO		2.3	1.6	0
- O_2	%	14	n.d	20.95
- PCDD/F	ng TEQ/Nm³	0.006	n.d	n.d.

(1) The higher recuperation rate (99%) is reached if only in-house core sand is regenerated. A rate of 95 % applies for mixed internal and external core sand
(2) Emission levels are calculated average values from continuous monitoring data over a period of several hours, during sampling for dust or PCDD/F
Source: [57, Umweltbundesamt 2002]

The performance of the regeneration technique and the quality requirements for the regenerated sand are evaluated on a location-specific basis. Specific data may be found in the references: [85, Stephan, J. 1996], [86, Stephan, J. 1997], [87, Stephan, J. 2000].

Thermal systems are normally used for chemically bonded sand systems and mixed sand systems, providing the share of chemically bonded sands (cores) is high enough. Nevertheless, a distinction can be made:

- Some binders may leave inorganic salt residues at the grain surface. When the temperature increases above the melting point, these spread out over the sand surface and may cause the sintering of the sand grains upon cooling. Known examples are resol resin and silicate resin-bonded sands.
- The thermal recycling of furan resins causes the emission of SO_2 if sulphonic acids are used as a hardening agent. The temperature of the exhaust system must be sufficiently high enough to prevent sulphuric acid condensation. If the emission is high, a wet flue-gas cleaning may be needed. Phosphor (from the phosphoric acid used as a hardener) does not evaporate but remains on the surface in salt form. This may lead to P accumulation upon recycling. If the P concentration rises above 0.5-0.7 %, a metallurgical reaction may occur, causing the rejection of the casting.

The degree of implementation of thermal regeneration is low compared to mechanical regeneration. In Germany, only 10 installations were reported to apply this technique in 1999 (compared to 200 mechanical units).
~~The Siempelkamp thermal regeneration unit in Krefeld has the ability to treat foundry dust along with the waste sand. Tests have been run on other mineral waste types as well.~~

Cross-media effects
Thermal regeneration requires fuel and generates emissions of dust and combustion related compounds (NO_X, CO; and in the case of oil: SO_2).

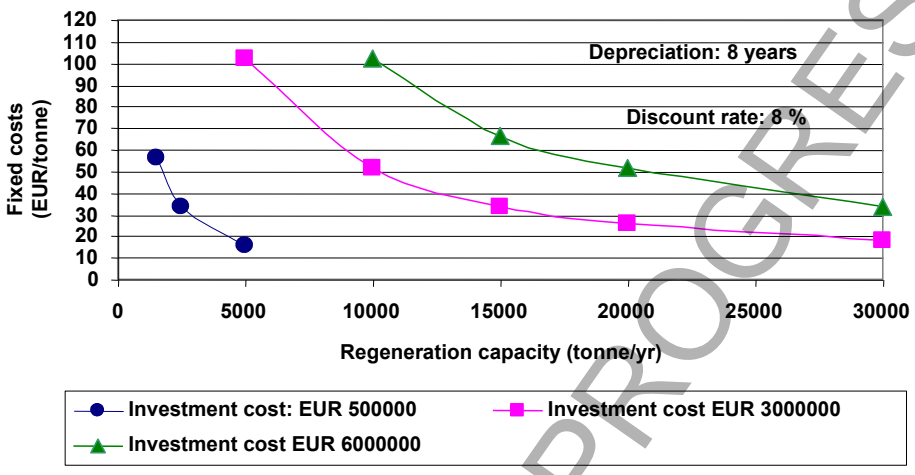
The high energy consumption and complexity of the installation are balanced by a low wearing of the sand grains and the recovery of the dust in a thermally inert form.

Thermal regeneration of furan bonded sand with paratoluenesulphonic acid as a hardener, requires flue-gas cleaning: i.e. ~~a~~ fabric filter, post-combustion of CO and/or the adsorption of SO_2.

Technical considerations relevant to applicability
Generally applicable.

Economics
Investment costs vary according to the size and type of equipment and are given in Figure 3.27. The data relate to thermal systems with a mechanical pre- or post-treatment step, as well as for

intensive mechanical regeneration (e.g. grinding units). Small scale installations have a capacity of 0.75 t/h or 1 500 t/y. A medium size foundry will produce between 2 500 t/y and 5 000 t/y. For a small-scale unit, the capital cost (with 8 years amortisation and 8 % interest rate) would be EUR 55/t. These costs do not include expenses for energy, personnel nor for the disposal of residues (all data from 1996).



Source: [34, IfG 1996]

Figure 3.27: Fixed costs in euros per tonne of regenerated sand for thermal regeneration and high level mechanical regeneration of mixed sands

Driving force for implementation

- ~~Legislation using~~ ~~h~~High disposal fees aiming to reduce the amount of residues for disposal.
- Legal requirements.
- Local conditions.

Example plants

~~- Fluidised bed, Metaalgieterij Giesen, the Netherlands~~
~~- Fluidised bed centralised regeneration plant, Bielefeld, Germany~~
~~- VAW Alucast GmbH, Dilingen, Germany, system CEC/VAW~~
~~- Werner Rietschle GmbH, Schopfheim, Germany, system Richards~~
~~- Siempelkamp Giesserei gmbH & Co, Krefeld, Germany, system Siempelkamp~~
~~- Sofogir, Ronchamp (F) system Regetherm 500~~
~~- Duranton Sicfond, Vénissieux (F), system Richards~~
~~- FOAM, Leumann (I), system Eco-rec~~
~~- Fonderie Bréa, Montluçon (F).~~

Reported in the SF data collection by plants: AT011, DE065, FR104, FR106, FR112, FR114, IT129 and PT139.

Reference literature

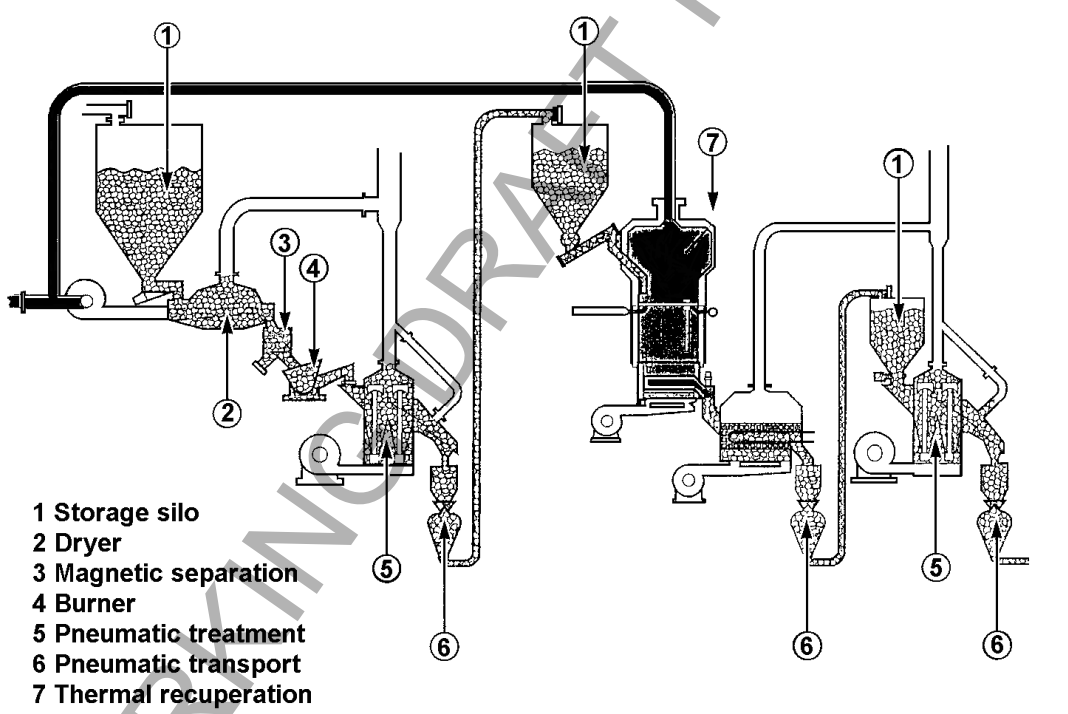
[3, Schneider, B. 1993], [14, CAEF 1997], [33, ERM Lahmeyer International GmbH 1999], [42, IHOBE 1998], [46, Metaalgieterij Giesen B.V. 1996], [85, Stephan, J. 1996], [86, Stephan, J. 1997], [87, Stephan, J. 2000], [169, TWG 2021]

3.2.1.4.4.9 Combined regeneration (mechanical-thermal-mechanical) for mixed organic-bentonite sands

Description
After pretreatment (sieving, magnetic separation) and drying, sand is mechanically or pneumatically cleaned to remove part of the binder. In the thermal step, organic constituents are burned and inorganic constituents are transferred to the dust or burned onto the grains. In a final mechanical treatment, these grain layers are removed mechanically or pneumatically and discarded as dust.

Technical description
In mixed organic-bentonite sands, cured bentonite and organic binders are present on the sand grains. The dust is composed of active and cured bentonite, coal dust (only for iron foundries), quartz fines and organic binder residues. Mixed sands occur mainly in iron foundries and represent some 75 % of the total used sand production. The regeneration can be performed using mechanical, pneumatic, thermal or combined systems.

The sand is pretreated (sieving, magnetic separation) and dried, in order to reduce the water content to < 1 %. After this, the sand is mechanically or pneumatically cleaned in order to remove part of the binder. In the thermal step, organic constituents are burned, and inorganic constituents are transferred to the dust or burned onto the grains. In a final mechanical treatment, these layers are removed mechanically or pneumatically and discarded as dust. A typical layout for a system using pneumatic treatment and fluidised bed thermal treatment is depicted in Figure 3.28.



Source: [37, FEAF 1999]

Figure 3.28: Mechanical-thermal-mechanical sand regeneration unit

Achieved environmental benefits
Reduction of the amount of sand for disposal and of the consumption of new primary sand.

Environmental performance and operational data
Operational data for a mechanical-thermal-mechanical treatment are given in Table 3.23.

Table 3.23: Operational data of a mechanical-thermal-mechanical treatment system (pneumatic - fluid bed - pneumatic)

Parameter	Units	Foundry N	Foundry O	Foundry P
Sand flow	(tonne/h)	1	2	3
Maximum humidity of the sand input	(%)	1	1	1
Total installed electric power	(kW)	150	215	400
Natural gas	(Nm^3/h)	31	62	155
Thermal treatment - average airflow (fluidisation + combustion)	(Nm^3/h)	700	1200	3000
Treatment temperature	(ºC)	800	800	800
Average treatment time	(min)	20	20	20
Flue-gas flow	(Nm^3/h)	200	300	500
Cooling - type - water flow in the circuit	(m^3/h)	Fluidised bed with water circulation 15	30	75
Sand temperature at exit	(ºC)	30 – 40		
Total energy consumption: - electric - gas		100 260	90 260	70 260
Compressed airflow	(Nm^3/h)	150	210	330
Efficiency of the installation		70 – 80 %		
Regenerate sand quality: - granulometry - loss on ignition		Unchanged ≤0.1 %		
Re-use of the regenerated sand: - mould making - core-making		100 % 70 – 80 %		
Source: [37, FEAF 1999]				

German data for a 85 000 tonne/y (13-15 tonne/h) installation provide the following off-gas composition:

- SO2: 118 mg/Nm³;
- NOX: 150 mg/Nm³;
- total C: 10 mg/Nm³;
- CO: 30 mg/Nm³.

This regeneration technique is used for mixed sands containing bentonite. The economical and technical success of the regeneration depends on the selection of the sand to be regenerated. It is not suitable to regenerate the whole sand volume. Sand which is not thermally damaged can be reused directly for new sand preparation. Its regeneration is not suitable, because active binders and additives would be removed. A selection and separation has to be made during shake-out, before homogenisation. The technique cannot be applied for core sands which disrupt bentonite characteristics (binders of acid nature) or which change green sand characteristics (e.g. water glass sand).

The regenerated sand can be used for core-making in the original process, for cores with low or medium geometrical demands. The applicability for core-making is related to the initial amount of chemically bonded sand. The applicability in other binder systems must be tested in each case. Furthermore, these sands may be applied without restrictions for the replacement of losses in green sand moulding cycles. Restrictions may apply in processes that use water glass or methyl formate bonded sands.

In recent years, various types of installations have been developed for the treatment of mixed sands, but they have not yet found broad implementation in the sector. Some only work on a pilot scale. Others have been developed for a specific foundry and produce a regenerated sand suitable for reuse only in the same process, and results cannot be transposed to other foundries.

Cross-media effects
The regeneration of sand requires additional energy and causes additional dust emissions and residual dust for disposal.

The general evaluation of internal regeneration versus external reuse, and the corresponding cross-media effects, are discussed separately below.

Technical considerations relevant to applicability
Generally applicable.

Economics
Costs for a three-step installation (mechanical-thermal-mechanical) using pneumatic cleaning as the mechanical step (3 tubes in 1 chamber, KGT type Jet Reclaimer) with a capacity of 2.5 tonnes/h are as follows: operational costs (consumption, personnel, maintenance) – EUR 21/t, investment costs (8-year amortisation) - EUR 30/t, thus yielding a total regeneration cost of EUR 51/tonne.

The consumption levels are as follows (1999 data):

- Electricity: 50 kWh/t;
- Natural gas: 18 Nm^3/t (depending on the moisture content of the sand);
- Compressed air: 60 Nm^3/t;
- Wear parts: 5 EUR/t.

Driving force for implementation
- ~~Legislation using~~ ~~h~~High disposal fees aiming to reduce the amount of residues for disposal.
- Legal requirements.
- Local conditions.

Example plants
Halberg Guss GmbH, Saarbrucken (D), thermal-mechanical system. This plant treats 13 – 15 t/h of mixed 30 % organic, 70 % inorganic bonded sand. The organic bounded sand is a 50/50 mixture of Croning and cold-box sand. The regeneration yield on the basis of the amount of used sand treated is 78 %. The regenerated sand is applied for core-making (100 % Croning; 70-100 % cold-box).

The mechanical primary regeneration, separation of chromite (from cores) and quartz sand (both chemically bonded) and thermal/mechanical treatment of quartz sand was demonstrated on a pilot scale in Germany (1993). Separation of both sand types was needed because sintering and eutectics formation occurred in the mixed sand. The plant later closed down due to other economic reasons.

Reported in the SF data collection by plants: AT009, AT013, DE037, DE047, DE073 and ES091.

Reference literature
[4, Schachtner et al. 1993], [17, Winterhalter et al. 1992], [37, FEAF 1999], [40, Kirst, J. 1999], [42, IHOBE 1998], [57, Umweltbundesamt 2002], [120, TWG 2003], [169, TWG 2021].

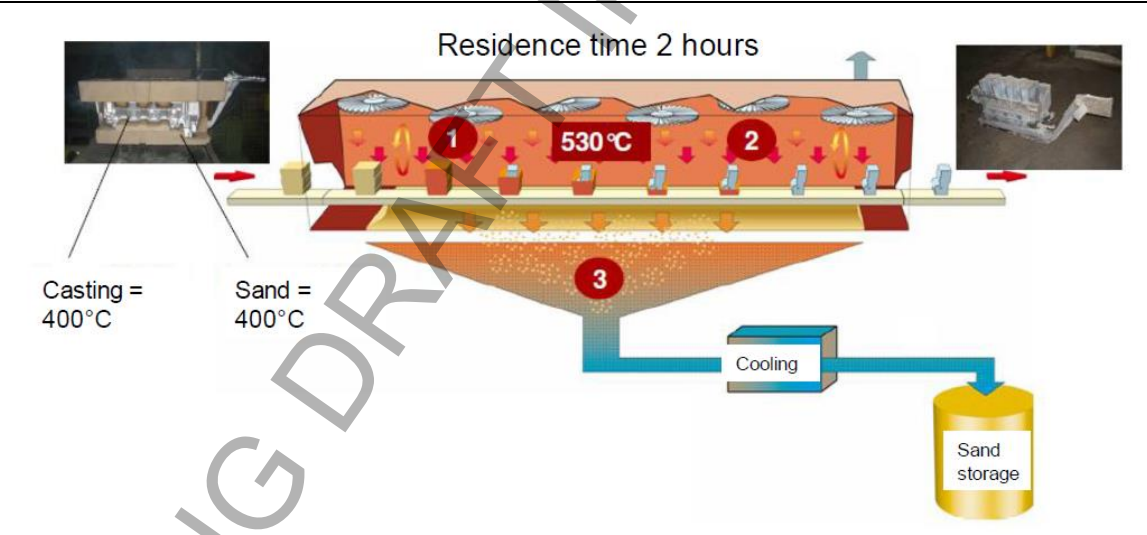
3.2.1.4.4.10 Combined sand regeneration and heat treatment of aluminium castings

Description
After pouring and solidification, mould/casting units are loaded into the furnace. When the units reach a temperature > 420 °C, the binders are burnt, the cores/moulds disintegrate, and the castings undergo heat treatment. The sand falls to the bottom of the furnace for final cleaning in a heated fluidised bed. After cooling, the sand is reused in the core sand mixer without further treatment.

Technical description
This new process uses an automatic system to carry out three foundry steps simultaneously in one automatic system:

- thermal de-coring / sand – casting separation;
- thermal sand regeneration;
- casting heat treatment.

The following figure shows a schematic of the system.



Source: [133, DE UBA 2014]

Figure 3.29: Schematic of the system: 1: separating: castings and sand; 2: annealing; 3: sand reclamation

Immediately after pouring and solidification, the castings are loaded into the furnace for heat treatment. Foundries load the castings within 15 minutes and moulds within 20-25 minutes into the furnace. No cooling, no mechanical sand removal and/or de-coring, and no riser cutting steps are needed.

The binder is burned as a fuel: only the presence of heat above 420 °C and oxygen causes the organic binder to burn and the mould/core will disintegrate. Special axial fans create a pressure drop across the castings (negative pressure) which results in turbulence inside the castings. This allows rapid sand removal from horizontal internal passages such as water jackets, oil passages and other thin cores.

The sand falls to the bottom of the furnace for final cleaning in a heated fluidised bed and will be released to the sand collecting vibratory conveyor underneath the furnace. Sand will be cooled for pneumatic transport back to the core shop. No further treatment is needed before being reused in the core sand mixer. Levels of loss-on-ignition (LOI) of the reclaimed sand are less than 0.07 %.

Castings are thermally processed (casting heat treatment) at temperatures between 485 °C and 535 °C (as specified by customer) and quenched after treatment.

Systems are available as:

- roller hearth furnace (batch type and continuous);
- deep fluidised bed (DFB) ('continuous' batch type); or
- chain type furnace (continuous).

Waste gases are thermally treated in an afterburner at 820 °C to burn nitrogenous gases. Hot exhaust runs through a heat exchanger, preheating fresh air for the fluidiser, air knives, and burners, before being directed to the bag filter.

This technique finds a number of applications, for example:

- castings in aluminium alloy;
- castings with sand;
- core and mould sand with organic binders;
- castings made in any process where sand (silica, zircon, etc.) is used for forming;
- the outer and/or inner contour of the casting (e.g. gravity die-casting process, low-pressure die casting process, precision sand moulds, Croning, no-bake);
- casting heat treatment capacities between ~30 and 180 castings/hour;
- sand removal and reclamation capacities up to > 35 t/hour.

Achieved environmental benefits

Reduced waste and reduced resource consumption by sand recycling

- It is a closed circuit 'core shop – pouring – thermal de-coring – sand reclamation – core shop'. About 97 % of the used sand loaded with the castings into the system's furnace will be transported back to the core shop as clean, regenerated sand.
- All sand from the foundry can be regenerated. Waste sand from the core shop, broken cores can be loaded into the furnace for reclamation as well.
- Only the loss (only about 3 % per hour; broken grains, and fine particles) will be separated and need to be replaced.
- Reduced waste amounts.
- Another environmental benefit is the reduction of truck transport between sand providing facility and foundry and/or between foundry and landfill.

Use of recovered heat

- Loading of hot castings into the furnace; heat for melting the metal is also used for sand reclamation and heat treatment.
- No cooling of castings; avoiding using energy in the cooling process (e.g. electric blowers).
- Organic binder creates heat when burned. This heat inside the furnace is used for sand reclamation and heat treatment.
- Binder chemicals are burned inside the furnace.
- Some foundries use the heat of exhaust gases for providing hot water or heating the building.

Waste gas treatment

- Minimised emissions.

Emissions

- Emissions of CO_2 are reduced.

Table 3.24: Emission levels corrected to 12 % O_2 measured using the combined sand regeneration / heat treatment technique

	Maximum authorised emission concentrations (mg/Nm³)	Emissions reported using the combined sand regeneration/ heat treatment technique (mg/Nm³)
CO	80	60.9
VOCs	20	7.9
NOx	250	230
Dust	10	6
Source: [133, DE UBA 2014]		

Environmental performance and operational data

Capacities casting treatment: Existing systems treat between 33 and 180 engine block and cylinder head castings per hour, based on customer specifications. The furnaces (as a modular construction) are engineered to specified thermal systems. Depending on the number of castings/hour, size of castings/moulds, temperature, heat up and soak time, etc., the furnaces will be designed as a number of modules.

Capacities sand reclamation: The installations provide the capacity to reclaim between 1 tonne and 30 tonnes of used sand per hour. The hopper-shaped bottom of the furnace is also designed to buffer a certain amount of sand during production stops in the sand system downstream of the furnace, meaning the furnace can continue to heat treat castings.

Energy consumption: Utilities estimate the consumption of gas, electricity, and compressed air based on the customer's process specification. Gas consumption for example depends very much on the temperature of castings during loading, treatment time and temperature, quantity of sand and binder content, etc. The share of recovered energy can be about 47 %. In general, operating such a system can reduce the energy consumption by 25-30 %.

Cross-media effects

It may be considered as an indirect disadvantage when risers and feeders are heat treated as well before being cut off. It may use more energy in the furnace. On the other hand, loading of hot risers and feeders increases the heat loaded into the furnace.

'Heat treated' risers and feeders can be cut off more easily. This saves costs for cooling.

Technical considerations relevant to applicability

Generally applicable.

Economics

Savings can be achieved by:

- reduced treatment time (energy);
- reduced space requirements;
- reduced personnel costs;
- less equipment, no stand-alone machinery;
- less handling operations, less damage;
- reduced emissions;
- recovery of energy;
- less inventory (work in progress).

Additionally reported reductions by one example plant were:

- labour costs by 46 %;
- energy costs by 25 %;
- gas consumption by 64 %;
- operating costs by 55 %.

Reported share of energy:

- gas: 42 %;
- electric power: 11 %;
- energy recovery 47 %;

No data on investment costs are available.

Example plants

- In total 37 of such 3-in-1 roller hearth and chain type systems have been installed worldwide and are used mainly for the treatment of engine block (gasoline and diesel) castings (low-pressure die casting), precision sand mould and gasoline and diesel cylinder head castings (gravity die casting, low-pressure die casting, precision sand mould).
- Hydro Aluminium Dillingen (now Nemak Dillingen) in Germany with four lines for producing engine blocks and heads with a total production capacity of about 480 castings/hour.
- Daimler Benz Mettingen, Germany, equipped with two lines for producing cylinder heads.

Reference literature

[133, DE UBA 2014]

3.2.1.4.4.11 Wet regeneration for green sand, silicate- or CO_2-bonded sands

Description

Sand is mixed with water to produce a sludge. The removal of grain-bound binder residues is performed through intensive inter-particle rubbing of the sand grains. The binders are released into the wash water. The washed sand is dried, screened and finally cooled.

Technical description

After metal removal, the sand is mixed with water to produce a sludge for easily separating the binder and to allow subsequent wet screening (1.6 mm). The removal of grain-bound binder residues is performed in the wet regeneration unit, through intensive interparticle rubbing of the sand grains. The binders are released into the wash-water. The washed sand is dried to a final moisture content of maximum 0.3 %, dry screened (at 1.2 mm), and then cooled. This may be followed by an additional magnetic iron extraction and a final dust collection. The binder residue is separated from the suspension and treated to allow its safe, disposal.

The main advantage of the process over mechanical and thermal processes is that it allows real time process monitoring. Through pH control, continuous follow-up of the process is possible, allowing corrective real-time action if needed and producing a continuous quality regenerated sand. The technique allows removal of the binder layer through wet mechanical action, combined with chemical action when needed, without wearing the sand grains.

The process mainly aims to lower both the oolitisation degree of used sand (LOI maximum 1 %) and the acid content.

Information from industry states that besides the waste water generation issue (see Cross-media effects below), wet regeneration usually has a poor yield (recovery rate of only up to about two thirds of the regenerated used sand). [134, CAEF 2020]

Achieved environmental benefits

Reduction of the amount of sand for disposal and of the consumption of new primary sand.

Environmental performance and operational data

No information provided.

Cross-media effects
The wet process generates a sludge for disposal and a waste water stream. A serious problem of this waste water flow is the bad sedimentation of bentonite, and its difficult removal out of waste water. Waste water from water glass sands regeneration shows the presence of alkaline ions. These ions are difficult to separate from the waste water.

Technical considerations relevant to applicability
Generally applicable.

The wet regeneration system can only be applied to green sand and silicate- or CO_2-bonded sands. Regeneration from these types of processes allows full re-use of the regenerated sand in both moulds and cores. Tests on regenerated green sand showed the possibility of producing good quality cold-box cores with an acceptable binder quantity (1.8 % in total).

Economics
Within the Italian foundry market, a centralised wet regeneration plant can offer regenerated sand at a price lower than that of new sand.

Driving force for implementation
This system is reported to be able to cope with changes in used sand quality better than mechanical or thermal processes. This makes it suitable when considering a centralised sand regeneration plant.

Example plants
Safond centralised green sand wet reclamation plant, which since 1981 has been treating 230 000 tonnes/y of used sand.

One Polish foundry (Odlewnia Zeliwa Srem s.a., Srem (PL)) operates a wet regeneration of furan bonded sand. The operation is governed by site-specific factors and the technique cannot be considered for transposing to other sites.

Reported in the SF data collection by plants:AT004, CZ024, DE028, DE063, DE067, DE069, FR111 and IT127. [169, TWG 2021]

Reference literature
[17, Winterhalter et al. 1992], [47, EU Thematic Network Foundry Wastes 2001], [120, TWG 2003], [134, CAEF 2020], [169, TWG 2021].

3.2.1.4.4.12 Regeneration of sodium silicate sand (water glass) using a pneumatic system

Description
Sand is heated to make the silicate layer brittle before the use of a pneumatic system (see Section 3.2.1.4.4.7). The regenerated sand is cooled before reuse.

Technical description
Water glass sand has been traditionally difficult to regenerate. The use of a pneumatic system has allowed the setting up of regeneration plants operating of a 60 % regeneration ratio. The system works along the same principle as mentioned above (see Section 3.2.1.4.4.7). For this type of binder however, the sand needs to be heated to 220 ºC before the regeneration, in order to make the silicate layer brittle. The sand should have a humidity below 0.3 % before regeneration. The regenerated sand may be re-used in the same system. In order for the ester to work properly, the regenerated sand must be cooled to below 20 ºC, before feeding back into the moulding cycle.

Water glass sand regeneration systems comprise the following process steps: breaking – drying/heating – (pneumatical) reclamation – cooling - filtration.

This technique has a lower performance than the thermal regeneration of organically bound sands. The following limitations occur:

- lower immediate compressive strength;
- shorter applicability times of the core sand mixtures;
- stability loss upon storage of cores;
- loss of retained compressive strength, especially with the use of binders with high collapsibility.

In order to compensate for these problems, changes to the processing scheme or the binder mixes are needed.

Achieved environmental benefits
The application of water glass sand as a binder has a low environmental impact, compared to the application of organic binders. This technique allows the (partial) regeneration of the water glass bonded sand and thus reduces the need for used sand disposal and primary raw material use.

Environmental performance and operational data
A German example plant operates a pneumatical unit in a step-wise cycle. The sand is first dried by the introduction of heated air (5 min/220 ºC). After this, the pneumatic cleaning is started by injecting of shots of compressed air (70 min). This is followed by a final dedusting phase, during which only fluidising air is introduced (2 min). There is no need for further cooling, since the sand cools down to a workable temperature.

The yield of regenerated sand for one cycle operation is reported to be 85 % of the initial weight (on the basis of SiO_2). In order to produce stable cores, and taking into account the further reduction of sand quality upon a second regeneration cycle, a maximum regeneration ratio of 62 % may be achieved (leaving 38 % new sand addition).

Specific consumption levels are as follows (for a 1 500 tonne/y; 0.5 tonne/h unit):

- natural gas consumption: 104.4 kWh/t used sand;
- electricity consumption: 74.5 kWh/t used sand.

A Polish example plant (in a cast steel foundry) consists of the followig units: vibratory crusher – drier – impact plate regenerator – cascade dedustor – electromagnetic separator. The technical details of the installation are given in Table 3.25. The regenerated sand is re-used in the preparation of silicate-bonded moulding-sand. The silicate-sand is used as backing sand in mould making, with alkaline sand used as contact sand. The total sand balance (on a yearly basis) shows a use of 45-47 % regenerated sand.

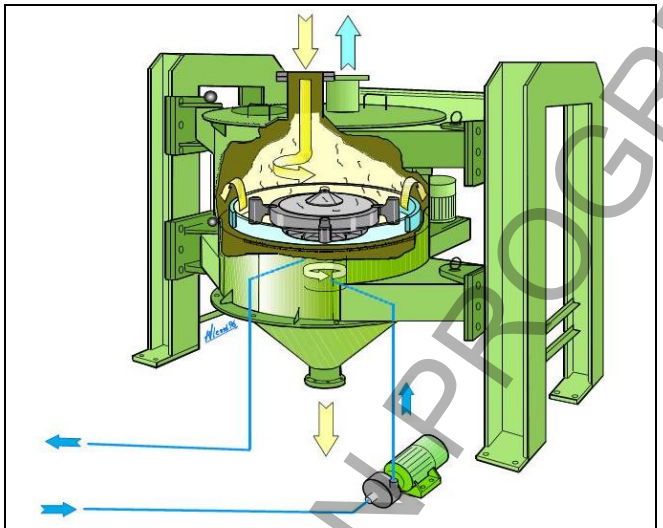
Table 3.25: Operational data of a silicate sand regeneration unit

Characteristic	Value
Capacity	10 tonne/h
Recovery ratio	90 %
Content of regenerated sand in the moulding-sand	50 – 60 %
Working power	76 kW
De-dusting system efficiency (2 bag filters)	99.4 %
Installation area for regeneration site	220 m²
Source: [98, Metalodlew s.a. 2002]	

A Spanish example plant (cast steel foundry) reported a reuse of 80-88 % (with a yearly average figure of 12.5 % new sand addition) of regenerated silicate-ester sand in a manual moulding line, used for the casting of big pieces. The regeneration system consists of: vibratory crusher –

heating in an indirectly heated reactor ('quemador' with gas burner in a side chamber) – cooling in a water-cooled heat-exchange tower – impact cleaning in a rotary mixing chamber.

An Italian example plants also use special equipment for heating sand to temperatures of 140 ºC to 150 ºC, to enable the removal of defects and the embritlement of the water glass coating. This is followed by mechanical treatment in a rotary wiper, dedusting and finally cooling. A schematical drawing of the rotary regeneration unit is given in Figure 3.30.



Source: [120, TWG 2003]

Figure 3.30: Rotary mechanical regeneration unit

The equipment has an energy consumption of 35 kW/tonne of regenerated sand. The operational loss of sand is about 5 %. For moulding and core making mixtures, over 90 % of regenerated sand can be used. The achievable regeneration ratio depends on the intensity and time of regeneration and the operational sand loss. Sand losses occur during each part of the whole cycle of mixing, preparation, transportation, mould production and regeneration.

Cross-media effects

In order to heat up the sand, natural gas is combusted. The corresponding CO_2 emission is estimated to be 18 kg/tonne of used sand. NO_X emissions will also occur.

Technical considerations relevant to applicability

Generally applicable.

The applicability of regeneration for water glass sands depends on the catalyst used. With classic polyacetate glycerol esters, regeneration is no longer possible after a number of cycles. With carbonaceous esters, regeneration is possible and even easier than for silicate-CO_2 sand. If the sand cannot be cooled below 20 ºC before returning to the mixer, esters with a slow reaction need to be used. These cannot be regenerated. This situation may occur during summer in hot climates.

The re-use of the regenerated water glass sand for the preparation of organically bound moulds or cores is problematic. The elevated content of electrolytes (binders) prohibits their use in other core binder systems. The highly basic water glass residues have a negative effect on bonding and core stability, in both neutral as well as alkaline binder systems. Applications in green sand cycles and acidic core binder systems have not yet been successfully implemented. This may be due to a reduced interest in the development of this application.

Because of the low quality of secondary regenerated sand, it is necessary during de-coring and sand collection to identify the amount of regenerated sand and its origin (e.g. number of cycles), and to then discard any unusable sand.

Economics
The processing cost of this technique for the German example plant is around EUR 60/tonne. This high cost was the reason one operator closed his plant down and went back to the disposal of the water glass sand, which he could do for the lower cost of EUR 30/tonne.
The reported operational cost by the Spanish example plant is EUR 10/tonne.

Due to the high costs and relatively low regeneration ratio, depreciation of the installation in a reasonable time can only be guaranteed for plants with a capacity > 2 500 tonnes/y.

Driving force for implementation
To enable the regeneration of water glass sand, which has a good environmental performance in certain applications.

Example plants
- KGT Jet Reclaimer centralised regeneration plant for 4 foundries, constructed 1998 at Fa. Bröer, Schwetzingen (DE) but stopped operation in 2001
- Metalodlew s.a., Krakow (PL)
- Lur Sue s.l., Lora Del Rio (ES)
- Fonderia Arno Metallurgia, S. Vittore Olona (IT)
- Faser Spa, Rogeno (IT)
- Talleres De Amurrio S.A. Amurrio (ES)
- Daros Piston Rings AB, Partilla (SE).

Reference literature
[42, IHOBE 1998], [56, Notzon and Heil 1998], [58, Baum 2002], [98, Metalodlew s.a. 2002], [108, Martínez de Morentin Ronda, J. 2002], [120, TWG 2003], [123, Galante et al. 1997]

3.2.1.4.4.13 Internal reuse of core sand (polyurethane (cold-box) and furan resin-bonded)

Description
Sand resulting from broken/faulty cores, and excess sand from the core-making machines (after hardening in a specific unit), are fed to a breaking unit. The resulting sand is mixed with new sand for the production of new cores.

Technical description
Core production generates sand residues in the form of broken cores, cores with small mistakes and excess sand from the core-making machines. The excess sand can be hardened in a specific unit. Subsequently the various unused core sand flows are fed to a breaking unit. The resulting sand may be mixed with new sand for the production of new cores.

Achieved environmental benefits
Raw material efficiency (less use of new sand) and minimisation of used sand sent for disposal.

Environmental performance and operational data
Internal recirculation of 5-10 % of the core sand, which otherwise would be disposed of.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.
This technique applies for polyurethane (cold-box) and furan resin-bonded sands. Other binders do not allow this technique.

The implementation of the technique necessitates changes in the process control. The optimum ratio of recirculated and new sand will need to be determined. Additionally, changes in binder addition or composition may be needed.

Economics
The technique requires an investment cost of EUR 250 000-500 000 for the combined treatment and breaking unit. Operational costs are about EUR 12/t (2001 data). These costs are balanced by a reduction in disposal costs and purchasing costs for new sand.

The technique is only viable for core intensive production.

Driving force for implementation
- Optimisation of the use of primary materials and reduction of the amount of waste for disposal.
- Legal requirements.
- Local conditions.

Example plants
The technique was reported by several large-scale foundries.

Reference literature
[34, IfG 1996], [38, VITO 2001]

3.2.1.4.4.14 Reuse of dust from the green sand circuit in mould making

Description
Dust is collected through the exhaust filtration from the shake-out installation and from the dosing and handling stations for dry green sand. The collected dust (containing active binder compounds) can be recycled into the green sand circuit.

Achieved environmental benefits
Reduction in the use of primary raw materials (binders, ~~(~~bentonite)~~,~~ and additives (carbon)~~through internal re-circulation~~.

Environmental performance and operational data
An iron automotive foundry, using an automated moulding line with a production of 8 000 t/y castings produces 480 t/y of dust. This sand is collected, cooled and recycled into the sand mixer. The collected dust contains 23 % active bentonite and 10 % carbon. 50 % of the dust can be re-circulated without any risk of loss of quality due to fine dust.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable. The technique may be applied in new and existing green sand installations.

Economics
The technique requires an investment of EUR 25 000 for storage and transport equipment. The amortisation period is 8 years, with a discount rate of 8 %, for a 240 tonne/yr installation, resulting in a capital cost of EUR 17/tonne of treated sand (2005 data). There are no additional operational costs since the operation of the overall installation does not change.

Driving force for implementation
To optimise the use of primary materials and to reduce the amount of waste for disposal.

Example plants
Iron automotive foundry in Germany.

Reference literature
[34, IfG 1996]

3.2.1.4.5 Reduction of generated waste and waste sent for disposal

In general, the waste streams comprise:

- raw material dusts collected in bag or cartridge filters;
- slag from desulphurisation;
- slag/dross from melting;
- melting dust and fume collected in a filter plant;
- casting dust and fume collected in a filter plant;
- fettling dusts collected in an abatement plant;
- chips and turnings from fettling;
- used abrasives from shot blasting;
- scrubber liquors and sludges and output from the effluent treatment plant;
- refractory waste from launders and ladles;
- sand;
- chemical and oil containers;
- general inert industrial waste.

Waste should be recovered wherever practicable. Other than sand, the most significant wastes are:

- slag from the melting and metal treatment processes;
- dust collected from abatement plants;
- collected sludge;
- refractory waste.

[62, UK Environment Agency 2002]

3.2.1.4.5.1 Off-site recycling of the used sand, the undersize sand and the collected filter dust

Description
Used sand and undersize sand resulting from the sand circuit or the sand regeneration process can directly be recycled in off-site applications such as:

- road construction;
- building materials (e.g. cement, bricks, tiles);
- filling of mining cavities;
- landfill construction (e.g. roads on landfills, permanent covers).

Filter dust, if not directly recycled in the furnace (see Sections 3.2.1.4.5.6 and 3.2.1.4.5.7), can be externally recycled, e.g. in metallurgy, sand fabrication, the construction sector.

Technical description
Used sand and undersize sand from the sand circuit or sand regeneration may find some external applications, as indicated above. ~~with the main areas of application being:~~

- ~~the construction industry (road construction, highway construction)~~
- ~~the building materials industry (cement, bricks, limestone manufacture)~~
- ~~in the filling of mining cavities~~

- ~~in landfill construction (roads on landfills, permanent covers).~~

The limits of these applications are given by either technical criteria for construction materials and/or environmental criteria for the given application. Environmental criteria are generally based on leaching properties and the content of organic compounds. These differ between various European regions. Used sands generally show a low metal leaching potential. An exceedence of the limit values may occur for materials with a high content of organic binder or with specific additives, such as lustrous carbon.

Due to its high quartz content and appropriate granulometry, used sand may be applied as a virgin sand substitute in road construction. Application in the production of building materials (concrete, bricks, tiles, glass wool, etc.) are technically feasible but require a higher level of composition control and logistics. Industrial scale trials have been successfully applied in:

- road bases;
- filling material;
- drainage material;
- concrete elements;
- cement production (depending on the silicon need of the process; in Germany this application is of major importance);
- filling of mining cavities (due to its good supporting capacities; used sand is used in this application in Germany);
- final cover on landfills (mixed with water glass and other wastes, examples in the Netherlands);
- construction material for the reinforcement of dikes;
- vitrification of hazardous waste.

An ovrview ~~survey~~ table which gives more detailed information for the different sand types is given in Section 3.2.1.4.5.3.

Other fields of application are the fabrication of bricks, secondary copper smelting and zinc recuperation.

It should be stressed that discussions on the (type of) external utilisation fall beyond the scope of the current reference document. However, in general, it can be stated that the sand usually needs no pretreatment and is transported from the foundry after collection and intermediate storage. Usually in order to guarantee a continuous quality of the material, a separate collection and storage system will be developed. Furthermore, the quality of the material needs to be controlled through regular analyses.

Achieved environmental benefits
In external applications, the used sand substitutes, and therefore saves, virgin materials. In general, the external application does not require any treatment of the sand and therefore does not generate any energy expense for the foundry.

Environmental performance and operational data
No information provided.

Cross-media effects
In general, no cross-media effects are reported. It may be the case that residues of organic coatings are possible sources of aromatic hydrocarbons.

Technical considerations relevant to applicability
Generally applicable.

This technique is applicable for new and existing installations, as long as they can find a buyer for the waste sand.

The use of surplus foundry sand does not reduce the wear resistance of asphalt concrete. The use of surplus foundry sand together with the dust from the same foundry process is possible in Portland cement concrete production. The use of surplus foundry sand together with fly ash and steel slag is possible in mineral wool production. The use of surplus foundry sand in the composting process of biowastes does not negatively affect the environmental or technical features of the final product, i.e. the topsoil. The use of surplus green sand in mineral liners is technically and environmentally possible in the top layers of the landfill.

Economics
Costs for external utilisation depend on the local market and the transport and storage costs needed.

Investment costs for separate collection and storage are minimal. Often these can be realised through organisational measures. Operational costs for analyses and administration may be up to EUR 5 000/y. On the benefit side, there is a reduction in the costs for disposal (up to EUR 125/tonne) (2000 data).

Driving force for implementation
- ~~Legislation using~~ High disposal fees aiming to reduce the amount of residues for disposal.
- Legal requirements.
- Local conditions.

Example plants
Multiple examples have been reported throughout Europe, e.g. by Finland, the Netherlands, Belgium, Germany, UK. An indicative list of plants reporting external recycling of spent sand in the cement industry and construction works includes plants: BE022, CZ026, DK079, FR109, FR110 and IT071. [169, TWG 2021].

Reference literature
[34, IfG 1996], [38, VITO 2001], [42, IHOBE 1998], [68, Orkas J. 2001], [70, The Castings Development Centre 1999], [169, TWG 2021].

3.2.1.4.5.2 Minimisation of slag forming

Description
Slag forming can be minimised by in-process measures, such as:

- using clean scrap;
- using a lower metal temperature;
- avoiding high temperature peaks;
- preventing long standing times of molten metal in the melting furnace;
- making adequate use of fluxes;
- making adequate choice of the furnace refractory lining;
- applying water cooling of the furnace walls to avoid the wear of the furnace refractory lining;
- liquid aluminium skimming;
- using compressed air to recover aluminium residues;
- separating collected metal chips from oils using drying.

Achieved environmental benefits
Minimisation of residue generation ~~production~~ and reduction of emissions to air.

Environmental performance and operational data
No information provided.

Cross-media effects
No cross-media effects occur from these minimisation measures. Concerning the melting of clean scrap, the considerations raised in Section 3.2.1.3.4 should be taken into account.

Technical considerations relevant to applicability
Generally applicable. This technique applies to all new and existing installations. The applicability of the use of clean scrap has been fully discussed in Section 3.2.1.3.4.

Economics
This technique does not involve any investement, since it concerns operational measures.

Driving force for implementation
High disposal costs for residues.

Example plants
This technique is part of existing operational procedures in the majority of European foundries.

Reference literature
[36, Vereniging van Nederlandse Gemeenten 1998]

3.2.1.4.5.3 Mechanical pretreatment of slag / dross / filter dust / spent refractory linings to facilitate recycling

Description
Generated slag / dross / filter dust / spent refractory linings are pretreated on site, by using techniques such as crushing, segregation, granulation and magnetic separation.

Technical description
In order to allow an external re-use of solid residues, the material may need treatment. Table 3.26 gives the required processing for the various (non-sand) solid residues and possible limitations for their reuse.

For cupola furnace slag, the physical form, and therefore to some extent its options for reuse, depend on the type of de-slagging used. Dry slagging, i.e. pouring of the slag in pots for cooling and solidification, produces a crystalline non-porous mineral. Concerning technological aspects, this slag is comparable to blast furnace slag. Wet slagging generates a granular slag by cooling the slag with a water jet.

Table 3.26: Necessary treatment and possible limitations for external reuse of solid residues

Residue type	Treatment	Limitations
Air-cooled cupola slag	Crushing	- generation of glassy dust - handling requirements due to glassy nature
Water quenched cupola slag	None	- generation of glassy dust - handling requirements due to glassy nature
Induction melting slag	Crushing	- generation of glassy dust - handling requirements due to glassy nature - little data available on leachates
EAF slag	Crushing	- generation of glassy dust - handling requirements due to glassy nature - little data available on leachates

Desulphurisation slag	Extraction of metal and other coarse particles	- handling requirements, CaC_2 needs careful handling to avoid injury - run-off - may be a special waste
Dusts and sludges	Sludge pressing, drying and granulation needed for most applications	- health and safety requirements for some dusts - problems with transport of dusty materials - high leaching potential due to nature of product and large surface area
Source: [70, The Castings Development Centre 1999]		

Achieved environmental benefits

In external applications, the reused material will serve as a secondary construction material and can substitute for virgin materials. The recycling results in a reduction in the amount of material for disposal.

Environmental performance and operational data

A summary of external reuse applications for various solid wastes is given in Table 3.27.

Table 3.27: Summary of external reuse applications for solid foundry residues (status 1999)

SUMMARY OF RE-USE APPLICATIONS	SAND						SLAGS					OTHER	
Construction type uses	Greensand	Alkaline phenolic	Phenolic urethane	Furan	Resin shell	Sodium silicate	Air-cooled cupola	Water quenched cupola	Induction	Electric arc furnace	Desulphurisation	Investment casting shell	Dusts and sludges
Asphalt	x	x	+	+	+	O	x						
Ballast							+			+			
Block making	+	x	+	+	x	+		x					
Brick manufacture	x	x	+	+	+		+	+					
Cement	x	x	+		x	x							
Coarse aggregate substitute							x		x	x		x	
Concrete		x	+	+	+								
Fine aggregate substitute	x	x	+	+	+	+							
Foamed concrete, etc.	x	x	+										
Insulating/mineral/glass wools	+	+	+	+	+	+	+	+					+
Lightweight aggregate production													+
Mortar production						+							
Road base construction		x	+		+	x	x		x	x		x	
Roofing felt				x									
Re-use in another foundry													
As new sand addition to greensand				x									
Soil type uses													
Artificial topsoils	x	+	+	x	+								+
Decorative ground cover							+	+					
Ground cover in riding stables								+					
Fertiliser filler													x
Landfill - capping	x	x	+										+
Landfill - daily cover	x	x	+	x	x	x							
Landfill - liner	+												+
Soil modifier/improver	+	+	+	+	+	+		+			+		+

Miscellaneous													
Abrasives/blasting media		x	+					x	+				
Absorbent media												+	
Blast furnace slag cement manufacture						+					+		
Chemical/industrial applications													x
Slaked lime replacement											+		+
Smelting fluxes		+	+		+	+							
Waste vitrification	+	+	+		+	+							

x Proven re-use application, with successful projects running in the UK
+ Re-use application that has been proven in theory but no re-use project is currently running in the UK
O Unsuitable for re-use in untreated from

[70, The Castings Development Centre 1999], [100, TWG 2002]

Cross-media effects
Pretreatment requires energy and may generate dust emissions.

Technical considerations relevant to applicability
Generally applicable.

The technique is applicable for new and existing installations, as long as there is a suitable a local market for the residue.

Economics
The costs associated with reuse are mainly the processing and transport costs, but these can possibly be reduced by taking into account the income generated from selling the material. However, the latter in general may be low or close to zero, whereas typically mechanical treatment costs are in the range of EUR 8/tonne.

The further the materials have to be transported, the greater the increase in costs. In order to assess the economic viability of the re-use option, the applicable disposal costs should be taken into account. These differ between various regions and depend on the residue type.

Driving force for implementation
Legislation stimulating the recycling of mineral wastes, partly by setting high disposal fees to reduce the amount of residues for disposal.

Example plants
Multiple examples of sand and slag reuse have been reported throughout Europe, e.g. in Finland, the Netherlands, Belgium, Germany and the UK.

Reference literature
[70, The Castings Development Centre 1999]; [100, TWG 2002]

3.2.1.4.5.4 Adjustment of the slag acidity/basicity

Description
Use of an appropriate flux (e.g. limestone for acidic and calcium fluoride for basic cupola operations) to render the slag fluid enough to separate from the iron.

Technical description
A flux is used to render the slag fluid enough to separate from the iron and to allow it to flow freely from the cupola. The most commonly used flux is limestone (calcium carbonate), which

calcines in the cupola shaft to form lime, a basic oxide, which then combines with the other slag-forming constituents (mainly acidic in character) to provide a fluid slag.

The basicity of a slag is given by the following ratio: (CaO % + MgO %)/SiO_2 %.

Most cupolas operate with an acidic or slightly basic slag (basicity < 1.2). Basic cupolas (basicity up to 2) offer three advantages:

- higher carbon;
- lower sulphur;
- possibility of charging lower quality scrap.

But they present the following disadvantages:

- silicon losses are high;
- refractory costs are high, unless operating with a liningless cupola;
- fluxing material costs are higher;
- metal analysis is more difficult to control than acid cupola melting.

For acidic cupolas, dry filters can be used. The slag of basic cupolas has a higher melting point. So a flux based on CaF_2 is generally used to make it fluid. In this type of cupola, there are emissions of fluor-containing components. ~~This necessitates the application of wet scrubbers for efficient capture of these components.~~ The application of wet scrubbers reduces emissions of fluorine-containing compounds.

Achieved environmental benefits
~~For acidic cupolas, dry filters can be used. The slag of basic cupolas has a higher melting point. So a flux based on CaF_2 is generally used to make it fluid. In this type of cupola, there are emissions of fluor-containing components. This necessitates the application of wet scrubbers for efficient capture of these components.~~
Improved operational conditions.

Environmental performance and operational data
No information provided.

Cross-media effects
When wet dedusting is applied, this can lead to additional/higher water consumption and to emissions to water.

Technical considerations relevant to applicability
Generally applicable. This technique applies to all new and existing cupola installations. If basic slag is used, a wet dedusting system is necessary.

Economics
No information provided.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
This technique is commonly applied in European foundries using cupola furnaces.

Reference literature
[20, ETSU 1993], [100, TWG 2002], [120, TWG 2003], [169, TWG 2021]

3.2.1.4.5.5 Collection and recycling of coke breeze

Description
Coke breeze generated during handling, transport and charging of coke is collected (e.g. by using collection systems below conveyor belts and/or charging points) and recycled in the process (injected into the cupola furnace or used for recarburisation).

Technical description
The handling, transport and charging of coke results in the production of coke breeze. Specific measures may be adopted for the collection and recycling of this material e.g. collection systems below conveyor belts or, at charging points.

The collected material may be recycled into the process by injection into the cupola or in its utilisation for recarburisation.

Achieved environmental benefits
Minimisation of the ~~production~~ generation of residues.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
Legal requirements.

Driving force for implementation
- High disposal fees for solid residues.
- Legal requirements.

Example plants
The technique is reported for several foundries in Europe.

Reference literature
No reference literature provided.

3.2.1.4.5.6 Recycling of filter dust in the cupola furnace

Description
Cupola filter dust is partially re-injected into the cupola furnace in order to increase the zinc content in the dust, up to a level that allows Zn recovery (> 18 %).

Technical description
Cupola filter dust can be ~~is~~ re-injected into the cupola furnace. The aim of this technique is to achieve an accumulation of ~~zinc~~ metals in the dust, mainly zinc, up to a level that allows reprocessing with Zn recovery (> 18 %). Zn recovery is performed using the Waelz process.

Recirculation of the dust can be done through re-injection at the tuyères or by charging dust pellets through the charging door. Both techniques are applied on an industrial scale. A mass

balance analysis can be used to show that the zinc is sublimated and reappears in the recuperated dust. After a number of cycles the dust is rich enough in Zn to allow recovery. Recovery is technically possible above an 18 % Zn level.

There are two limits to recycling dust:

- The zinc essentially appears in the form of Zn_2SO_4, a compound containing 64 % Zn. This therefore sets the maximum level of enrichment.
- The dust is also enriched in alkali, which causes flame extinction in the combustion chamber. This effect may be solved by injecting water vapour into the combustion air.

Injection at the tuyères can be based on several principles. There are fifteen (status May 2001) European foundries recycling dust by injection at the tuyères. Eleven use the positive pressure technique, and four use the venturi suction technique. The advantage of the venturi technique is that it consumes less injection air and so cools the melting zone less. With both techniques, the dust becomes sticky after successive cycles. In the case of the venturi technique, the dust must therefore be mixed with petcoke to allow its transport in the pipes.

The recirculation of dust through agglomeration and charging is much less common than tuyère injection. This is because the process is much more difficult to automate. Furthermore, good control and knowledge of the pelletisation process is needed to give the pellets the necessary consistency. Ferrosilicon can be added to produce pellets with good consistency. In practical tests a mix of 2/3 FeSi with 1/3 of dust was needed to allow good operation. On the other hand the pellet technique can be used to treat large quantities. For cupolas with larger diameters, tuyère injection of the dust into the centre of the fire is difficult, this therefore favours the use of pellets.

The properties of both techniques are compared in Table 3.28.

Table 3.28: Properties of injection techniques for recirculation of cupola furnace dust

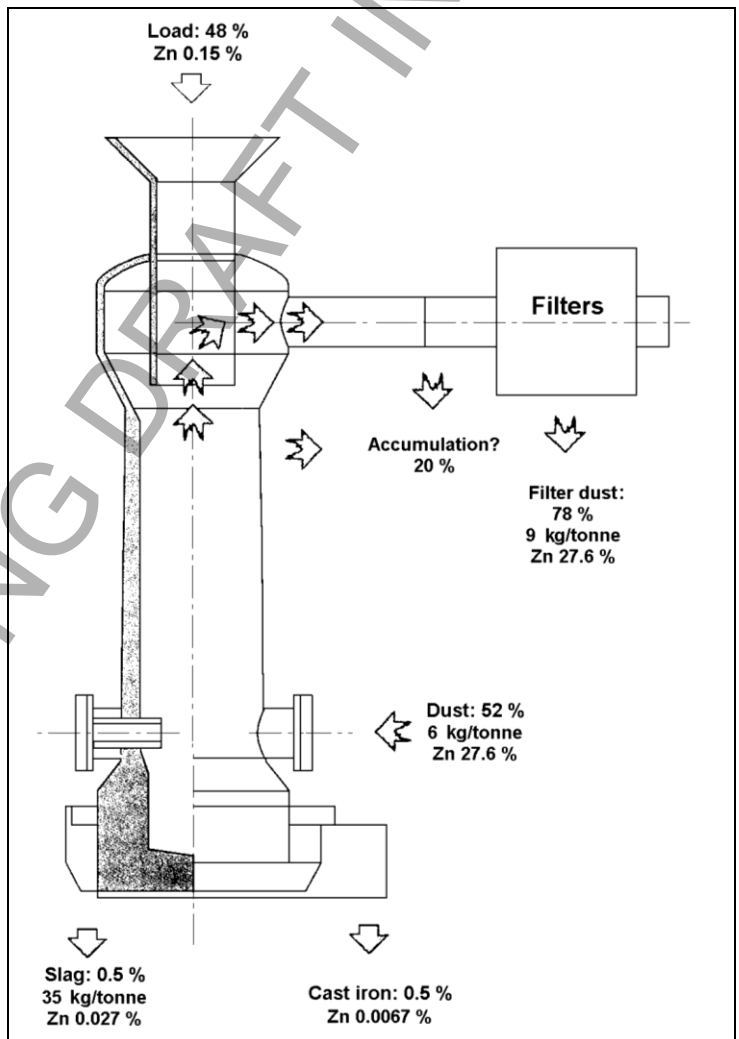
Re-use of the fines collected in the purification of the cupola off-gas	Injection through nozzles	Introduction as pellets	Observations
Influence of the waste			
Limitation in the introduced amount of fines	7 – 8 kg/tonne metal		Problem of extinction of flame
Reduction in the generated amount of fines	40 %	50 %	Approx.(1)
Increase in the content of zinc in the fines	30 %	20 %	Approx.(1)
Increase in slag production	?	?	
Influence on the operation of the cupolas			
Amount of coke necessary to counteract the temperature loss	0.5 – 0.6 %	0.2 – 0.3 %	Approx.(1)
Variation in the analysis of off-gases	No	No	n.a
Influence in melted metal			
Increase in the metal content (Zn, Pb) in the iron	Limited	No	(in the order of thousandths)
Influence in the losses to fire	10 – 30 %	No	Approx. (1)(2)
Effectiveness to add other products (C, FeSi) with the same method	Yes	No	n.a
Costs			
Reduction in the disposal cost of the fines	60 %	50 %	Approx.(1)
Operations			
Possibility of automating the process	Yes	No	n.a
Additional Problem	No	Yes	Crash-resistance of the pellets

Implementation of technology			
Existing Facilities	Yes	Yes	Preferably cupolas of large size
New facilities	Yes	Yes	

(1) Approximation, real value depending on the initial zinc oxide content the fines, of the degree of necessary enrichment for its re-use, and on the characteristics of the cupola.
(2) Function of the amount of steel in the load of the cupola.
n.a: not applicable.
Source: [37, FEAF 1999]

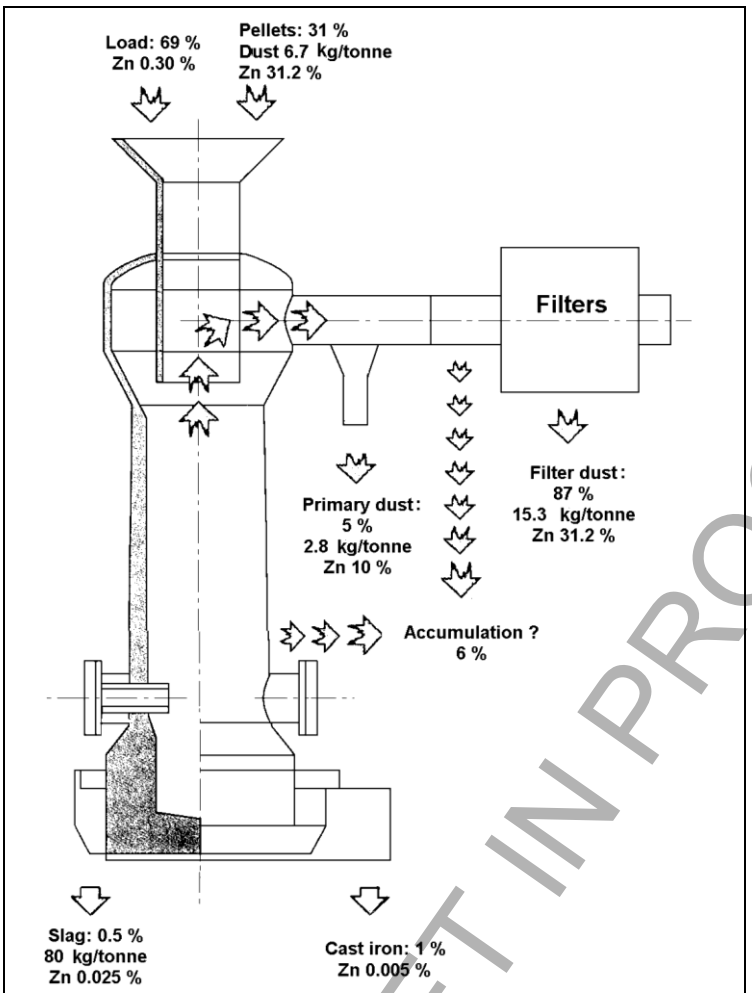
Achieved environmental benefits
The main benefit of the technique is a decrease in the net amount of dust sent out by the foundry, for disposal or recovery. The foundry typically sends out a smaller amount of dust, but with a higher load of metals. This allows the recovery of Zn from the cupola dusts. The technique results in an enrichment of the Zn in the cupola dust, while for Pb a larger share ends up with the iron. If the Zn is effectively recuperated from the dust, the technique decreases the heavy metal load of the final dust for disposal, as well as its amount. On the other hand, the amount of slag produced increases.

Environmental performance and operational data
An analysis of the input and output flows of French cupolas resulted in the mass balance shown in Figure 3.31 and Figure 3.32. The contribution of each flow to the Zn in/output is given together with the zinc level (as mass and %). The percentages given are average values over the indicated measuring period.



Source: [59, Godinot 2001]

Figure 3.31: Zinc distribution for tuyère injection, upon injection during 20 days



Source: [59, Godinot 2001]

Figure 3.32: Zinc distribution for recirculation through the charge, upon charging during 11 days

The analysis of the input and output flows do not allow a full closure of the zinc balance. This indicates that a considerable part of the zinc (20 % for tuyère injection, 10 % for pellet charging) remains and accumulates in the system. Upon recirculation, the dust gets sticky and deposits in the combustion chamber, heat-exchanger and filters. The recirculation will therefore require increased cleaning efforts and will result in a material for disposal at this cleaning stage.

The recirculation of cupola dust (yearly iron production: 30 000 tonnes) in a Dutch iron foundy reduced the net amount of dust by 156 t on a yearly basis, without any significant effect on the environmental and construction qualities of the slag.

Cross-media effects

Both techniques consume energy, i.e. coke, to melt the product. An increase in coke use of 0.15 kg to 0.25 kg cokes/kg dust at a thermal efficiency of 40 % of the furnace is reported.

In addition, the injection of cold dust in the hot melting zone will lower the flame temperature, which accordingly will have to be restored by an injection of oxygen. The total amount of slag produced will also increase.

The loading of sticky dust to several of the internal parts of the system will cause medium-term loss of efficiency and possibly operational problems. These have not been quantified.

Technical considerations relevant to applicability

Generally applicable.

Recovery is technically possible above an 18 % Zn level. Cupolas with a Zn-rich charge have Zn levels in the dust > 20 %, without recirculation. A minimal content of 40 % zinc is needed for cost neutral recovery (see also Economics below).

It is not possible to re-inject the full dust production of a furnace. Injection of more than 8 kg/tonne metal results in an extinguishing of the flame.

New and existing cupola furnaces with continuous operation can be equipped with these dust recirculation installations.

Economics
Recovery is technically possible above an 18 % Zn level. Operators report profitability of the recirculation and Zn recovery occuring for a Zn level > 40 %.

From the practical data from two foundries in France, additional operational costs were calculated. Tuyère injection showed an additional operational cost of EUR 0.35/tonne cast iron; pellet injection EUR 0.90/tonne cast iron (2001 data). This calculation does not take into account any extra costs for slag disposal or maintenance works.

In the case of Venturi injection, the following data apply. In a German reference plant over a 5-year period an average of 7.5 kg zinc dust/tonne melted iron could be delivered to the processing industry. Disposal costs were thereby reduced by EUR 1.97/tonne liquid iron. Furthermore, 20 % of the cokes could be replaced by petcokes. This allowed a reduction in the fuel cost of 15 %, which corresponded to a cost reduction of EUR 2.56/tonne liquid iron (2001 data). This calculation does not take into account any extra costs for slag disposal or maintenance works.

Driving force for implementation
- High disposal costs for furnace dusts.
- Legal requirements.
- Local conditions.

Example plants
- Venturi (NPT):
  - Pont-a-Mousson, Brebach (FR)
- Positive Pressure (VELCO):
  - John Deere, Mannheim (DE)

Reference literature
[37, FEAF 1999], [38, VITO 2001], [47, EU Thematic Network Foundry Wastes 2001], [59, Godinot 2001], [80, Ruffin, A. and Godinot, P. 1998], [96, Fischer 0], [100, TWG 2002]

3.2.1.4.5.7 Recycling of filter dust in the EAF

Description
Collected dry filter dust, usually after pretreatment (e.g. by pelletising or briquetting), is recycled in the furnace to enable the recovery of the metallic content of the dust. The inorganic content is transferred to the slag.

Technical description
Dry collected furnace dust can, under certain circumstances, be recycled in the furnace. The dust will preferably be pretreated, e.g. by pelletising or briquetting, as this will reduce the amount of dust that is just blown through the furnace. The idea is to recover the metallic part of the dust and to melt the inorganic part to slag. In general, the dust is added at the beginning of each melting cycle.

As discussed for cupola furnaces, and for the EAF, in some cases where significant quantities of Zn-containing scrap are used, recycling can lead to a Zn enrichment of the furnace dust up to a level where it can be used in the zinc industry for the recovery of Zn if economically viable (up to 30-40 %).

Achieved environmental benefits
The main benefit of the technique is a decrease in the net amount of dust sent out by the foundry, for disposal or recovery. The produced dust contains a higher load of metals. ~~This allows the recovery of Zn from the EAF dusts. The technique results in an enrichment of the Zn in the cupola dust, while for Pb a larger share ends up in the iron. If the Zn is effectively recuperated from the dust, the technique decreases the heavy metal load of the final dust for disposal, as well as its amount. On the other hand, the amount of slag produced, increases.~~~~This allows the recovery of Zn from the EAF dusts. The technique results in an enrichment of the Zn in the cupola dust, while for Pb a larger share ends up in the iron. If the Zn is effectively recuperated from the dust, the technique decreases the heavy metal load of the final dust for disposal, as well as its amount. On the other hand, the amount of slag produced, increases.~~

Environmental performance and operational data
Operational data from EAF steelmaking show a plant which recycles 75 % EAF dust from an original yield of 20-22 kg/t, and so only has to take care of about 50 % of the dust, with an average zinc content of 35 %.

Cross-media effects
Dust recycling possibly reduces furnace efficiency and rises the consumption of electrical energy (approximately 20-30 kWh/tonne). The technique results in an increased production of slag.

Technical considerations relevant to applicability
Generally applicable.

The technique is mainly used in case of ~~generally applies for~~ dusts with a high metallic load. The actual use ~~applicability~~ though depends on many factors, which may be dissimilar for different plants.

Economics
The technique does not involve any additional investment.

Driving force for implementation
- High disposal costs for furnace dusts.
- Legal requirements.
- Local conditions.

Example plants
This technique is ~~performed~~applied ~~performed~~ in several European foundries.

Reference literature
[14, CAEF 1997], [109, COM 2013]

3.2.1.5 Diffuse emissions to air

~~Fugitive~~ Diffuse emissions occur when emissions from specific process sources are not collected. Besides the process-related emission sources, potential sources of diffuse ~~fugitive~~ emissions to air include:

- storage areas (e.g. bays, stockpiles, heaps);
- the loading and unloading of transport containers;

- transferences of material from one vessel to another (e.g. furnace, ladle, silos);
- the mixing and curing of chemical binders (inorganic and organic chemical emissions);
- mould coatings (solvents);
- conveyor systems for moving material around;
- pipework and ductwork systems (e.g. pumps, valves, flanges, catchpots, drains, inspection hatches, etc.); these type of emissions are discussed in detail in the LVOC-BREF;
- poor building containment and extraction;
- bypass of abatement equipment (to air or water);
- an accidental loss of containment from a plant or equipment failure, including leakages, e.g. from the sand reclamation plant;
- spills.

In order to minimise diffuse ~~fugitive~~ dust emissions, the following techniques may be employed:

- the covering of skips and vessels;
- the avoidance of outdoor or uncovered stockpiles;
- where outdoor stockpiles are unavoidable, using sprays, binders, stockpile management techniques, windbreaks, etc.;
- cleaning wheels and roads (i.e. avoiding the transfer of pollution to water and wind);
- using closed conveyors, pneumatic conveying (although note the higher energy needs), and minimising drops;
- vacuum cleaning of the moulding and casting shop in sand moulding foundries, with the exception of areas where the sand has a technical or safety-related function, e.g. the pouring area, and with the exception of hand-moulding jobbing foundries;
- keeping outside doors shut, e.g using an automatic shutter system or flaps;
- carrying out good housekeeping, i.e. ensuring that regular inspections are carried out by responsible and delegated staff as a practice of good housekeeping and keeping up-to-date records;
- in-process or primary measures for avoiding or reducing emissions (e.g. Minimisation of binder and resin consumption).

[62, UK Environment Agency 2002], [64, UK Environment Agency 2002], [1, COM 2017]

3.2.1.5.1 Covering the delivery equipment (containers) and the cargo space of transport vehicles

Description
The cargo space of transport vehicles and delivery equipment (containers) is covered (e.g. with tarpaulins).

Achieved environmental benefits
Reduction of uncontrolled diffuse emissions to air.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable. The technique is applicable to all new and existing installations.

Economics
The technique does not involve any additional investment or operational cost.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[169, TWG 2021]

3.2.1.5.2 Cleaning roads and transport vehicle wheels

Description
Roads as well as the wheels of transport vehicles are regularly cleaned, e.g. by using mobile vacuum systems, water lagoons.

Achieved environmental benefits
Avoiding the transfer of pollutants to water and air.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
The technique does not involve any significant additional investment or operational cost.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[62, UK Environment Agency 2002], [64, UK Environment Agency 2002], [1, COM 2017], [169, TWG 2021]

3.2.1.5.3 Use of closed conveyors

Description
Materials are transferred using conveyor systems, e.g. closed conveyors, pneumatic conveying. Material drops are minimised.

Technical description
Material is transferred using closed conveyors, pneumatic conveying (although it may be associated with ~~note the~~ higher energy needs). Special attention is paid to minimising material drops as much as possible~~and minimising~~.

Achieved environmental benefits
Reduction of uncontrolled diffuse emissions to air.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
Pneumatic conveying requires additional energy.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[62, UK Environment Agency 2002], [64, UK Environment Agency 2002], [1, COM 2017], [169, TWG 2021]

3.2.1.5.4 Vacuum cleaning of moulding and casting process areas

Description
The moulding and casting process areas in sand moulding foundries are regularly vacuum cleaned.

Technical description
Vacuum cleaning of the moulding and casting shop in sand moulding foundries, with the exception of areas where the sand has a technical or safety-related function, e.g. the pouring area, and with the exception of hand-moulding jobbing foundries;

Achieved environmental benefits
Reduction of uncontrolled diffuse emissions to air.

Cross-media effects
None.

Technical considerations relevant to applicability
May not be applicable in areas where the sand has a technical or safety-related function.

Economics
The technique does not involve any significant additional investment or operational cost.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[62, UK Environment Agency 2002], [64, UK Environment Agency 2002], [1, COM 2017], [169, TWG 2021]

3.2.1.5.5 Substitution of alcohol-based coatings with water-based coatings

Description
Substitution of alcohol-based coatings of moulds and cores with aqueous coatings. Aqueous coatings are dried in ambient air or using drying ovens. See Section 3.2.1.9.12.

3.2.1.5.6 Emissions control from quenching baths

Description
This includes the following:

- Minimising the generation of emissions from quenching baths by using water-based polymer solutions (e.g. containing polyvinylpyrrolidone or polyalkylene glycol).
- Collecting emissions from quenching baths (especially from oil quenching baths) as close as possible to the emission source, using roof ventilation, extraction domes or edge extractors. Extracted off-gases may be treated, e.g. by using a fabric filter (see Section 3.2.1.10.4).

Technical description
To establish certain metallurgical properties, steel castings are subjected to heat treatments. It may be necessary for the parts to be rapidly cooled. Usually liquid or gaseous substances such as water, oil or compressed air are used for quenching of castings.

Emission capture and reduction essentially involves the capture of fume at the quenching baths, especially at the oil quenching baths. Roof ventilation, extraction domes and edge extractors are used. Here similar difficulties arise as with shake-out grids. The baths must be frequently loaded by a crane, so the extraction hoods need to be installed high above the hall floor.

Abatement systems are not widely applied at this point in general, but if any abatement is performed, electrostatic filters are mostly used.

A new system has also been developed where quenching baths are filled with a polymer solution. The polymer solution consists of an aqueous polyvinyl concentrate with anti-rust, anti-foam additives and preservatives. It contains no hazardous ingredients and is non-flammable.

By changing the concentration of the polymer solution, different cooling curves can be realised. This is particularly inspired by similar oil-cooling curves, where the disadvantages of quenching in oil emulsions such as oil fumes, odour nuisance and fire hazards can be avoided.

By using a polymer solution with a concentration between 12 % and 15 %, similar hardness and delay results can be achieved compared to an intense high-quenching oil.

Usually aqueous solution at concentrations between 5 % and 15 % are used. Polymer basic materials are usually products based on polyvinylpyrrolidone (PVP), polyalkylene glycol (PAG). [133, DE UBA 2014]

Achieved environmental benefits
In case of oil-based quenching of castings, extraction of exhaust gases results in reduction of diffuse emissions of oil-mists.

Advantages of using polymer solution compared to the use of oil-water emulsion for quenching are:

- favourable emission characteristics;
- lower odour nuisance;
- not combustible.

Environmental performance and operational data
In terms of emissions, the use of polymer solutions offers significant advantages over the use of quenching oil. Thermal stress of the quenching oil at a temperature range between 120 °C and 300 °C results in increasing oil vapour rates. Higher temperatures may lead to formation of cracked gases. In case of incomplete combustion, flue gases may result containing carbon monoxide, hydrocarbons, oil vapour, aldehydes, carbon black, partly also aromatic or polycyclic hydrocarbon compounds.

By using polymer solution vapour is minimised and no dip flame are produced so that no fumes are released.

The following table summarises operational data for quenching with polymer solutions.

Table 3.29: Operational data quenching

Pool size	Ca. 30m^3
Content	30 000 litres
Rec. concentration	10 – 30 %
Application temperature	20 – max. 50 °C
Source: [133, DE UBA 2014]	

Cross-media effects
Extraction of exhaust gases consumes energy.

In the case of polymer-based quenching, due to the extreme thermal stress of the polymer components during the quenching process, formation of thermal degradation products, such as short-chain hydrocarbon compounds or carbon dioxide, can be expected. Anyhow, the total amount of emitted organic substances is lower compared to the use of oil. No measuring and analytical data are available. [133, DE UBA 2014]

Technical considerations relevant to applicability
Generally applicable.

The ~~applicable~~ usually applied extraction techniques for different types of baths are characterised in Table 3.30.

Table 3.30: ~~Applicability of~~ Usually applied fume collection techniques for quenching baths

	Roof ventilation	Dome-shaped roof	Dome, rigid	Dome, adjustable	Edge extraction
Water	x				
Emulsion	x	x	x	x	x
Hardening oil	x	x	x	x	x
NB: x : applicable *Source*: [14, CAEF 1997]					

Edge extractors are only effective up to a certain size and lose their effectiveness almost completely at the time of the highest emissions, i.e. when a hot workpiece is submerged in the bath. In spite of this, edge extraction is the most sensible capture measure, utilising big baths combined with a blast veil and a roof dome.

The following factors may influence the applicability of polymer-based quenching:

- Check whether the required cooling curves can be realised. Certain cooling curves may not be possible.

- Technically, existing oil quenching baths (pools, tanks for oil emulsion) can be usually converted for application of polymer solution without problems.
- The quenching baths of polymer solution may require more space. [133, DE UBA 2014]

Economics
Application of the polymer-based quenching technique does not require additional installations. Significant changes in the operating, maintenance and disposal costs are not to be expected either. [133, DE UBA 2014]

Driving force for implementation
- Regulations on emissions and occupational health and safety.
- Legal requirements.

For polymer-based quenching, the following were reported:

- favourable emission behaviour with respect to organic substances in comparison to an oil bath;
- simple control of the concentration which is responsible for the quenching effect;
- occupational safety: no risk of fire.

Example plants
Extraction of emissions from quenching ~~The technique~~ is ~~used~~ applied in several foundries around Europe.
Polymer-based quenching: Stahlwerke Bochum GmbH 44791 Bochum, Germany.

Reference literature
[14, CAEF, 1997] [133, DE UBA 2014]

3.2.1.6 Channelled emissions to air

3.2.1.6.1 Limiting the number of emission points

Description
The combined treatment of waste gases with similar characteristics ensures more effective and efficient treatment compared to the separate treatment of individual waste gas streams. The extent to which the number of emission points can be limited depends on technical (e.g. compatibility of the individual waste gas streams) and economic factors (e.g. distance between different emission points). Care is taken that limiting the number of emission points does not lead to the dilution of emissions.

Technical description
In order to obtain maximum advantage from thermal buoyancy, hot emissions may be combined into the minimum practicable number of chimneys. A multiplicity of discharge points may thus be avoided. This is particularly important when new plants are being designed or when changes are being made to existing processes.

Foundries are generally equipped with more than one furnace, and several moulding, core-making and casting lines may be used in the same plant. Emissions from the same type of processes that are generating waste gases with similar characteristics are combined and treated together for better treatment effciciency and to reduce the energy consumption associated with the operation of multiple abatement systems.

Achieved environmental benefits
Gathering multiple off-gas streams into one stack allows control of the emissions and increases the total volume (and load) going to treatment and thus reduces the total emission level.

Energy savings and improved abatement efficiency of emissions to air are other benefits.

Environmental performance and operational data
In a number of foundries, several emission points are often combined, e.g.:

- emissions form the same type of furnaces may be combined into one (e.g. melting furnaces / heat treatment furnaces);
- emissions from parallel moulding / core-making lines;
- emissions from casting, cooling and shake-out operations.

Cross-media effects
None expected.

Technical considerations relevant to applicability
Generally applicable.

Economics
Costs will depend on technical (e.g. compatibility of the individual waste gas streams) and economic factors (e.g. distance between different emission points).

Driving force for implementation
Reduction of monitoring and abatment costs due to a lower number of emission points.

Example plants
Widely used in foundries.

Reference literature
[62, UK Environment Agency 2002]

3.2.1.7 Emissions to air from thermal processes

3.2.1.7.1 Selection of an appropriate furnace type

Description
Selection of the appropriate furnace type(s) based on the level of emissions and technical criteria, e.g. type of process such as continuous or batch production, furnace capacity, type of castings, availability of raw materials, flexibility depending on raw materials' cleanliness and alloy change. The energy efficiency of the furnace is also considered (see Section 3.2.1.3.1).

Technical description
Given the fact that various melting techniques show overlapping fields of application, a basic technique is the selection of the melting technology. In this selection, the decisive criteria include:

- metal type (alloying concept);
- continuous or batch production;
- size of the series (long or short series production/product portfolio);
- metal throughput or capacity;
- flexibility towards input material type and cleanliness;
- flexibility towards alloy change;
- type of product made;
- overall production volume;
- emissions and other environmental considerations;
- availability of raw materials;
- availability of fuels/electricity.

The application of the different melting techniques is very dependent on the criteria indicated above. In addition, considerations based on the energy efficiency of the various furnaces and potential melt losses associated are also key factors to consider. This is discussed separately in Section 3.2.1.3.1).

For cast iron production, the following generalities can be made~~deduced~~:

- *Metal type*: Electrical furnace are better ~~placed~~ suited for production of nodular or alloyed cast iron.
- *Continuous production:* Cupola is better ~~placed~~ suited for continuous production of cast iron.
- *Batch production*: Electrical or rotary furnace ~~is~~ are better placed for batch production of cast iron.
- *Flexibility towards input material type and cleanliness*: Cupola ~~is better placed~~ allows better flexibility towards input materials (e.g. use of scrap of lower quality).
- *Flexibility towards alloy change*: Induction and rotary furnace ~~is better placed~~ offer better flexibility in terms of alloy change.~~;~~
- *Environmental considerations*:
    - cupola is better placed only if well de-dusted;~~, cokeless show better environmental performance than HBC or CBC~~
    - induction furnaces have a lower CO, SO_2, NO_X, dioxin emissions and slag formation rate than cupola furnaces; indirect emissions from electricity production need to be considered. ~~, but this it needs to be borne in mind there will also be emissions from the required electricity production.~~
- *Availability of raw materials:* When cheap scrap is available, the cupola is better placed.

~~In fact~~When selecting an appropriate furnace type, all these criteria must be considered together. Table 3.31 gives a summary of the criteria to consider when choosing between cupola, induction or rotary furnaces in the case of cast iron production~~, based on the technical considerations~~. Furthermore, economic data for the various cupola types and the induction furnace are given in Section 9.1 (Annex 1).

As shown in Section 9.1 (Annex 1), the use of cupola furnaces for production of lamellar cast iron or nodular iron has been shown to be more cost-effective only for total throughputs above 10t/h and 20t/h, respectively. Accordingly, induction or rotary furnaces, which provide a better environmental performance overall than cupola furnaces, are often a preferred choice in small foundries.
~~On the basis of the stated criteria, the replacement of the cupola by induction or rotary furnaces may be considered. The selection of induction or rotary furnaces is given priority over cold blast cupolas for small foundries casting a variety of products in several European countries (e.g. Austria, Belgium (Flanders)).~~

Table 3.31: Technical choice of the melting equipment for cast iron melting

CRITERION		ONLY GREY CAST IRON					GREY + NODULAR	ONLY NODULAR CAST IRON			ONLY MALLEABLE CAST IRON
Type of product made		Counter weights	Sewer castings, pipes, urban furniture	Enameled castings, heating appliances	Mechanical parts		Mechanical parts	Sewer castings, pipes, urban furniture	Mechanical parts		Mechanical parts
Size of series		Medium to large	All	Medium to large	Batch to small	Medium to large	All	All	Batch to small	Medium to large	Medium to large
Cupola	Cold blast	++	++ (<10 - 15 t/h)	++ (<10 - 15 t/h)		++ (<10 - 15 t/h)			(+)		
	Hot blast	+	++ (>10 - 15 t/h)	++ (>10 - 15 t/h)	0	++ (>10 - 15 t/h)		++ (>10 - 15 t/h)	0	+ (>10 - 15 t/h)	
	~~Cokeless~~				~~0~~	~~+~~		~~+~~	~~0~~	~~+~~	
Induction			+	+	++	++	++	+	++	++	++
Rotary furnace		(+) batch			++	+	++	(+) batch or small series	++		++

NB:
++: technically more adapted;
+: technically adapted
(+): adapted in some cases
0: not adapted
Source: [100, TWG 2002]

Achieved environmental benefits
Replacement of a cupola by an induction or rotary furnace results in a reduction in the direct emissions of CO and SO_2 and a reduced amount of slag. Induction furnaces show a reduced emission of NO_x and a lower risk of dioxin formation. The indirect emissions generated by the use of induction furnaces, depend on the local electricity generation infrastructure.

Environmental performance and operational data
See Section 9.1 (Annex 1) for cast iron production.

Cross-media effects
Replacement of a cupola by an induction furnace generates a strong increase in electricity consumption.

Technical considerations relevant to applicability
The replacement of a cold blast cupola by an induction or rotary furnace is applicable under the criteria stated above and upon major refurbishment of the installation.

For new installations, the criteria of Table 3.31 apply besides local and site-specific considerations. If cupola and induction or rotary furnaces are indicated as most adapted, the induction and rotary types may be preferred on the basis of their environmental benefits.

Economics
A survey of economic data for the various types of cupola furnaces and for the induction furnace is given in Section 9.1 (Annex 1).

In Table 3.32 a summary is given of cost data collected by an example Spanish foundry that wanted to replace an existing cupola by a rotary or electric furnace. No emission collection or filtration equipment costs are included. Data are from 1997 - 1998. The comparison involves the following three systems:

- cold blast cupola: 3.5 tonnes/h capacity;
- oxy-fuel~~gas~~ rotary furnace: 3 tonnes capacity;
- 2 medium frequency induction furnaces: 2 + 1 tonne capacity.

The cost calculation was performed for melting costs for a melting production of 1 tonne/h, working 8 hours/day. For the induction furnace a distinction is made between peak-time electricity costs and off-peak-time. Since electricity is the major component of the costs, this distinction makes a big difference to the final cost. Operation of the induction furnace during off-peak time (night-time) results in costs comparable to rotary furnace costs. The data show that the investment has a 5-9-year payback period.

Table 3.32: Example plant cost data for replacement of an existing cupola with a rotary or induction furnace

Costs in EUR/tonne of molten metal	**Cupola**	**Rotary**	**Induction**	
Energy	30.7	29.8	40.8 27.2	(peak) (valley)
Refractory	3.6	1.3	1.4	
Man power	52.9	22.7	22.7	
Raw materials	205	205	205	
Total cost	292	259	270	
Yearly costs in EUR				
Cost for melting 1320 tonne/year	385000	341000	356000 338000	(peak) (valley)
Savings	none	44000	29000	(peak)

			47000	(valley)
Investment	none	250000	260000	
Building		Not needed	Needed	

Data from 1997 - 1998, Spain
[100, TWG 2002]

Driving force for implementation

- Reduction of direct emissions from cast iron melting.
- Legal requirements.

Example plants

~~Most Austrian foundries, which are small and medium-sized enterprises, have changed from cupola melting to induction furnaces. As a consequence there are only three Austrian foundries left which still use cupola melting.~~

Reference literature

[100, TWG 2002] [38, VITO 2001], [120, TWG 2003]

3.2.1.7.2 Use of clean scrap

More information on the technique

See Section 3.2.1.3.4.

3.2.1.7.3 Techniques for maximising the thermal efficiency of furnaces

More information on the technique

See Section 3.2.1.3.2.

3.2.1.7.4 Use of a fuel or a combination of fuels with low NO_X formation potential

Description

Fuels with a low NO_X formation potential include natural gas and liquefied petroleum gas.

Technical description

In order to reduce or control NO_X emissions, a fuel or a combination of fuels with low NO_X formation potential can be used. This technique generally involves the use of fuel gas (e.g. natural gas) instead of liquid fuels. Fuel gas usually has a low content of nitrogen compounds and complete combustion is achieved more easily than with liquid fuels.

Achieved environmental benefits

Reduced NO_X emissions.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation
Legal requirements.

Example plants
Many plants use natural gas as fuel gas. Some plants also reported the use of LPG.

Reference literature
[169, TWG 2021]

3.2.1.7.5 Use of a fuel or a combination of fuels with low sulphur content

Description
Fuels with low sulphur content include natural gas and liquefied petroleum gas.

Technical description
In order to reduce or control SO_2 emissions, a fuel or a combination of fuels with low sulphur content can be used. This technique generally involves the use of fuel gas (e.g. natural gas) instead of liquid fuels. Fuel gas usually has a low content of sulphur compounds (e.g. H_2S, mercaptans) and complete combustion is achieved more easily than with liquid fuels.

Achieved environmental benefits
Reduced SO_2 emissions.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
Legal requirements.

Example plants
Many plants use natural gas as fuel gas. Some plants also reported the use of LPG.

Reference literature
[169, TWG 2021]

3.2.1.7.6 Low-NO_X burners

Description
The technique (including ultra-low-NO_X burners) is based on the principle of reducing peak flame temperatures. The air/fuel mixing reduces the availability of oxygen and reduces the peak flame temperature, thus retarding the conversion of fuel-bound nitrogen to NO_X and the formation of thermal NO_X, while maintaining high combustion efficiency.

Technical description

Low-NO_X burner is a general term for a series of burners that combine several design features to reduce the NO_X emission level. The main principles of these burners are the reduction in peak flame temperature, the reduction in residence time in the high-temperature zone and the reduction in oxygen availability in the combustion zone. This is generally achieved by air staging, fuel staging and/or internal flue-gas recirculation. [168, COM 2021]

A common mode of operation of low-NO_X burners is the creation of a fuel-rich zone within the flame. This favours the conversion of fixed nitrogen, chemically bound fuel-nitrogen, to N_2. It also has the effect of reducing the peak flame temperature. Both fuel and thermal NO_X mechanisms are retarded and the formation of NO_X is reduced. There are two main types of low-NO_X burners which both involve the use of staged combustion to achieve the desired effect. These are air-staged and fuel-staged burners.

Achieved environmental benefits

- Reduced NO_X emissions.
- Increased energy efficiency.

Environmental performance and operational data

Two foundries in the SF data collection reported the use of low-NO_x burners:

Plant AT015

NO_X emissions from an annealing furnace equipped with low-NO_X burners (emission point N.6) ranged from 30 mg/Nm^3 to 120 mg/Nm^3 using natural gas and the corresponding CO emissions ranged from 34 mg/Nm^3 to 70 mg/Nm^3.

Plant DE065

NO_X emissions from a heat treatment furnace (roller hearth furnace) equipped with low-NO_X burners (emission point N.3) ranged from 18 mg/Nm^3 to 66 mg/Nm^3 using natural gas and the corresponding CO emissions ranged from 0.8 mg/Nm^3 to 18 mg/Nm^3.

Cross-media effects

None.

Technical considerations relevant to applicability

Applicability to existing plants may be restricted by design and/or operational constraints.

Economics

No information provided.

Driving force for implementation

Legal requirements.

Example plants

[AT015], [DE065]

Reference literature

[168, COM 2021], [169, TWG 2021]

3.2.1.7.7 Oxy-fuel combustion

More information on the technique

See Section 3.2.1.3.7.

3.2.1.8 Emissions to air from heat treatment

3.2.1.8.1 Selection of an appropriate furnace type

More information on the technique
See Section 3.2.1.7.1.

3.2.1.8.2 Techniques for maximising the thermal efficiency of furnaces

More information on the technique
See Section 3.2.1.7.3.

3.2.1.8.3 Use of a fuel or a combination of fuels with low NO_X formation potential

More information on the technique
See Section 3.2.1.7.4.

3.2.1.8.4 Low-NO_X burners

More information on the technique
See Section 3.2.1.7.6.

3.2.1.8.5 Off-gas extraction as close as possible to the emission source

Description
Off-gases from heat treatment furnaces (e.g. annealing, ageing, normalising, austempering) are extracted using hoods or cover extraction. The collected emissions may be treated using techniques such as fabric filters (see Section 3.2.1.12.7).

Technical description
More information on applied extraction systems is provided in Section 3.2.3.1.3.

Achieved environmental benefits
Reduction of emissions.

Environmental performance and operational data
See Section 3.2.3.1.3.

Cross-media effects
Off-gas extraction increases the energy consumption.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[169, TWG 2021]

3.2.1.9 Emissions to air from core-making and moulding using lost moulds

3.2.1.9.1 Use of best practices for green sand moulding

Description
This includes techniques such as:

- precise addition of the required quantity of key components (e.g. clay, water, coal dust or other additives) to restore the chemical properties of the returned green sand;
- when needed, addition of new silica sand (e.g. up to 10 %) to the returned green sand and disposal of an equivalent amount of spent sand;
- regular testing (e.g. daily) of the green sand properties (e.g. moisture, green strength, compactability, permeability, loss on ignition, volatile content).

Technical description
After pouring iron and steel into green sand moulds, the heat evaporates some water from the sand and burns some of the additives (e.g. coal dust) and a proportion of the clay destroying its bonding properties. It is essential to restore the sand properties by removing burnt clay, coal dust and ash and adding in new clay, coal dust (or dextrin) and water. The following additions are usually carried out at the sand reconditioning mill:

- 0.3-0.5 % of new clay;
- 0.3-0.5 % of coal dust (or 0.2 % dextrin);
- 1.5-2.5 % of water.

Another priority is that new sand must be added on a continuous basis to the returned sand in the ratio of about 10 % of the weight of metal poured, or 2-3 % of the sand mixed. Often foundries consider that the sand returned via cores is sufficient, but experience showed that this can create extensive problems. Indeed, care must be taken because certain core binder residues (particularly from phenolic-isocyanate binders) can degrade the green sand properties.

Good green sand control is essential and depends on careful monitoring of the sand system. The normal additions of clay, coal dust or other additives at each cycle represent only about 10 % of the total active clay or coal present in the system. It is important to bear in mind that changing the total clay or coal dust content quickly is not possible since any change takes about 20 cycles to work its way fully into the system. For example; an addition of 0.3 % clay is usually sufficient to maintain the total clay level at 3.0 %. If the clay addition is increased to 0.4 %, the total clay content after one cycle will only rise to about 3.1 % and it will take 20 cycles (about 1 week) for the clay level to rise to around 4.0 %.

Regular testing of the green sand quality is very important. It is recommended that a minimum of five samples are taken per shift and analysed for key parameters such as: moisture, green strength, compactability and permeability. In addition, the loss on ignition (LOI) and the volatile content should be monitored on a daily basis. It is also good practise to keep a record of the following:

- weight of clay, coal dust and new sand added each day;
- number of moulds made;
- weight of iron poured;
- weight of used sand removed from the system each day.

Achieved environmental benefits
Reduced emissions during pouring.

Environmental performance and operational data
Typical green sand properties for an iron foundries are summarised in the following table.

Table 3.33: Typical green sand properties in iron foundries depending on the type of moulding

Type of moulding	Jolt or squeeze moulding machines	Automatic moulding machines (e.g. DISA)
Water content (%)	3 – 4	2.5 – 3.2
Green strength (kPa / psi)	70 – 100 kPa / 10 – 15 psi	150 – 200 kPa / 22 – 30 psi
Compactability (%)	45 – 52	38 – 40
Permeability	80 – 110	80 – 100
Live clay (%)	5.0 – 5.5	6.0 – 10.0
Volatiles (%)	2.5	2.0
LOI (%)	7.0 – 7.5	6.0
Source: [73, Brown, J. R. 2000]		

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Material efficiency - minimisation of the number of casting defects.
- Environmental requirements.

Reference literature
[73, Brown, J. R. 2000]

3.2.1.9.2 Preparation of clay-bonded sand by vacuum mixing and cooling

More information of the technique
See Section 3.2.1.4.4.3.

3.2.1.9.3 Substitution of coal dust

Description
Coal dust is replaced by clays (e.g. bentonite) containing additives such as graphite, coke flour and zeolites, resulting in significantly lower diffuse emissions during the casting process.

Technical description
The addition of coal dust in green sand has been shown to greatly improve the stripping of the iron castings after pouring as well as the surface finish of castings. This is due to the formation of lustrous carbon during the heating of the coal dust by the liquid iron which improves the casting surface finish. However, coal dust typically has a volatile content ranging from 33 % to 36 %, generating significant emissions during casting.
To minimise emissions while maintaining the surface finish of castings, coal dust replacement may be used. They generally consist of blends of natural clays (e.g. bentonites) to which additives which may contain essential volatiles are added (e.g. graphite, coke flour, zeolites).

Presently, one of the best substitutes is graphite in combination with an adequate dispersing agent.

Achieved environmental benefits
Reduction of VOCs and odour emissions. The reduction ratio depends on the core sand inflow. The positive effect regarding emissions depends on the following factors: [133, DE UBA 2014]

- reduced or no use of lustrous carbon formers (coal);
- enhanced adsorption of emerging casting gases that result mainly from core binders;
- filtration measurements of operating moulding sands from core-intensive green sand systems. Comparing coal-free products with traditional moulding sand additives shows that the reduction of condensates and dust formation during casting can be over 50 %.

Resulting environmental benefits are: [133, DE UBA 2014]

- cleaner workplace: less smoke; carbon monoxide concentrations at the workplace are reduced by approximately 50 %;
- benzene emissions are reduced by approximately 40 %;
- blends have a higher percentage of bentonite than traditional blends with coal; consumption is related to bentonite, so less blend (not bentonite) is used, resulting in less truck loads needed (5-10 %);
- increased possibilities of moulding sand reuse, due to lower content of pollutants and condensates;
- smaller air extraction and filter installations and less cleaning/maintenance.

Environmental performance and operational data
In general, inorganic coal replacements do not emit VOCs during heating/casting. Due to this, they cannot generate lustrous carbon (graphite film from pyrolysis) and carbon residues. Coal replacements are in general graphite, specially treated graphite, coke flour, porous minerals and swelling minerals. Each producer can have a different composition depending on their own research and experience. Products are customised and can be blended with traditional coal-containing products.

Bentonite binders should be of high quality and have a high clay/montmorillonite content to reduce accumulation of accompanying non-clay minerals.

Bentonite preference:
- 85 % montmorillonite,
- durability 50 % after heating the clay for 2 hours at 550 °C,
- compression strength according to VDG P69, above 8 N/cm^2 and
- wet tensile strength above 0.25 N/cm.

Product classification: not dangerous and no auto-ignition, if not blended with coal.
[133, DE UBA 2014]

The use of a mixture containing bentonite, microcrystalline graphite and zeolite instead of coal dust for iron casting was tested by the University of Science and Technology of Krakow, showing that emissions of VOCs and BTEX were reduced by 50 %. [190, Holtzer et al. 2000]

Cross-media effects
None.

Technical considerations relevant to applicability
- Applicability may be restricted by operational constraints (e.g. less efficient shake-out or occurrence of casting defects).

- The technique is applicable as a pure inorganic binder system or as a blend in combination with classical products (coal). It is added to the moulding sand like a traditional moulding sand binder or blends.
- Applicability considerations may arise because of poorer behaviour during shake-out (separation casting and mould) and occurrence of specific casting defects.

Economics
Coal-free blends have higher raw material costs. This can be partly compensated by reduced consumption and by the lower operation cost for air extraction, such as for a smaller installation, less cleaning and maintenance. Less contaminants in the moulding sand waste make it easier to reuse it in other applications and industrial sectors. Savings in transport costs can be achieved due to coal replacement by minerals of which less is needed.

Driving force for implementation
- Legal requirements regarding reducing emissions and regarding occupational health reasons.
- Local requirements.
- Operational requirements:
    - normal moulding sand practice;
    - less/no penetration defects, grey iron casting;
    - in the case of coreless production, no air extraction is required;
    - waste sand is cleaner.

Example plants
- Iron foundry Componenta in Heerlen/NL.
- The use of a mixture containing bentonite, microcrystalline graphite and zeolite instead of coal dust for iron casting is implemented in a few foundries in the EU. [190, Holtzer et al. 2000]

Reference literature
[73, Brown, J. R. 2000], [133, DE UBA 2014], [190, Holtzer et al. 2000]

3.2.1.9.4 Use of cereal binders

Description
Cereal binders (e.g. starch, dextrins) are added to increase the toughness of the sand and prevent fracture of the compacted sand during mould drying.

Technical description
Cereal binders (e.g. starch and dextrins) are used mainly in steel casting production, but occasionally in iron casting for specific applications. Cereals tend to increase green strength, dry strength and sand toughness, but sometimes can also reduce flowability.

Dextrins promote better flowability and plasticity. They help with moisture retention and are particularly useful in providing harder and less friable mould surfaces and edges when drying out.

Starches are very good anti-scabbing agents and typically the higher the amount of starch, the greater the resistance to expansion scabbing. Starch is more effective in preventing expansion scabbing than a dextrin and should be employed when making larger green sand moulds.

Achieved environmental benefits
- Increased material efficiency.
- Reduced emissions during pouring.

Environmental performance and operational data
The proportion of cereal binders to new green sand typically ranges from 0.5 % to 0.75 %. Cereal binders lose ther properties at temperatures above 225 °C. It is recommended to add between 0.1 % and 0.25 % of cereal binders at each recycle depending on the amount of cereal burn-out.

Cross-media effects
None.
Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
Minimisation of the number of casting defects.

Example plants
No information provided.

Reference literature
[73, Brown, J. R. 2000]

3.2.1.9.5 Minimisation of binder and resin consumption

More information on the technique
See Section 3.2.1.4.3.3.

3.2.1.9.6 Use of best practices for cold-setting processes

More information on the technique
See Section 3.2.1.4.3.5.

3.2.1.9.7 Use of best practices for gas-hardening processes

More information on the technique
See Section 3.2.1.4.3.7.

3.2.1.9.8 Use of non-aromatic solvents for cold-box core production

Description
Non-aromatic solvents are used that are based either on protein or animal fat (e.g. fatty acid methyl esters of vegetable oil) or on silicate esters in order to reduce emissions of VOCs (e.g. benzene, toluene).

Technical description
Classical cold-box systems use organic solvents. These cause releases of noxious and odorous VOCs during core production and storage. Furthermore VOC emissions (benzene, toluene, xylene) occur during pouring, cooling and shake-out. Alternative solvents for cold-box core production are based on protein or animal fat (e.g. vegetable-oil methyl esters) or on silicate esters. These solvents are not noxious to workers health, nor inflammable and therefore transport and storage are easier.

The low volatility of the vegetable-oil methyl esters enhances the storage capabilities in humid atmospheres and their persistence when applying water-based coatings.

The resulting cores have a higher strength, lower sticking of the sand and good shake-out properties.

Achieved environmental benefits
There is no vaporisation due to the high boiling point (about 300 ºC) and thus there is no solvent odour emission during storage.
VOC emissions are reduced during core manufacturing and storage, and (more importantly) during pouring, cooling and shake-out.

Environmental performance and operational data
Table 3.34 shows operational emission values for benzene, toluene, xylene and phenol, as measured in one aluminium green sand foundry. Measurements were performed both at the shake-out grate and in the exhaust-air stack. Data are given for the traditional cold-box system and for one using vegetable-oil based solvents. A clear reduction in BTX and C emissions is observed (25-50 % of stack emissions).

Table 3.34: Emission data for cold-box core systems in an aluminium foundry, measured at the shake-out grate and in the exhaust-air stack

Compound	At shake-out			At exhaust-gas stack		
	Aromatic based (mg/m³)	Vegetable-based (mg/m³)	Difference (%)	Aromatic based (mg/m³)	Vegetable-based (mg/m³)	Difference (%)
Benzene	0.08	0.05	- 44	0.1	0.07	- 30
Toluene	0.12	0.05	- 58	0.08	0.06	- 25
Xylene	0.09	0.04	- 56	0.09	0.05	- 41
Phenol	14.8	14.6	- 2	7.2	6.57	- 9
Total C	61.0	29.5	- 52	37.0	18.5	- 50
Source: [88, Hüttenes-Albertus 2002]						

Results of emission measurements in a German iron foundry are given in Table 3.35. For this table, the measured emission of each compound is expressed relative to the emission of the same compound for the aromatic-based system. For example: the emission of toluene at the second cooling is only 58 % of the toluene emission for the aromatic system. The table shows a clear reduction of VOC emissions in the second cooling and shake-out phase.

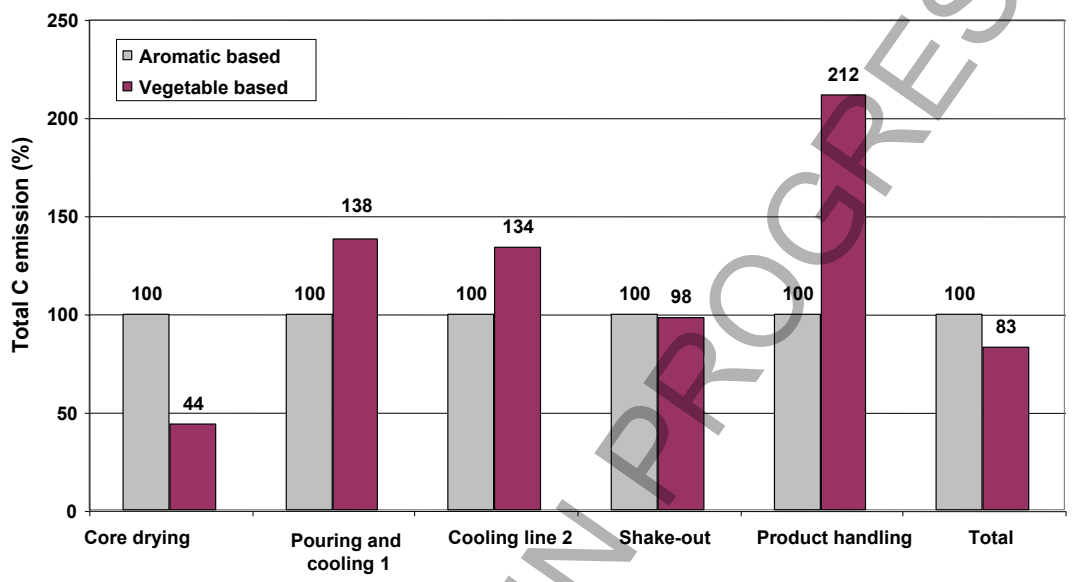
Table 3.35: Emissions (%) of selected compounds from vegetable-based cold-box core systems

	Benzene	Toluene	Xylene	Phenol
Pouring and cooling 1	83	100	100	100
Cooling 2	78.5	58	46	74
Shake-out	78	78	78	12
Emission data expressed as %, relative to emission of the aromatic based system (set at 100 % for each measurement) Source: [114, Hobelsberger et al. 1997]				

The total mass flow reduction of the specified compounds was:

- benzene: - 21 %;
- toluene: - 26 %;
- xylene: - 30 %;
- phenol: - 62 %.

A survey measurement of the total carbon emission over the full foundry process is given in Figure 3.33. The data show that the vegetable-based solvents partially result in a shift of emissions from the core-making area to the finishing area. Nevertheless, an overall reduction of 17 % carbon emission reduction is reached.



NB: Values in % expressed relative to emission of the aromatic based system.
Source: [114, Hobelsberger et al. 1997]

Figure 3.33: Total carbon emissions from various process steps, using aromatic- and vegetable-based solvents

Cross-media effects

Vegetable-based solvents cause increased fume production during pouring and (in the case of die-casting) upon opening of the die. This is due to the low evaporation and consequently high residual solvent content upon pouring. This effect does not occur with silicate ester solvents.

Protein and animal fat based solvents produce a distinctive odour, and have been reported to cause odour problems inside the foundry.

Technical considerations relevant to applicability

Generally applicable.
~~Non-aromatic solvents can be applied in all processes using cold-box sand. The technique is relatively new and operational results as stated above need to be confirmed through repeated application. The technique has been implemented in foundries for the full range of automotive castings, as well as in castings for machinery, and in the construction and electronics industry. Both ferrous and non-ferrous applications are reported.~~

Economics

Data from the Italian foundry association indicate that non-aromatic solvents have a cost that is double that of the aromatic equivalent, e.g. EUR 0.82/kg against EUR 0.36-0.48/kg.

Operational data from a large series ferrous foundry showed that binder prices for aromatic cold box were around EUR 2/kg (2001) and went up with some 30 %, upon changing to the non-aromatic system. After one year (2003), the price lowered again however, to a level 10 % above the price of the traditional system.

Driving force for implementation
- Reduction of VOC and odour emissions.
- Legal requirements.

Example plants
Widely used.
~~The technique is reported to be used in large-scale foundries in Germany.~~

Reference literature
[49, Inasmet and CTIF 2002], [88, Hüttenes-Albertus 2002], [100, TWG 2002], [114, Hobelsberger et al. 1997], [120, TWG 2003]

3.2.1.9.9 Use of best practises for hot-curing processes

Description
Several hot-curing processes may be used and a series of measures are in place to optimise each process including for the following:

Hot-box process:
- Curing is carried out within the optimum temperature range (e.g. 220 ºC to 300 ºC).
- Cores are usually pre-coated using water-based coatings to prevent burns at the core surface which may result in brittleness during pouring.
- Core blowers and the area around them are well ventilated and exhausted to capture efficiently the formaldehyde liberated during curing.

Warm-box process:
- Curing is carried out at a lower optimum temperature range than the hot-box process (e.g. 150 ºC to 190 ºC), resulting in lower emissions and energy consumption than the hot-box process.

Shell (Croning):
- Pre-coated sands with a phenol-formaldehyde resin are binded using hexamethylenetetramine that decompose at 160 ºC releasing formaldehyde, necessary for cross-linking the resin, and ammonia.
- The curing and/or core blowers area is well ventilated and exhausted to capture efficiently the ammonia and formaldehyde liberated during curing.

Technical description
Hot-box process
The hot-box core-making method employs a starting sand mixture comprised of resin binders and a liquid catalyst. A wide range of resins can be used: urea-formaldehyde, urea formaldehyde-furfuryl alcohol, urea-formaldehyde-phenol. The catalysts are aqueous solutions of ammonium chloride or ammonium nitrate (acid salts), with urea additions to reduce the free formaldehyde. Cores are usually pre-coated using water-based coatings to prevent burns at the core surface. The mixture is blown into the interior of the core box and polymerisation takes place by applying heat. The heat generates an acid vapour from the catalyst which triggers the hardening reaction. Heat is conducted from the outer regions of the sand core to the interior regions and, although the curing action starts at temperature as low as 50 °C, it is necessary to reach temperatures within the range of 220 °C to 300 °C for complete polymerisation of the sand core within a short period of time (e.g. 5 to 10 seconds in the case of thin cores, the curing time may vary depending on the size and shape of the cores). It is essential to capture emissions from core blowers and ensure that the work area is well ventilated and exhausted.

Warm-box process
The warm-box process is very similar to the hot-box process; it only differs in the type of resins used that are curing at a lower temperature and in the type of catalyst used. In the warm-box

process, the binder is based on furfuryl alcohol (with a typical composition containing around 70 % mass furfuryl alcohol or a low polymer of furfuryl alcohol). Curing takes place at a lower optimum temperature range than the hot-box process (e.g. 150 ºC to 190 ºC), resulting in lower emissions of formaldehyde and ammonia and lower energy consumption than the hot-box process. The catalysts are copper salts derived from aromatic sulphonic acids; in water or alcohol solution, they are nitrogen-free. The resins are formulated to a low nitrogen content (less than 2.5 wt-%).

Shell (Croning)

This process is the only one among all moulding and core-making processes that uses pre-coated sand, directly available from suppliers and ready for use. Sand is pre-coated with a solid phenolic novolak resin and a catalyst to form a dry, free-flowing material. The coated sand is blown into a heated core box or deposited onto a heated pattern, causing the resin to melt and harden. In this process, the catalyst is in the form of hexamethylenetetramine (as a hardener) that decomposes at at 160 ºC, releasing formaldehyde, necessary for cross-linking the resin, and ammonia. When core boxes are used, they should be made of cast iron and heated to 250 ºC. The minimum curing time is 90 s, but 2 minutes is usually employed. It is essential that the core blowers area is well ventilated and exhausted to efficiently capture the ammonia and formaldehyde liberated during curing.

Achieved environmental benefits

- Reduction of formaldehyde, ammonia and VOC emissions.
- Increased energy efficiency in the case of the warm-box process.

Environmental performance and operational data

Hot-box resins contain 4 % to 10 % free formaldehyde and 6 % to 13 % nitrogen (the catalyst containing about 15 % to 25 % nitrogen). The formaldehyde odour is irritating and is most apparent at the core-making station. Nitrogen is also present and emitted in the form of ammonia.

The emissions will generally contain formaldehyde in a concentration range of 0.1 ppm to 0.75 ppm. By capturing these emissions, the odour level in the ambient air around the process station is substantially reduced after opening of the core box.

The warm-box process leads to substantial energy savings of about 15-25 % compared to the hot-box process.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

The cost of the resins used in the warm-box process are substantially higher than the resins used in the hot-box process.

Driving force for implementation

Legal requirements.

Example plants

Hot-box process: [AT006, Line 2], [ES094, Line 1], [IT132, Line 3], [PL137, Line 1]
Warm-box process: [DE076, Line 2]
Shell (Croning): [AT006, Line 1], [DE039, Line 1], [FR119, Line 3], [PL138, Line 1]

Reference literature

[73, Brown, J. R. 2000], [191, Holtzer et al. 2015]

3.2.1.9.10 Use of aliphatic organic binders

Description
Use of organic binders based on aliphatic polyalcohols, instead of aromatic binders.

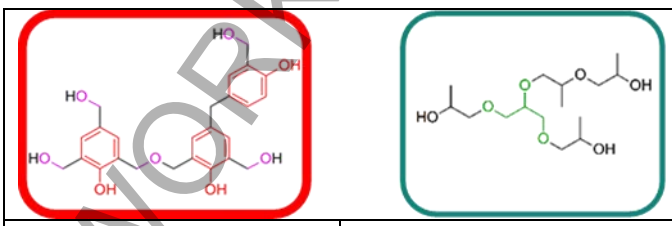
Technical description
The use of organic binders is necessary in numerous applications for process and casting quality reasons and is state of the art in many foundries. Nevertheless, they cause harmful emissions in all application steps (especially when using aromatic compounds), e.g. during the preparation of moulds, moulding and after casting (cooling and demoulding). These emissions are highly problematic both from an occupational hygiene perspective and for environmental reasons; indeed emissions can also contain high contents of phenol and BTEX, for example.

Organic binders for the formation of moulds in a foundry are currently nearly completely based on resins derived from phenol or furfuryl alcohol, both used in combination with formaldehyde. These are designated as aromatic organic binders. As an intrinsic property, these materials decompose during the casting, resulting in highly detrimental emissions containing high levels of aromatic compounds, e.g. phenol or benzene (BTEX). The monomeric components phenol and furfuryl alcohol are toxic. Also, the formaldehyde used is toxic, especially in its monomeric form. The solvents, mainly also aromatic solvents, used for the resin and the hardener are highly volatile and evaporate during use. During casting, the polymeric structures based on furfuryl alcohol or phenol decompose, which results in a release of the toxic monomers or derivatives of these compounds. Often higher aromatic compounds are formed from the recombination of fragments. The abatement of these emissions requires high investments and running costs. Since any input of aromatic substances in the process leads to increased aromatic emissions, the problem cannot be solved as long as aromatic substances are employed. Only the extent of emissions during the formation of the moulds might be slightly influenced by reducing the content of free monomers in the starting materials of these resins.

Alternatively, it is possible to use a resin that is based only on aliphatic polyalcohols in order to avoid the use of harmful aromatic monomers. This resin has proven to deliver a high technical performance in the preparation of casting moulds while significantly reducing the level of emissions during casting. It is designated as an aliphatic organic resin.

The new binder is also a two-component system consisting of resin and hardener. The final product formed is a polyurethane, similar to the final product obtained with the phenolic resin and hardener system but the resin is now based on a fully aliphatic structure. The aliphatic organic resin contains only aliphatic compounds, mainly polyalcohols. None of the compounds used are toxic or dangerous and do not require labelling for hazardous material.

Environmental performance and operational data
The basic difference between the phenolic organic binder and the new aliphatic organic binder is shown in Figure 3.34.

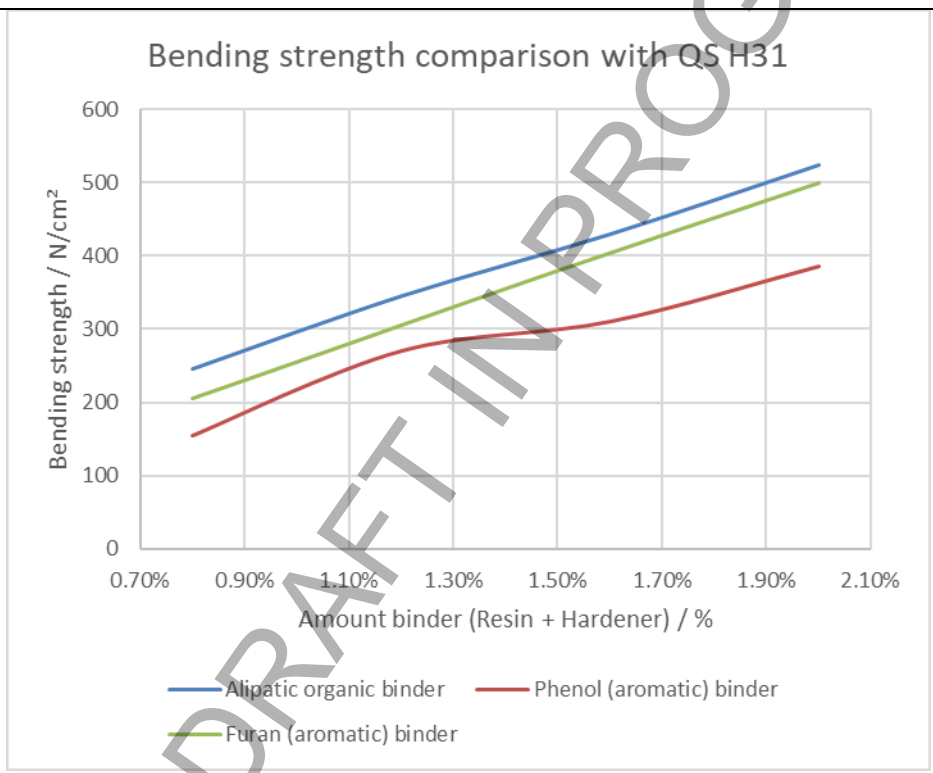


Phenolic (aromatic) organic resin	Aliphatic organic resin
Source: [143, DE 2019]	

Figure 3.34: Structural elements of phenolic (aromatic) organic resin compared to aliphatic organic resin

Using the aliphatic organic resin, there is no need to use volatile aromatic solvents, significantly reducing the risk of exposure during preparation of the mould. The hardener can be changed in the composition as a result. While an isocyanate is still used as an active ingredient, the corresponding solvents can be adapted to solvents less prone to cause emissions and pollution.
In terms of preparation and technical performance, the resin and hardener are mixed together with the moulding material. Using quartz sand with different grain sizes as moulding material, a strong bending flexural strength can be observed.

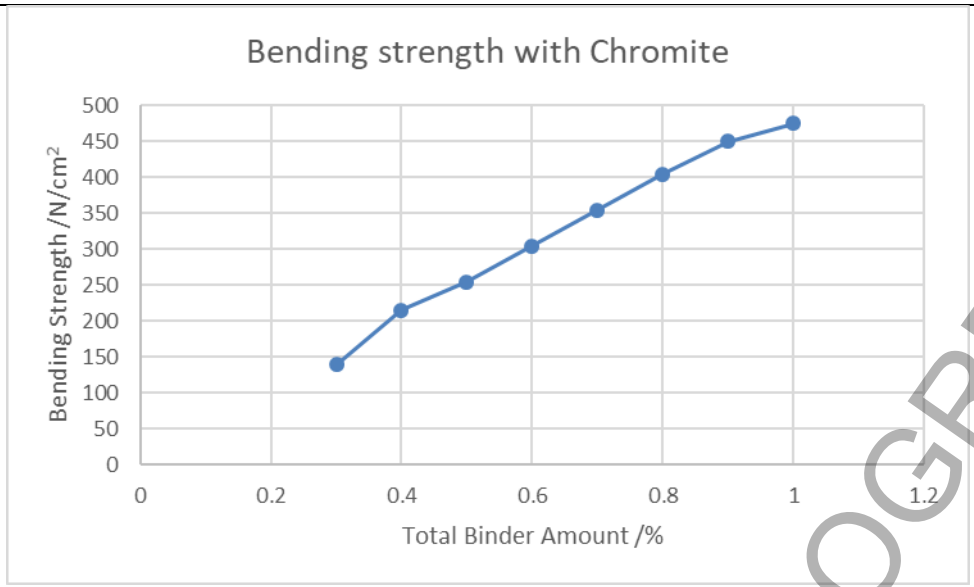
A comparison of the flexural bending strength of all three binders (furan, phenol and the alternative aliphatic organic binder) is shown in Figure 3.35. The results show a favourable bending strength using similar binder amounts for the new binding system.



Source: [143, DE 2019]

Figure 3.35: Bending strength comparison of the aliphatic organic binder, phenol (aromatic) binder and furan (aromatic) binder with quartz sand

With different types of moulding materials, a high bending strength has also been demonstrated as shown with chromite in Figure 3.36. This high strength provides the option of using reduced amounts of binder in the formation of the mould, which results in significant environmental benefits.



Source: [143, DE 2019]

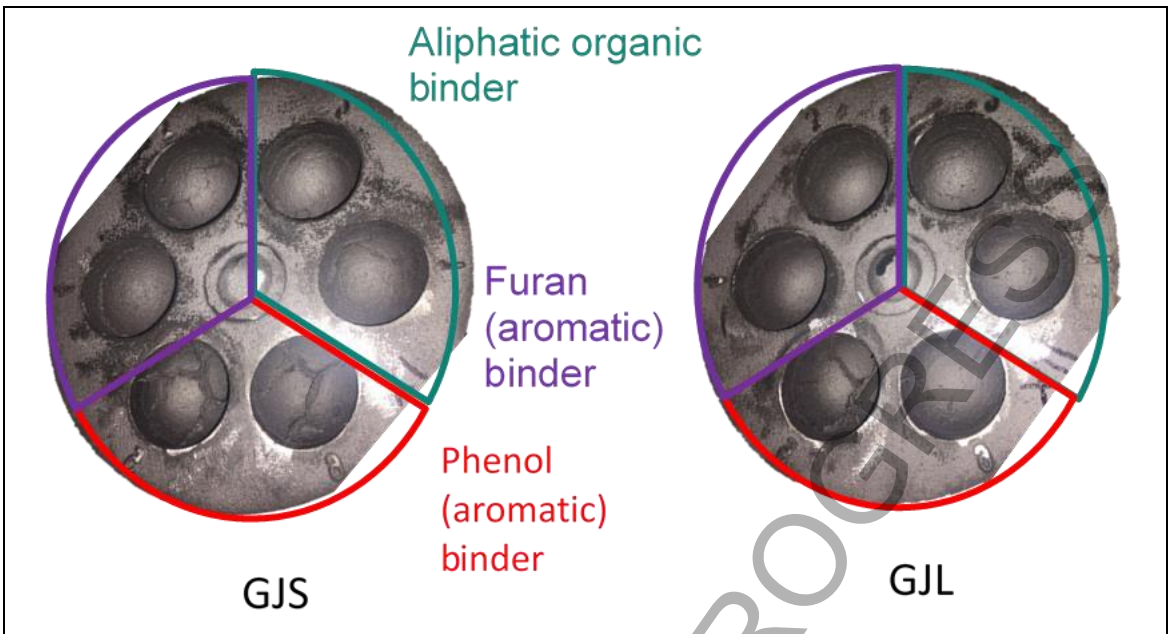
Figure 3.36: Bending strength of the aliphatic organic binder with chromite

The handling time for formation can be adjusted to the needs depending of the amount of catalyst used in the reaction. The catalyst used is usually a tertiary amine in small amounts (0-0.3 % catalyst based on the total amount of binder). The amine can be mixed into the resin during production of the binder or added afterwards in the overall mixture. The binding material is compatible with bentonite moulds, which are used in combination.

The reclamation of moulding materials based on the new aliphatic organic binder results in similar values to a phenolic (aromatic) binder.

The amount of gas developed when heated is similar to a phenolic (aromatic) binder.The gas permeability is also similar to the permeability of the phenol (aromatic) binder.

The tendency for casting errors was investigated by a standard test. The results for testing of veining properties is shown in Figure 3.37. A tendency to be less prone for casting errors is directly visible. Even a phenolic (aromatic) binder used in combination with additives does not allow a similar result. These observations have been confirmed at several foundries using different metals. The binder can actually be used for a wide range of metal applications ranging from aluminium and magnesium to iron casting and steel. Furthermore, the quality of the casting surfaces have been highly satisfactory.



Source: [143, DE 2019]

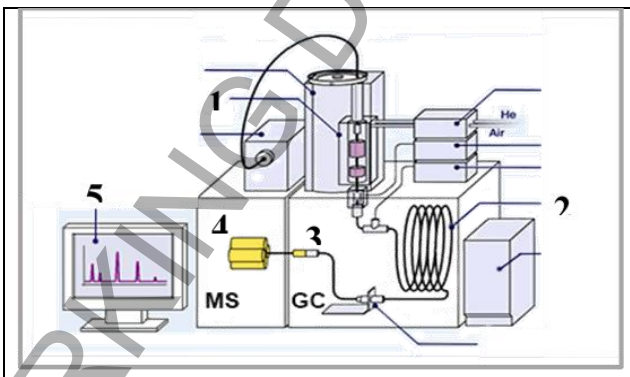
Figure 3.37: Iron casting – Veining comparison

Achieved environmental benefits

Due to the avoidance of hazardous and toxic monomers combined with the use of less volatile and hazardous solvents/additives, emissions during casting and the quantity of hazardous substances in the remaining moulding material during reclamation or deposition are greatly reduced.

This has been investigated in pyrolysis experiments and in measurements in a foundry at all steps along the process chain (mould formation - casting- remaining moulding material).

The pyrolysis measurements were based on GC-MS techniques. The basic set-up is shown in Figure 3.38.

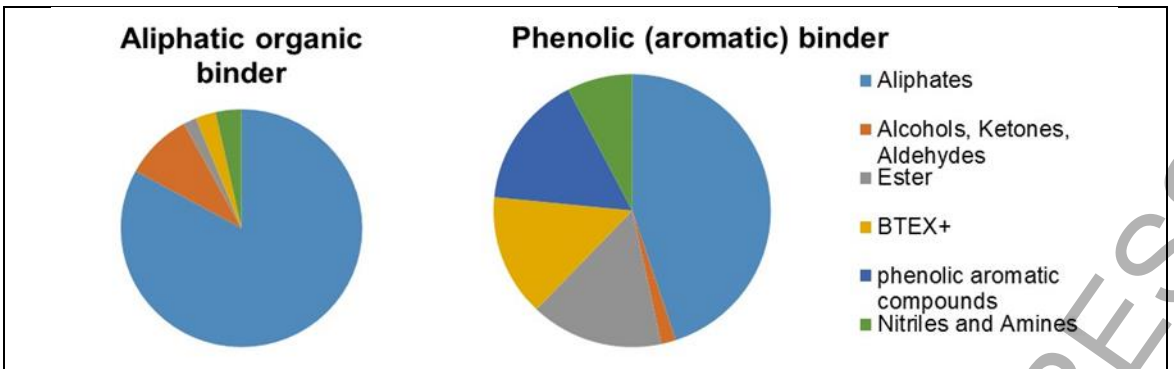


Source: [143, DE 2019]

Pyrolysis of binder sample (1)
- Separation of fragments (2)
- Determination of amount (3)
- Identification (4)
- Analysis(5)

Figure 3.38: GC-MS set-up for pyrolysis

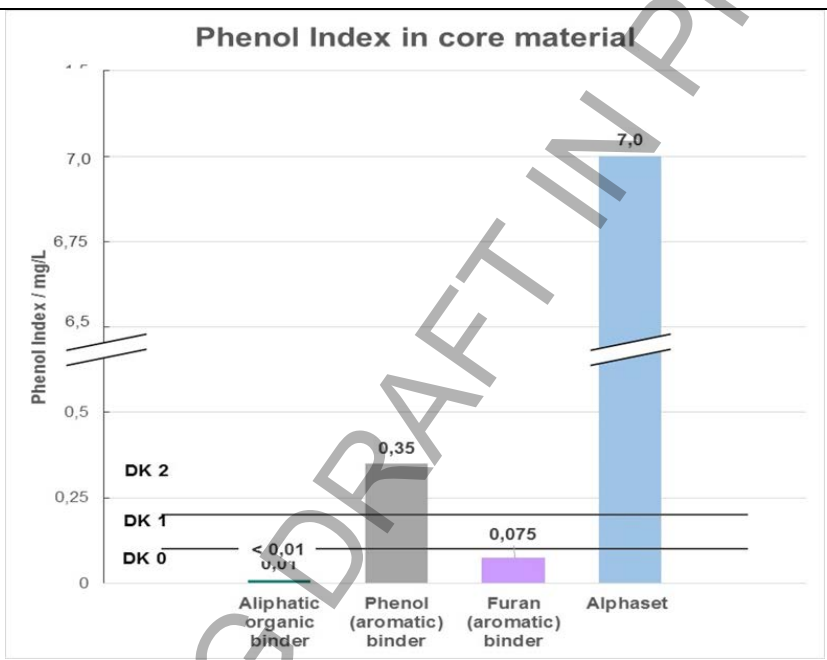
The results of the pyrolysis measurements are shown in Figure 3.39, showing a reduction of aromatic compounds in the composition of the aliphatic organic binder resulting in a significantly reduced amount of hazardous emissions especially of aromatic components (BTEX).



Source: [143, DE 2019]

Figure 3.39: Distribution of type of compounds detected after pyrolysis

Measurements of the phenol index in the core material in a foundry were also performed during formation of the mould and during casting. Samples of the remaining moulding materials were taken for analysis. In Figure 3.40 a summary of the results is shown.



Source: [143, DE 2019]

Figure 3.40: Phenol index in core material

Table 3.36 shows the results of emission measurements (moulding and casting), realised at a foundry utilising aliphatic organic binders, for a number of chemical compounds including diisocyanates, ammonia, benzene, formaldehyde, isopropylalcohol, triethylenediamine. This analysis shows that low emissions of hazardous substances can be achieved, mainly diisocyanates, phenol, formaldehyde and aromatic compounds.

Table 3.36: Selected compounds in analysis during mould formation and casting

Parameter	Moulding (mg/m^3)	Casting (mg/m^3)	Emission limit value (mg/m^3)
2,4-toluene diisocyanate (2,4-TDI)	<0.001	-	0.035
2,6-toluene diisocyanate (2,6 TDI)	<0.001	-	0.035
Hexamethylene diisocyanate (HDI)	<0.001	-	0.035
Methylene diphenyl diisocyantate (MDI)	<0.001	-	0.05
Aromatic compounds (C7-C8)	0.043	0.064	200
Aromatic compounds (C9-C10)	0.019	-	100
Ammonia	-	<0.19	14
Benzene	0.040	<0.012	3.25
Formaldehyde	0.026	-	0.37
Isopropylalcohol	0.0017	0.3	500
CO	-	7.8	35
NO	-	0.18	0.63
NO_2	-	0.35	0.95
Triethylenediamine	<0.001	-	-

Source: [143, DE 2019]

Cross-media effects
None.

Technical considerations relevant to applicability
Only applicable to cold-setting processes.

Economics
In terms of process, this technique is similar to the work with the aromatic binders. Therefore, no additional cost for infrastructure adaptations are necessary.

The direct cost of the new binders are slightly higher than that of the aromatic binders.

However, potential savings may arise from the following:

- The reduction of volatile solvents during moulding, leading to savings in protective measures and reduced health risks for the workers. A direct effect is also seen in the air ventilation system, resulting in a reduced volume needed.
- The observed improvement in the casting quality constitutes a significant benefit for the foundry. This results in time savings for grinding and polishing, which are very labour-intensive. It also reduces the overall number of casting defects.

Driving force for implementation
Legal requirements.

Example plants
This technique is mainly in use in foundries situated in Germany, but it has also been tested in Austria and Switzerland. The total number of companies using this technique is around 15 (at the end of 2019).

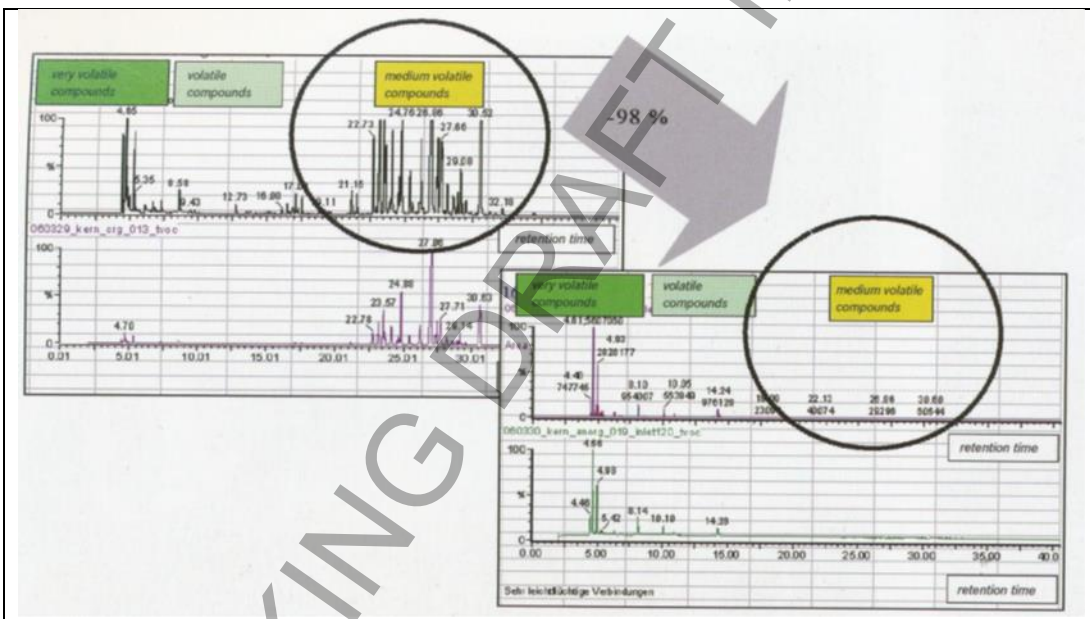
Reference literature
[143, DE 2019]

3.2.1.9.11 Use of inorganic binders in aluminium die-casting

Description
Inorganic binders such as sodium silicates (water glass) hardened using, for example, CO_2, organic esters are used in aluminium die-casting.

Technical description
Inorganic binder systems are used in aluminium die-casting foundries. They combine a liquid component (a modified sodium silicate solution) with additives known as promoters, which contain high concentrations of minerals. The system is cured by use of heated tools. Flushing the system with hot air removes moisture and helps to optimise curing times and storage times of the cores.

Achieved environmental benefits
- Prevention of amine emissions in core-making.
- Reduction of 98 % of the organic carbon emissions and odour emissions after pouring, compared to organic cold-box binders.
- Reduction of energy consumption and related CO_2 and air pollutant emissions: 20 % of die-casting compared with die-casting using urethane cold box cores or hot-box cores. Specific energy consumption per tonne of mixed sands:
  - 0.089 kWh per tonne mixed sand (quartz sand, 2.95 % inorganic binder & promoter);
  - 1.723 kWh per tonne mixed sand (quartz sand, 1.2 % urethane cold box binder, part 1 and 2).
- Reduction of noise (less tool cleaning).



Source: [133, DE UBA 2014]

Figure 3.41: Reduction of organic emissions using inorganic binders in aluminium die-casting

Environmental performance and operational data
Aluminium serial production of automotive castings:

- 5 000 to 150 000 castings per year.
- BMW foundry in Landshut, Germany (in 2010):
  1. foundry processes using sand cores: gravity die casting, low pressure die-casting;
  2. 45 000 t aluminium and magnesium castings (only high pressure die casting): cylinder heads, motor blocks.
- Adapted core shooting machine, gassing equipment and sand reclamation plant.

- Core box temperature: 180 °C.
- Curing air temperature: 150 °C.
- Gravity die-casting, low-pressure die-casting.

Cross-media effects
Energy consumption for curing of inorganic binders with heat (drying process). Note: For the urethane cold-box process, curing is carried out without heat by using the catalyst amine.

Thermal sand regeneration (600 °C to 700 °C) is performed with a reclamation efficiency of 90 % to 95 %.

Technical considerations relevant to applicability
The technique is applicable in foundries with aluminium gravity die-casting and low-pressure die-casting and serial production, with short-term core storage in the case of hot and wet climates.

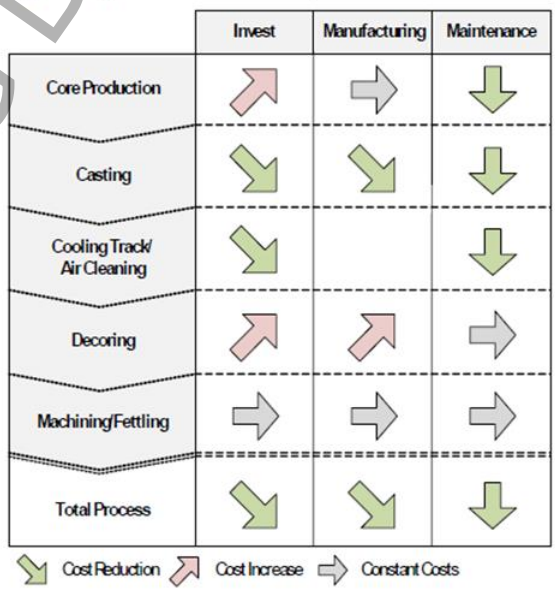
The conversion of an existing foundry line needs many process stages (see Economics). It also needs heated core boxes made of metal; many SME foundries use core boxes made of wood or plastics.

In the die-casting process there is only one kind of sand, which is a precondition, using inorganic binders in serial production. In iron or steel foundries, for example, there is a self-curing no-bake sand system or there are green sands with cores. In both processes, there is no alternative to organic binders.

Economics
Conversion of an existing foundry or production line
When using inorganic binders, all stages of an aluminium foundry process have to be adapted: die design, core box design, sand mixer, heated core box, core shooting machine, gassing (hot air) equipment, core handling and storage (climate-dependent), thermal sand reclamation.

Building of a new foundry or production line:

Investment and running costs: there is an advantage compared to a foundry or a production line with the urethane cold-box process.



Source: [133, DE UBA 2014]

Figure 3.42: Depiction of economic aspects

- Productivity increase +10 %.
- Tool maintenance -50 %.
- Tool cleaning -75 %.
- Manufacturing cycle time (casting) -10 %.
- Thermal post-combustion of the exhaust air -100 %.

The economic effects of the application of this BAT candidate depend on numerous factors and cannot be described in more detail.

Driving force for implementation
Sustainability within production:

- Reduction of emissions, exposure and fire risk.
- Improvement of aluminium casting quality: lower temperature of the die (< 200 °C) therefore smaller dendrite arm spacing in Al castings and higher strength.
- Higher productivity and less maintenance (-50 %) compared to a foundry process with urethane cold-box cores

Example plants
- BMW AG, Landshut, Leichtmetallgießerei.

Users of other kinds of inorganic binders with heat hardening: VW Nutzfahrzeuge Gießerei, Hannover and Posnan, DC Foundry.

Reference literature
[133, DE UBA 2014]

3.2.1.9.12 Substitution of alcohol-based coatings with water-based coatings

Description
Substitution of alcohol-based coatings of moulds and cores with aqueous coatings. Aqueous coatings are dried in ambient air or using drying ovens.

Technical description
Coatings are applied to the surface of moulds and cores to create a refractory barrier at the mould-metal interface and to ensure a good surface appearance. Coatings serve to reduce veining, erosion and metal penetration defects and also help to reduce finishing operations. The carrier liquid forms a suspension with the base material. In this way, the coating material can be processed. Such carrier liquids are generally water or alcohol. Alcohol-based coatings are mainly based on isopropyl alcohol (IPA - isopropanol). The coating is dried by evaporation or by a burning-off of the solvent. This produces VOC emissions. Water-based coatings have been developed as an alternative.

Before the cores and mould parts are assembled together to prepare the final mould, cores and mould parts must be completely dry. The drying process depends on the size and geometry of the parts to be dried. Large parts or parts with varying formats, which have been typically made from furan or phenolic resin-bonded moulding materials (cold resin process), must be dried for several hours or days in the hall. For smaller parts with unvarying shapes, a drying oven can be used.

If drying is supported by using heat, energy consumption and energy efficiency might be an issue. A newly developed drying oven, already used in foundries, shows increased energy efficiency. In this drying oven, the airflow is optimised in a way that the air jet can be guided directly to the coated mould surface. With this airflow, the air temperature can be set below 90 °C.

The advantages of water-based coatings are:

- safety (no fire risk);
- workers' health (less exposure to organic compound vapours);
- reduced costs of reagents (water vs. alcohol);
- mostly better surface finish of castings.

The difficulties for implementation are:

- the need for greater (process) time and space; also, cores need a longer drying time, which results in the need for a drying line, passing through a drying furnace;
- changing the process requires a case-by-case optimisation period;
- growth of bacteria, which cause short shelf-life of coatings (1-2 weeks) and causes odour emissions;
- cost of re-approval by specific customers in aerospace and defence related applications.

Water-based coatings can be dried in ambient air, or by using a drying furnace or a microwave or an infra-red furnace. They generally need a longer drying time compared to alcohol-based coatings. The drying does not generate noxious emissions, but may cause odour emissions. Drying is done using a drying line, which transports the cores from the core-making to the mould assembly, thus allowing for the necessary drying time. The line may also pass through a drying furnace. Microwave and infra-red drying is applied for small, medium and large series.

The different rheological properties of water-based coatings compared to solvent-based coatings has necessitated the development of new application techniques. These allow a constant coating quality.

Achieved environmental benefits
The main advantage of using aqueous coatings and drying in the ambient air is the reduced diffuse solvent emissions. No additional energy is needed for drying in ambient air.

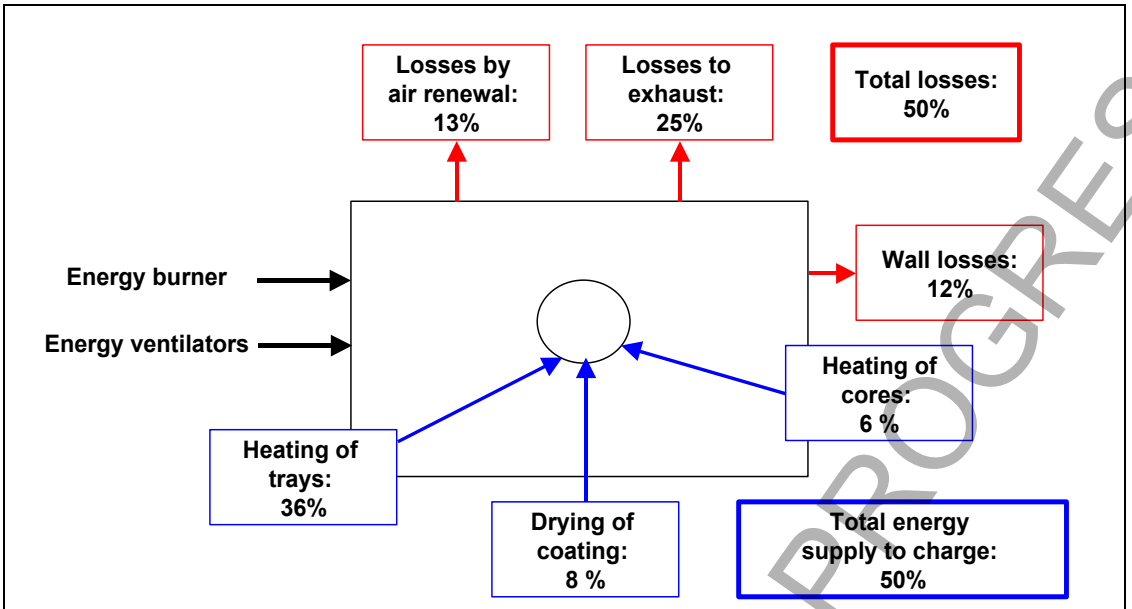
If use of aqueous coating is combined with the use of newly developed (energy-efficient) drying ovens, energy consumption and related CO_2 emissions are reduced compared to the use of traditional drying ovens.
~~A life cycle assessment (LCA) study evaluated the impacts of water- and alcohol-based coatings. The use of water-based coatings with drying in ambient air shows clear environmental benefits, mainly due to the reduced emission of VOCs and the low energy use. When a stove is used for drying, the reduced emissions are partially counterbalanced at the LCA level by an increased energy use. The overall environmental index using a drying stove shows a small benefit over isopropyl alcohol (IPA) use and burning-off.~~

Environmental performance and operational data
Changing from IPA-based to water-based coatings is becoming more widespread in various foundries nowadays. Automotive foundries have changed the majority of their production to water-based, leaving solvent-based coatings being used only for specific applications (see applicability).

Operational data were obtained from a Dutch foundry. When drying in ambient air, the air velocity is the main factor (rather than temperature or humidity). In order to allow sufficient air velocity over the drying trajectory, additional fans and ventilators were installed in the foundry. In order to reach a good and constant quality, the fines content of the (regenerated) core-making sand was reduced. Water-based coatings can cause a swelling of the fine residual (bentonite and coal dust) particles, which then causes core defects.

Operational data ~~were~~ obtained from a foundry in France, operating a ~~stove~~ dryer with a capacity of 540 cold-box cores, which is heated with a natural gas burner. Two ventilators are used to evacuate the fumes and to mix the fresh air. The design temperature of the hot air is 165 ºC. A heat balance was set-up on the basis of measurements using 0.4 kg cores with a

humidity of 5.5 %. The balance, as given in Figure 3.43, applies for a throughput of 390 cores, which is equivalent to 72 % of full capacity.



Source: [49, Inasmet and CTIF 2002]

Figure 3.43: Thermal balance of a ~~stove~~dryer for core drying, working at 72 % capacity

The balance shows that 50 % of the energy is lost, with indeed effectively less than 10 % being used for core drying. The balance gives a consumption of 8.5 kWh per kg of water evaporated, which corresponds to 465 kWh per tonne of cores at a throughput of 156 kg/h. When the dryer ~~stove~~ works at a lower capacity rate, the losses increase further. Similar measurements in another foundry confirmed the high (> 50 %) losses and low (< 10 %) effective energy use. Energy efficiency can be increased using microwave drying. This ~~will be~~ is discussed in Section 3.2.1.3.10.

Newly developed energy-efficient drying ovens make the use of water-based coatings less energy-demanding compared to previously used ovens. The following table describes operational data of newly developed drying ovens and compares them to the previous technique.

Table 3.37: Operational data for new developed drying oven

	Previously used drying ovens	Newly developed drying ovens
Thermal processing power [kW]	400	225
Electrical power input [kW]	30	55
Drying time [h], castings with 10 tonnes	3,5	1,9
Drying time [h], castings with 5 tonnes	2,7	1,4
Drying time [h], castings with 3.5 tonnes	2,8	1,4
Mean specific energy consumption [kWh/t]	303	79
Source: [133, DE UBA 2014]		

Cross-media effects

None, if drying takes place in ambient air. Higher energy consumption and related CO_2 emissions arise when conventional drying ovens are used compared to alcohol-based coatings. Energy consumption can be reduced by using drying ovens with improved energy efficiency (see Environmental performance and operational data above).

Aqueous coatings contain a variety of (organic) chemicals to enhance their properties. This may affect the emission profile upon shake-out.
Drying the aqueous coating results in an increased volatilisation of binder solvents. This may cause increased odour emissions, due to the evaporation of BTX-containing core solvents.

Water-based coatings require a higher use of energy due to transport (during air drying) and drying in a furnace.

Drying in ambient air may result in a reduction of the air temperature in the foundry. In a Dutch foundry, an overall reduction of the ambient temperature of 2 ºC was experienced. This results in a higher consumption of fuel for heating during wintertime.

Technical considerations relevant to applicability
Applicability may be limited in the case of large or complicated casting shapes because of difficulties for the drying air to penetrate.

Not applicable to water glass-bonded sands, to magnesium casting or to the production of manganese steel with MgO coating.

The implementation of water-based coatings is applicable for new and existing large-scale, large series foundries. For new and existing small-scale foundries, the implementation may be hindered by technical or economic factors.

Water-based solvents can be used in most situations. However, alcohol-based coatings cannot be replaced in some specific applications and will still need to be used:

- for ~~big~~ large or complicated moulds/cores, where drying problems may occur due to difficulties for the drying air to penetrate;
- for water glass bonded sands;
- in Mg casting: water creates $Mg(OH)_2$ and thus causes technical problems;
- in the production of manganese steel with MgO-coating.

The use of aqueous coating and the mould/core drying time require consideration of certain aspects of the production process:

- size of the cores or moulds and their increasing drying time with greater size;
- processing times;
- space in the foundry for the storage of forms/cores.

In the planning of a new foundry, these three variables should be taken into account.

In particular, in existing foundries, area and space requirements can be limits, which are not possible to overcome.

Economics
The investment cost depends on several factors, such as the available space for a drying line in the foundry, the choice of the drying technique, and the need to adapt the sand mix.

The complete replacement of alcohol-based coatings by water-based coatings in a Dutch iron foundry, using ambient air drying involved a total investment of EUR 71 000. This included the installation of ventilators and optimisation of the sand quality. A reduction of the IPA-emission of 161 tonne/yr corresponded to EUR 62.5/tonne IPA emission reduction.

The operational costs involve increased controls of the coating and cores (viscosity, layer thickness, water content, product quality) and amount to EUR 9 000/yr. Drying 1 tonne of coating consumes 2 100 kWh of energy.

On the benefits side of the economics balance is the reduction in expenses for the purchasing of solvent. For bigger foundries, examples exist where investment in a water-based system was paid back in 2 years, on the basis of the reduced purchasing costs of the IPA~~alcohol~~ only.

The operational cost of drying is EUR 0.01/kg (2002 data, non-ferrous foundry in France).

The drying of mouldings coated with water-based coatings requires more space and increased production time.

The table below compares economic aspects of the application of a newly developed efficient drying oven with the previously applied drying technique.

Table 3.38: Expenditure in drying ovens

	Previously used drying ovens	Newly developed drying ovens
Investment (10-year amortisation) [EUR]	420 000	500 000
Maintenance costs per year [EUR]	4 200	5 000
Casting capacity per year [t]	4 000	7 000
Energy costs per ton of casting [EUR]	16.00	4.80
Total cost per ton of casting [EUR]	27.55	12.66
NB: 2013 data. *Source*: [133, DE UBA 2014]		

In total, savings of up to 54 % can be achieved when applying the new drying technique.

There are no energy costs for drying in ambient air. Costs for space requirements are variable.

Driving force for implementation

~~Pressure from authorities increasing attention to the emissions of organics.~~

- Avoidance of of solvent-based emissions in the work areas of the core shop and the moulding shop.
- Improved safety (no fire risk).

Example plants

- PSA Sept-Fons (FR)
- Fonderie Bréa, Montluçon (FR)
- De Globe b.v., Weert (NL).

Air-drying

- Stahlwerke Bochum GmbH, DE
- Heger Ferrit GmbH, DE
- C. Grossmann Stahlguss GmbH, DE

Drying in oven

- AVA GmbH, Magdeburg

Reference literature

[43, infoMil 1999], [49, Inasmet and CTIF 2002], [53, Beauvais et al. 2001], [133, DE UBA 2014]

3.2.1.9.13 Selection of a low-emission cold-setting binder system

Description
A cold-setting binder system generating low emissions of formaldehyde, phenols, furfuryl alcohol, isocyanates, etc. is selected. This includes the use of:

- no-bake furan resins with low furfuryl alcohol content (e.g. less than 25 wt-%);
- no-bake phenol/furan systems with a low-sulphur acid catalyst;
- inorganic geopolymers based on polysialates ;
- ester silicate;
- alkyd oil;
- resol-ester;
- cement.

Technical description
Cold setting binders generating low emissions can be selected. This includes the use of the following binder systems:

- *No-bake furan resins with low furfuryl alcohol content (e.g. less than 25 wt-%):* No-bake furan resins are based on the polycondensation of furfuryl alcohol using an acid catalyst and are modified using formaldehyde, urea or phenol. Since the entry into force of the Regulation (EC) No 1272/2008, the furan resins containing furfuryl alcohol above 25 % are classified as toxic. See Section 3.2.1.4.3.5 for further information.
- *No-bake phenol/furan systems with a low-sulphur acid catalyst*: See Section 3.2.1.4.3.5 for further information.
- *Inorganic geopolymers based on polysialates*: The use of geopolymeric inorganic binders has been developed in the Czech Republic. It is based on polymers containing polysialates which contains chains of tetrahedrons of SiO_4 and AlO_4. At the start, the binder has a low degree of polymerisation but during the hardening reaction, which may be triggered by heat or by the use of hardeners, a higher degree of polymerisation is reached. During this process, no odours are generated and the geopolymers emit extremely low quantities of VOCs in comparison to other more conventional moulding or core-making techniques. Furthermore, it is possible to reclaim the sand mixture when using this type of binder. The inorganic geopolymer binders may be used in cold-setting processes, gas curing systems using CO_2 (see Section 3.2.1.9.14) and in hot-curing processes (See Section 3.2.1.9.15).
- *Ester silicate:* In the ester silicate process, sand is mixed sodium silicates (typically within 2.5 % to 3.5% are used depending on the sand grade). A liquid organic ester hardener (e.g. glycerol diacetate, glycerol triacetate) is added (10-12 % based on the weight of silicate). Often, breakdown agents are also added. The curing process takes usually between 20 to 120 minutes.
- *Alkyd oil:* There are no emissions during the production of cores and moulds when using cold-setting. Odour emissions are only observed when heat is used for curing alkyd oil binders.
- *Resol-ester*: The resol-ester resin contains unreacted phenol and formaldehyde, but their emissions are extremely low and environmentally insignificant.
- *Cement*: The use of cement as a binder is not widespred but has been used for the production of heavy steel castings as well as other alloys. In this case, silica sand containing about 11 % Portland cement and 6 % water can be used in a boxless block moulding system using mounted patterns in temporary wood frames There are no environmental issues associated with this technique.

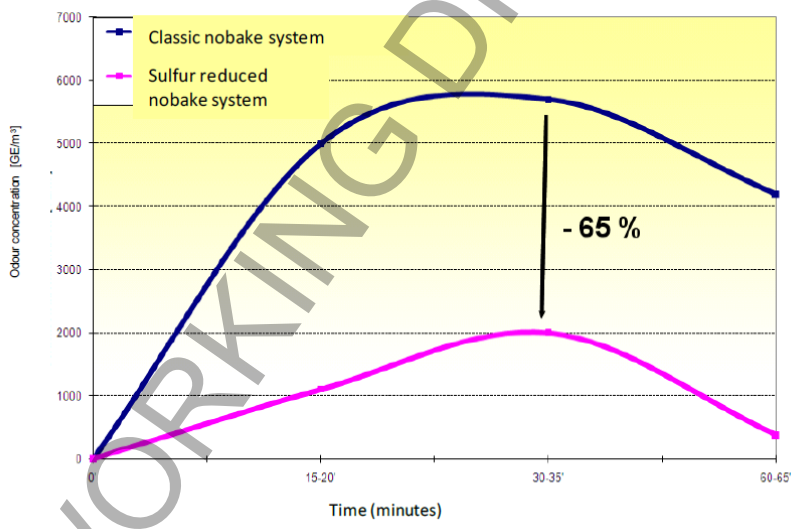
Achieved environmental benefits
Reduced emissions of VOCs.

Environmental performance and operational data

- *No-bake furan resins with low furfuryl alcohol content (e.g. less than 25 wt-%):* See Section 3.2.1.4.3.5 for further information.

- *No-bake phenol/furan systems with a low-sulphur acid catalyst:* Applying a sulphur-reduced bake system, the odour emissions in a steel foundry (See Figure 3.44) can be reduced by 65 % when using new sand moulds and new sand cores. See also Section 3.2.1.4.3.5 for further information.

- *Inorganic geopolymers based on polysialates*: In the cold-setting process, the required addition rate of the geopolymer binder to achieve the required strength and properties of the moulds and cores ranges typically from 1.4 % to 2.0 % with new sand and from 1.8 % to 2.0 % for sand mixtures containing between 75 % and 100 % reclaimed sand. After 24 hours, the flexural strength achieved with the geopolymer-based binder (ranging from 1.3 MPa to 1.9 MPa) is very similar to those obtained with conventional methods such as the alkaline phenolic ester process or the furan no-bake process. The BTEX emissions reported when using the inorganic geopolymer binders are 36 mg/kg, compared to 666 mg/kg when using a furan-based resin containing less than 25 % furfuryl alcohol, 249 mg/kg when using a no-bake binder system based on an alkaline phenolic resin and 252 mg/kg when using green sand. No PAH emissions were reported when using the inorganic geopolymer binders, compared to 12 mg/kg when using a furan-based resin containing less than 25 % furfuryl alcohol, 5 mg/kg when using a no-bake binder system based on an alkaline phenolic resin and 2 mg/kg when using green sand.
  The used sand mixtures with the geopolymer binder exhibit significantly easier reclaimability in comparison to organic binder systems. A better collapsibility of the used sand mixtures with geopolymer binder after pouring has been reported by foundries producing both aluminium and non-ferrous castings. The reported utilisation of the reclaimed sand is 75 % for the facing sand mixture and 100 % for the backing sand mixture.
- *Ester silicate:* The system has been widely applied in the manufacture of steel castings with very little odours and fumes emitted during casting.



NB: Emissions are plotted from the start of pouring up until 60 minutes after pouring
Source: [133, DE UBA 2014]

Figure 3.44: New binder to reduce emissions of sulphur compounds (odours and pollutants) in a steel foundry

Cross-media effects
None.

Technical considerations relevant to applicability
Applicability may be restricted due to product specifications.

Economics
- The use of emission-reducing binders requires no investment.
- The costs of the innovative binders are typically higher than that of the conventional binders.

Driving force for implementation
- Legal requirements.
- Reduction of VOC and odour emissions.

Example plants
Inorganic geopolymers are used in:

- a grey iron foundry in the Czech Republic (since 2004), in replacement of a no-bake binder system based on an alkaline phenolic resin;
- an aluminium foundry in the Czech Republic (since 2014);
- a large steel foundry in the US producing die blocks and gear segment castings up to 50 tonnes.
- a steel foundry in the Middle East producing castings up to 7 tonnes.

Reference literature
[133, DE UBA 2014], [200, Zennaro et al. 2019], [201, Vykoukal, M. et al. 2019], [202, Merta, V. et al. 2021]

3.2.1.9.14 Selection of a low-emission gas curing binder system

Description
A gas curing binder system generating low emissions of amines, benzene, formaldehyde, phenols, isocyanates, etc. is selected. This includes the use of:

- inorganic binders, e.g. sodium silicate (water glass) or inorganic geopolymers based on polysialates cured with CO_2;
- aliphatic organic binders based for example on aliphatic polyalcohols (instead of aromatic organic binders);
- phenolic urethane binders with very low free phenol and formaldehyde content;
- phenolic urethane binders with reduced amounts of solvents.

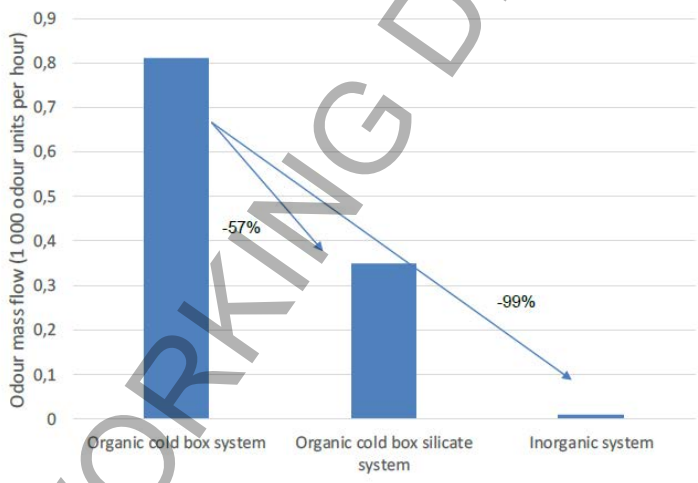
Technical description
- *Inorganic binders - sodium silicate (water glass) catalysed with CO_2:* Inorganic sodium silicate binders can be hardened using CO_2. When using a high ratio of sodium silicate (e.g. 3.0 % to 3.5 % addition rate), the gassing times and the consumption of CO_2 are reduced and improved post-casting breakdown is observed. However, reduced core strength and poor core storage properties may arise. When using a lower ratio of sodium silicates (e.g. 2.0 % to 2.2 %), better core storage is achieved but the gassing times are extended and the breakdown properties are not as good. Often, the second option is preferred.
- *Inorganic binders - geopolymers based on polysialates cured with CO_2*: Inorganic geopolymers can be used in the production cores, or even moulds, and cured using CO_2. During the curing process, a polymerisation of the inorganic geopolymer takes place.

Some additives (accelerators in a liquid or solid form) may be added to the sand to achieve faster the required strength and minimise the consumption of CO_2.
Typically, the inorganic geopolymer binder is added to quartz sand at levels ranging from 2.3 % to 3.0 %; the accelerators are added at levels ranging from 0.5 % to 0.8 %, based on the weight of sand.

- *Aliphatic organic binders based for example on aliphatic polyalcohols (instead of aromatic organic binders)*: See Section 3.2.1.9.10 for further information.
- *Phenolic urethane binders with very low free phenol and formaldehyde content*: A new binder system for use in the cold-box process has been developed in which the free phenol content of the resin has been drastically reduced with the aim of minimising emissions during casting. The binder based on ultra-low free phenol is composed of two parts. The solvents used in the first part to solubilise the phenolic resin do not contain any hazardous materials that would need to be mentionned (compulsory labelling) due to their workplace exposure limits. The solvents used in the second part used to dilute the isocyanate resin still require labelling. The free phenol content of this binder is below 1 % and, in addition, the free formaldehyde content is below 0.1 %. [203, Vacelet et al. 2018]
- *Phenolic urethane binders with reduced amounts of solvents*: Another binder system has been developed for the cold-box process (both for iron and aluminium casting) where no solvents are actually used in the second part for dilution of the isocyanate resin, instead selected additives are employed.

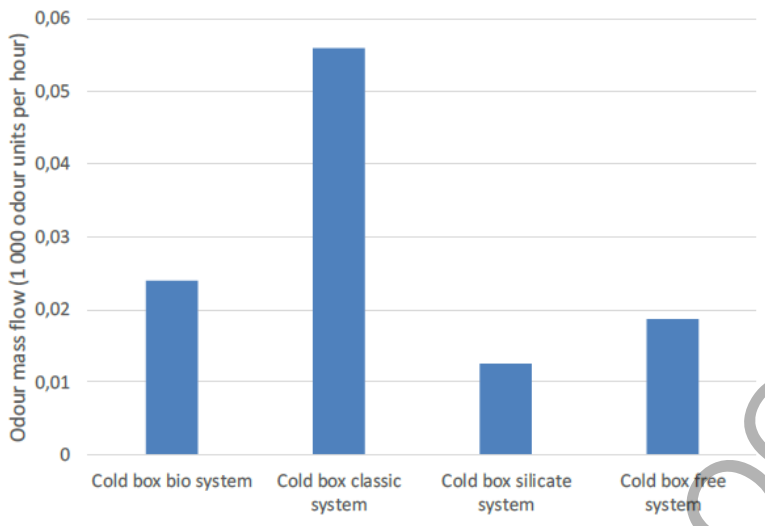
Achieved environmental benefits
Reduced emissions of VOCs.

Environmental performance and operational data
Inorganic binders – e.g. based on sodium silicate or hydrated sodium silicate: The manufacture of cylinder heads from a cast aluminium alloy shows that the change of the binder system in the cold-box process from an organic system to a silicate system resulted in an odour emissions reduction of approximately 60 %. Additionally, when the process was further changed to an inorganic method based on hydrated sodium silicate, an almost complete elimination of the odour emissions was achieved (-99 %). This is illustrated in Figure 3.45 and Figure 3.46. The new binder systems also reduced significantly BTX emissions from the aluminium foundry.



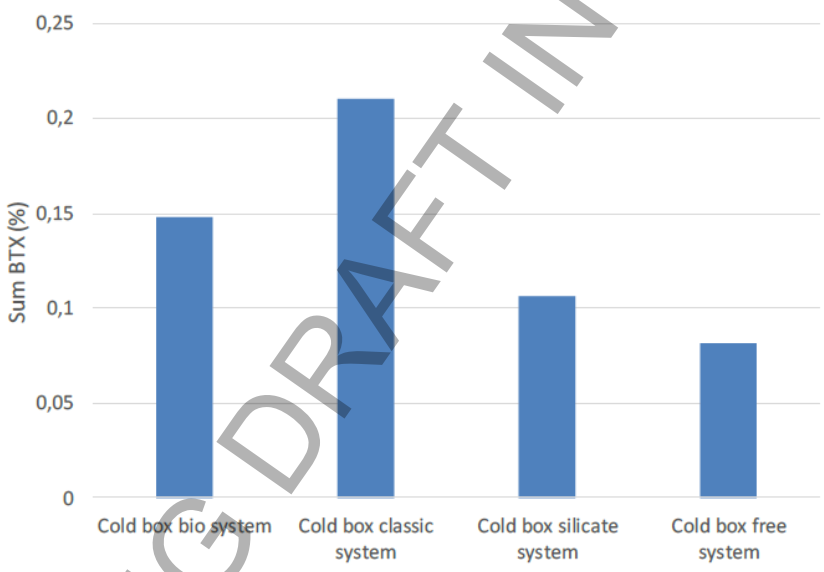
Source: [133, DE UBA 2014]

Figure 3.45: New inorganic binder systems used in an aluminium foundry – Effects on odour emissions compared to conventional organic cold-box systems



Source: [133, DE UBA 2014]

Figure 3.46: New inorganic binder systems used in an aluminium foundry – Effects on odour emissions compared to conventional organic cold-box systems

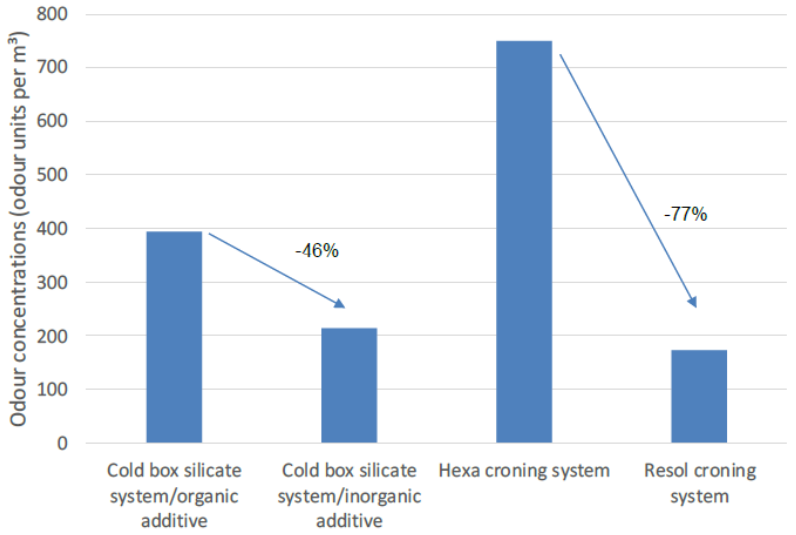


Source: [133, DE UBA 2014]

Figure 3.47: New inorganic binder systems used in an aluminium foundry – Effects on odour emissions compared to conventional organic cold-box systems

When using a silicate system in combination with an inorganic additive instead of using a classic silicate system with an organic additive (a wood flour additive), the odour emissions from the production of gear houses in an iron foundry were reduced by 46 %. (See Figure 3.48.)

When replacing the hexamethylenetetramine-hardened shell moulding sand with resol-hardened sand, test results showed a reduction of odour emissions of 77 % (see Figure 3.48), similarly achieved at the Harzguss Zorge and at Halberg Guss in Brebach (crankshaft masks) reference plants.



Source: [133, DE UBA 2014]

Figure 3.48: New binder system for odour and BTX reduction in an iron foundry – Part A

- *Phenolic urethane binders with very low free phenol and formaldehyde content:* The use of ultra-low phenolic urethane binders in the cold-box process, particularly in iron and steel casting, leads to reduced emissions throughout the the production process from the core production to casting. A long-term analysis showed a 22 % reduction in the binder consumption compared to a conventional cold-box binder system and reduced benzene emissions by 66 %. [203, Vacelet, et al. 2018]
- *Phenolic urethane binders with reduced amounts of solvents:* Using this binder technology, the consumption of solvents is reduced by a third compared to a conventional cold-box system. This leads to reduced emissions of VOCs. Furthermore, it has been reported that the amine consumption is also reduced. [204, Vacelet, et al. 2013]

Cross-media effects
None.

Technical considerations relevant to applicability
Applicability may be restricted due to product specifications.

Economics
- The use of emission-reducing binders requires no investment.
- The costs of the innovative binders are typically higher than that of the conventional binders.

Driving force for implementation
- Legal requirements.
- Reduction of VOC and odour emissions.
- Reduced consumption of binders.

Example plants
VW-Gießerei AG Nutzfahrzeuge, Hannover
Eisenwerk Brühl GmbH , Brühl
Harzguss Zorge GmbH, Zorge
Edelstahlwerke Schmees GmbH, Pirna
Binder developers:
ASK Ashland-Südchemie-Kernfest GmbH, Hilden
Hüttenes-Albertus Chemische Werke GmbH, Düsseldorf

Phenolic urethane binders with a very low free phenol content: Düker GmbH, Laufach, Germany, a foundry producing valve bodies and pressure pipe for drinking water and gas supply.

Reference literature
[133, DE UBA 2014], [203, Vacelet, et al. 2018], [204, Vacelet, et al. 2013]

3.2.1.9.15 Selection of a low-emission hot-curing binder system

Description
A hot-curing binder system generating low emissions of formaldehyde, phenols, furfuryl alcohol, benzene, isocyanates, etc. is selected. This includes the use of inorganic binders such as geopolymers based on polysialates.

Technical description

- *Low-emission hot-curing binder systems*: Conventional hot-box systems are typically furan- or phenol-based. They all contain urea and their free formaldehyde content may vary from 2 % to 10 %. In addition, the nitrogen content of the resins is typically between 6 % and 13 %, originating from the catalysts used (e.g. aqueous solutions of ammonium chloride or ammonium nitrate). For the hot-box process, binders with lower free formaldehyde content are commercially available; however, they may present lower reactivity. Alternatively, in the warm-box process, binder systems with a free formaldehyde content lower than 2.5 % are available. More recent binders with a free formaldehyde content of less than 0.1 % have also been reported. [205, P.R. Carey, 2021]
- *Inorganic binders cured with heat:* Inorganic geopolymers based on polysialates can be used in the serial or mass production of cores cured with heat in non-ferrous metal applications. The sand mixture is introduced into a heated core box and the curing process is facilitated by blowing hot hair within the range of 100 °C to 200 °C. Typically, the inorganic geopolymer binder is added to the sand at levels ranging from 1.4 % to 2.0 %; an accelerator is also added at levels ranging from 0.3 % to 0.9 %, based on the weight of the sand. [201, Vykoukal, M. et al. 2019]
  Inorganic binders which may be cured using a warm-box process have also been reported. They do not contain phenol or formaldehyde and therefore can significantly reduce VOC emissions. [206, V. Haanappel, 2021]

Achieved environmental benefits
Reduced emissions of VOCs.

Environmental performance and operational data
The production of cores using inorganic geopolymers does not generate fumes or odours during the pouring process, compared to cores produced using the cold-box technology, for example. In addition, the inorganic geopolymers enable the achievement of higher mechanical properties than resin-coated sands typically used in the Croning process (i.e. phenol-formaldehyde type – novolak), in particular higher transverse strengths (both hot and cold). Another important aspect to consider is the collapsibility of the cores. In the case of of the inorganic geopolymer binder system, comparable or even better collapsibility of the cores has been reported in comparison to resin-coated sands used in the Croning process.

Cross-media effects
None reported.

Technical considerations relevant to applicability
Applicability may be restricted due to product specifications.

Economics
The cost of a warm-box system is significantly higher than the conventional hot-box system. Compared to to a hot-box phenolic system, the price of the resins used in the warm box process are two to three times higher and the price of the catalysts used can be three to seven times higher. [205, P.R. Carey, 2021]

Driving force for implementation
- Legal requirements.
- Reduction of VOC and odour emissions.

Example plants
No information provided.

Reference literature
[205, P.R. Carey, 2021], [201, Vykoukal, M. et al. 2019], [206, V. Haanappel, 2021]

3.2.1.9.16 Extraction of off-gases generated from moulding and/or core-making

Description
Off-gases generated from moulding and/or core-making are extracted. The extraction system selected depends on the type of moulding/core-making process.

- Natural/green sand moulding: Off-gases generated in the natural or green sand preparation areas (e.g. transport, sieving, mixing and cooling) and in the moulding areas, especially during pouring, are extracted. In the case of automatic moulding machines, appropriate extraction systems are used to collect emissions (e.g. roof extraction). In the case of hand moulding, extraction as close as possible to the emission source is achieved using mobile extraction hoods.
- Cold-setting, gas curing, hot-curing processes: In the case of automatic moulding machines, extraction systems are used to collect emissions (e.g. fixed extraction hoods, canopy extraction). In the case of hand moulding, extraction as close as possible to the emission source is realised using mobile extraction hoods.

Core shooting machines are enclosed and off-gases are extracted. Extraction is also applied during checking, handling and storage of freshly made cores (e.g. by using hoods at the checking table, above the handling and temporary storage areas).

Technical description
<u>Mould preparation</u>
Only a few of the different green sand preparation stages cause significant dust generation, namely the vibrating screen, dedusting and cooling process stages. These stages are equipped with dust capture and treatment. The units are enclosed and connected to a centralised dedusting unit. The set-up of the dedusting system has to take account of the dew point of the exhaust air and the type of dust.

The exhaust air from the green sand preparation is saturated with water. Therefore, wet systems (often of the low pressure type) seem to be most suitable for exhaust capture. However, the wet system is widely being replaced by dry dust abatement. The latter has the advantage that part of the dust may be recirculated and that no waste water stream is generated. Additionally, the wet systems are prone to internal corrosion and the build-up of dust and oxidation products. The wet separation of exhausted air impurities can result in problems for the waste water cleaning. Dust contains bentonite which is difficult to dispose of due to its anti-sedimentable effects. [120, TWG 2003]

When applying fabric filters, condensation problems need to be prevented. Condensation may cause a deposition of dust, clogging and/or a tearing of the filter. The addition of cooling water

to the sand needs to be done in a controlled way in order to minimise steam formation. The dew point of the airflow may be increased through heating with gas burners.

One benefit is that the collected dust is dry and so can be easily transported. After size separation, the coarse fraction and part of the fine fraction may be recirculated into the sand mixing.

Core-making
The type of binder and hardener used will determine the type of emissions that occur. The exhaust gas from core-making with chemical binders consists mainly of a mixture of organic solvents. Emissions of phenol, formaldehyde, or ammoniac etc. are much smaller and depend on the binder type. Mixing, core shooting and drying can be enclosed to varying degrees, depending on the emissions occurring. Various binder-specific techniques apply, and these are discussed in the subsequent sections. Volatile organic carbon emissions occur with all chemically bonded sand types, except for water glass sands. For self-setting and cold-setting binders, the emissions during mixing are low, given the low resin usage (1-2 % resin:sand ratio). The emissions during hardening, coating and drying can be considered for capture and treatment.

Upon regeneration of the chemically bonded sand, dust generation occurs in the shake-out drum. Sand cooling and dedusting is generally performed in a dry unit, since there are no problems with water condensation. It is not possible to recirculate the dust. [38, VITO 2001]

Achieved environmental benefits
Reduction of dust emissions to air.

Environmental performance and operational data
See data and relevant information in the sections below (on the abatement techniques) and in Section 2.3.

Cross-media effects
Extraction consumes energy.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Regulation of dust emissions.
- Legal requirements.
- Local requirements and local conditions.

Example plants
Widely used.

Reference literature
[38, VITO 2001], [120, TWG 2003], [169, TWG 2021]

3.2.1.9.17 Cyclone

Description
Equipment for the removal of dust from an off-gas stream based on imparting centrifugal forces, usually within a conical chamber. Cyclones are used as a pretreatment before further dust abatement or abatement of organic compounds. Cyclones can be applied alone or as multicyclone.

Technical description
Cyclones are used to remove dust, both as a recovery and as an abatement technique.

Achieved environmental benefits
- Possible material recovery.
- Reduced emissions to air.

Environmental performance and operational data
Cyclones can be used alone, but are often used in combination with other waste gas treatment techniques.

Reported data from five plants (7 EPs) using cyclones show a range for dust emissions from 0.4 mg/Nm^3 to 14.3 mg/Nm^3 with 5 out of 7 EPs with values lower than 1.5 mg/Nm^3. [169, TWG 2021]

Cross-media effects
Disposal of the dust, if it is not used. Further information is provided in the CWW BREF [179, COM 2016].

Technical considerations relevant to applicability
Generally applicable. Generally, there are no technical restrictions to the applicability of this technique. Further information is provided in the CWW BREF [179, COM 2016].

Economics
Cyclones are a low-cost technique. There is also the potential benefit of material recovery which depends on the dust concentration in the waste gas. Further information is provided in the CWW BREF [179, COM 2016].

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
DE029, DE039, DE064, ES082 and PT141.

Reference literature
[169, TWG 2021]

3.2.1.9.18 Fabric filter

More information on the technique
See Section 3.2.1.12.7.

Environmental performance and operational data
Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from 62 plants (107 EPs) using fabric filters show a range for dust emissions from 0.01 mg/Nm^3 to 27 mg/Nm^3 with a median value of 1.27 mg/Nm^3 and an average value of 2.88 mg/Nm^3. [169, TWG 2021]

Example plants
Widely used.

Reference literature
[169, TWG 2021]

3.2.1.9.19 Wet scrubbing

More information on the technique
See Section 3.2.1.13.4.

Environmental performance and operational data
Wet scrubbing is used alone or in combination with other waste gas treatment techniques.

Reported data from 10 plants (17 EPs) using wet scrubbing show a range for dust emissions from 10.01 mg/Nm^3 to 27 mg/Nm^3 with a median value of 0.9 mg/Nm^3 and an average value of 2.8 mg/Nm^3 [169, TWG 2021]

Example plants
BE028, DE039, DE043, DE062, DE064, ES082, FR114, IT132, IT155 and PT141.

Reference literature
[169, TWG 2021]

3.2.1.9.20 Adsorption

See Section 3.2.2.2.1.12.

Further information is provided in the CWW BREF [179, COM 2016].

Reference literature
[179, COM 2016]

3.2.1.9.21 Thermal oxidation

More information on the technique
See Section 3.2.1.12.9.

Environmental performance and operational data
Reported data from one plant using regenerative thermal oxidation show a TVOC emission level of 1.3 mg/Nm^3. [169, TWG 2021]

See also Section 3.2.1.12.9.

Example plants
FR114 [169, TWG 2021]

Reference literature
[169, TWG 2021], [179, COM 2016]

3.2.1.10 Emissions to air from the casting, cooling and shake-out processes using lost moulds

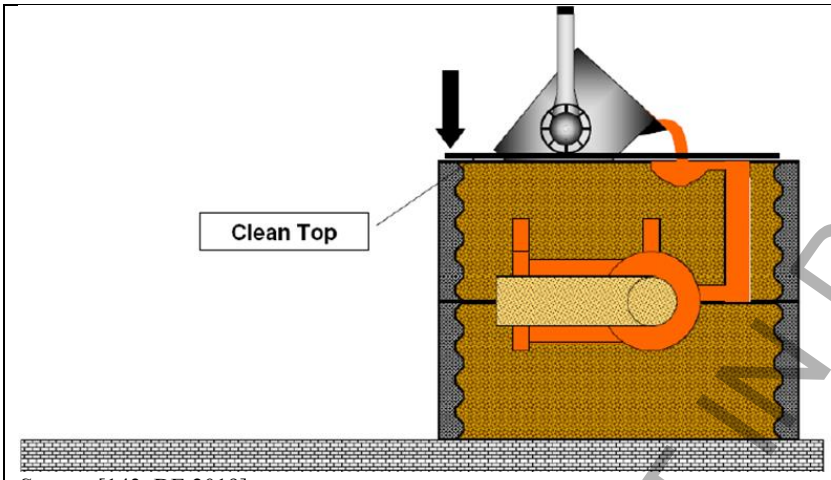
3.2.1.10.1 Use of mould coating material with adsorbent properties

Description
A layer of coating material with adsorbent properties is applied on the upper surface of the mould to adsorb emissions of, for example, volatile organic compounds and SO_2 during the casting process. Typical components of the layer include calcium carbonate, coarse aluminium silicate, activated carbon, lime and water.

Technical description
Before casting, a coating material with adsorbent properties is applied on top of the moulds. A possible composition of the coating material can be:

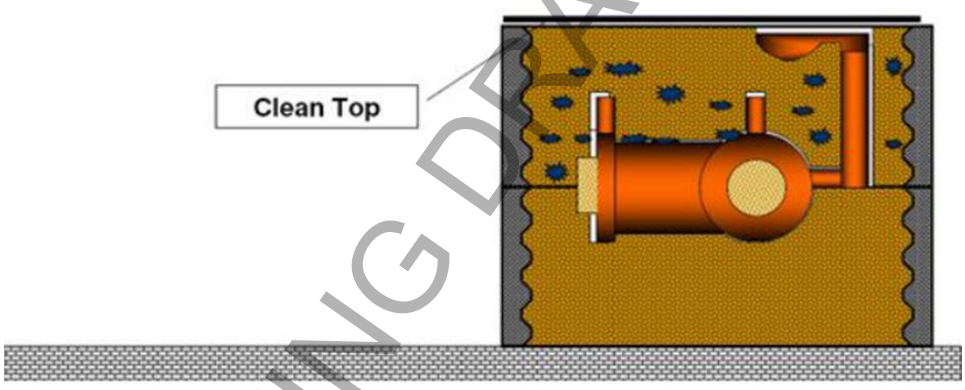
- calcium carbonate;
- aluminium silicate (coarse);
- activated carbon;
- lime;
- water.

The technique is shown schematically in the following figures.



Source: [143, DE 2019]

Figure 3.49: Exemplary application of clean top



Source: [143, DE 2019]

Figure 3.50: Exemplary application of clean top

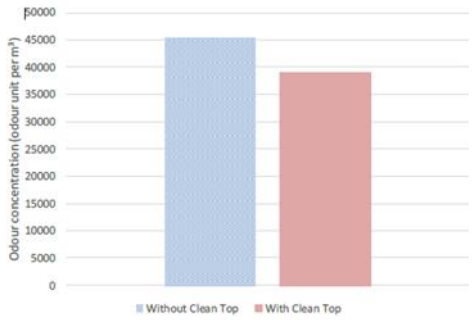
Achieved environmental benefits
The applied coating material has the following properties:

- Adsorption of the emissions generated during the casting process like inorganic and aromatic volatile pollutants such as benzene, toluene, xylene and sulphur dioxide.
- Adsorption of fine dust or fumes.

Using this technique, diffuse emissions can be reduced.

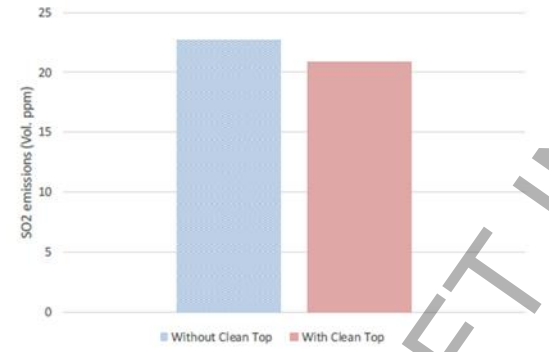
Environmental performance and operational data

BTX and SO_2 emissions of the casting process were measured in the iron foundry in Bocholt Hulvershorn. The following diagrams show the results of the measurements.



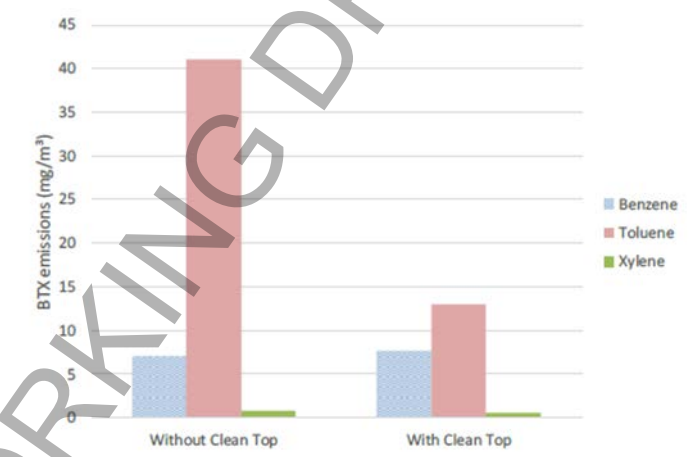
Source [143, DE 2019]

Figure 3.51: Reduction of odour emissions



Source [143, DE 2019]

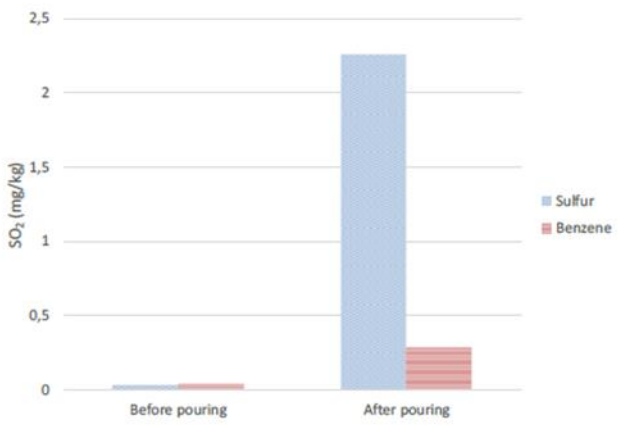
Figure 3.52: Reduction of SO_2 emissions



Source: [143, DE 2019]

Figure 3.53: Reduction of BTX emissions

To examine the effect of the coating material, the sulphur and benzene concentration was determined in the layer before and after casting. The result is shown in the following diagram.



Source: [143, DE 2019]

Figure 3.54: Effect of the coating material on SO_2 and benzene emissions

Cross-media effects
Pollutants adsorbed in the coating material end up in the moulding material. Compared with the amount of moulding material, the amount of coating material is low. If moulding material is recycled, accumulation of pollutants in the moulding material could occur. However, it is assumed that fine-grained coating mass is separated and discharged with dust from de-dusting during the regeneration of used sand. Data are not available.

Technical considerations relevant to applicability
The method can be used for hand moulding procedures and in the cold resin moulding procedure.

Economics
The use of the emission-reducing binder requires no investment.

The material cost of the feed material depends on the specific nature of the binder and the volume purchased by the foundry.

The costs of this technique are relatively low, compared to other downstream measures to reduce pollutant emissions: EUR 1/m^2 form surface, resulting in EUR 100 000/y in the reference plant.

Driving force for implementation
- Legal requirements.
  - reduction of pollutant emissions and exposures (diffuse emission sources);
  - reduction of odour emissions.
- Local requirements and local conditions:
  - the foundry does not cause problems with the neighbourhood.
- Operational requirements:
  - relief from pollution control licensing procedures.

Example plants
Hulvershorn Eisengießerei GmbH & Co. KG, 46395 Bocholt, Germany

Reference literature
[143, DE 2019]

3.2.1.10.2 Extraction of off-gases generated during the casting, cooling and shake-out processes

Description
Off-gases generated during the casting (especially emissions from pouring), cooling and shake-out processes are appropriately extracted.

For the casting and cooling processes, this includes:

- restricting the pouring process to a fixed area or position to facilitate the capture of emissions using ventilators and enclosure (e.g. in serial pouring);
- enclosure of pouring and cooling lines.

For the shake-out process, this includes:

- use of ventilator panels situated on both sides and at the rear of the shaker;
- use of enclosed units equipped with roof openings or removable covers (e.g. doghouse);
- installation of an extraction point situated underneath the shaker in the sand collection box.

Technical description
The emissions during pouring, cooling and shake-out are diverse and differ broadly in quality and quantity from one foundry to another. Basically, dust emissions are produced, as well as inorganic and organic gaseous compounds. These are mainly reaction products, caused by the high temperature and the reducing atmosphere upon pouring and cooling. The composition of pouring fumes is complex. They consist mainly of CO, CO_2, H_2, and methane as the main representatives of the organic decomposition products. Polycyclic aromatic hydrocarbons and benzene occur, depending on the composition of the mould- and core-system.

The capture and treatment of the off-gases of these process stages is generally possible for automated moulding and pouring installations. [13, Batz, R. 1986]

Relative emissions (as kg/t of molten metal) increase over the pouring-cooling-shake-out sequence. Exhaust capture efforts will need to take this variation into consideration.

Casting and cooling processes
The collection of emissions during pouring, cooling, and shake-out is as a rule more extensive as the plant becomes bigger.

The further the pouring process can be restricted to a fixed area or position, the smaller the amount of extracted air will be, and the easier it will be to capture emissions with ventilators and housings, and therefore air-treatment can be carried out more effectively.

In serial pouring, the emissions increase with increasing production capacity. Without extraction, the air at the pouring plant could at some point reach unacceptable concentration levels of noxious substances. To lessen the pollution in the work area, extractor ventilators or extractor surfaces are fitted as close to the moulds as possible, but without hindering the pouring process. The extractor elements are arranged in such a way that all emissions occurring during pouring, are moved away from the work area to the extracting equipment. The air-speed at the free extraction cross-section is kept between 0.5 m/s and 1 m/s.

Shake-out process
The technique used for the emission collection from shake-out depends on the degree of mechanisation, the emissions to be extracted and the size range of the castings, in particular the smallest and largest item cast on the same machine.

The system of collection and extraction of exhaust gases ~~reducing emissions~~ most commonly used is a ventilator panel on the side of the shaker. Usually, panels are installed on both sides of the shaker, regardless of the shaker size. If possible the rear of the shaker is enclosed in this way too. Frequently an extraction point is provided under the shaker in the sand-box, operating through a projecting pipe. This presents the risk of sand being extracted if the box is filled with sand up to the pipe. Moreover the pipe's inlet is often obstructed by sand lumps or adhering steam and dust.

The best way of achieving good emission levels with relatively small ventilation rates is when shake-out is performed in enclosed units. Roof openings, possibly with a moving screen, doors and entry/exit chutes make it possible to use a crane or other means of transport. In addition, the closed cabins reduce the noise level.

In automatic moulding plants, the casting-mould package is often pressed out of the moulding box by a hydraulic jack with a mounted pressing plate. Afterwards the casting is separated from the sand firstly on a jig-shaker and then to a rotating shake-out drum or tube or a sand cooler. Extraction drums or tube drums, which are now increasingly being used, are much more suited to the collection of emissions than the usual shakers, but they have the disadvantage of possible odour emissions.

The quantity of extracted air is not only determined by the workplace limit values required, but also by processing requirements. Large air volumes may be required for cooling and for protection of the filter bags. This needs to be balanced against the demands of any pollution abatement techniques, that usually need highly charged waste gases with small air volume streams in order to be effective.

Appropriate techniques for dedusting are cyclones combined with wet scrubbers or dry filters. Biofilters are also used and are discussed in Section 3.2.1.10.8.

For gravity die-casting and centrifugal casting, post combustion, chemical washing and adsorption to activated carbon are used in order to reduce organic emissions and odour. ~~These systems have already been described above.~~

Achieved environmental benefits

Casting and cooling processes

Reduction of diffuse emissions of dust, CO, PAHs and other organic decomposition products. Extraction allows subsequent treatment of the collected exhaust gases.

For the example plant referred to in Environmental performance and operational data below, the following benefits were reported:

- in the case of subsequent dust abatement (with an assumed abatement efficiency of 95-99 % for the case of bag filter), the diffuse dust emissions are reduced by about 50 %;
- reduction of noise emissions by 3-9 dB(A), in the case of full enclosure;
- reduction in dust and CO concentration in the working area at percentages of about 50 % or more.

Shake-out process

Reduction of the emissions of VOCs and dust to air.

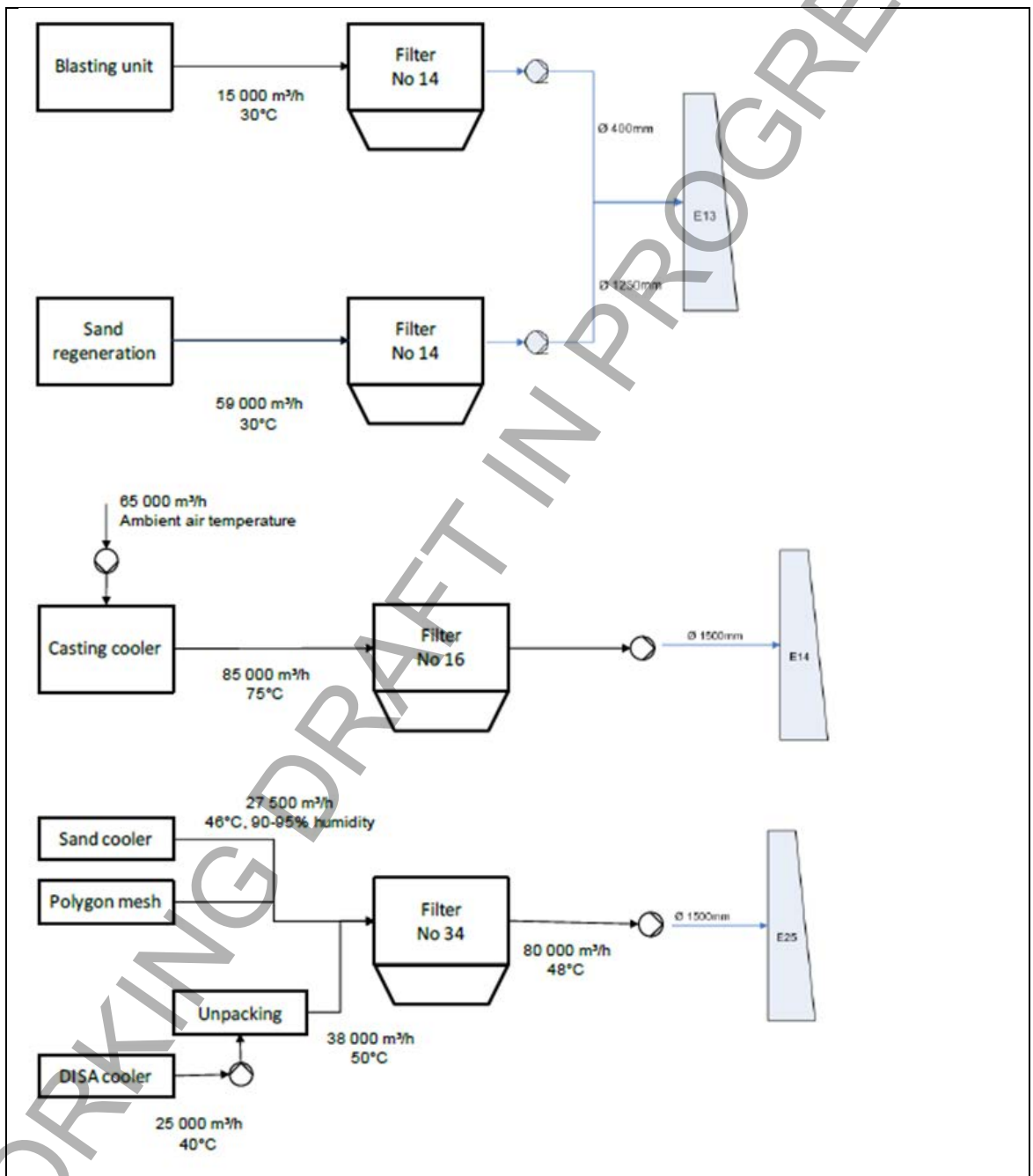
Environmental performance and operational data

Casting and cooling processes

The following data refer to a foundry that produces over 3.5 million cast parts with a total tonnage of 33 000 tons per year. The production site is in Gutersloh, Germany.

An evacuation system is operated at the primary cooling area of the box-less moulding plant. The area of the secondary cooling section, which comprises the separation of sand and castings, the conveying in the cast cooler and the blasting of the castings, has been enclosed completely.

From the blasting unit 15 000 m^3 are extracted to filter No. 14, and from sand treatment 59 000 m^3 to filter No. 22. Most off-gas results from the cooling of the cast (85 000 m^3 to filter No. 16). From cooling of sand and the polygon mesh 27 500 m^3 and from the DISA cooler and the unpacking unit 38 000 m^3 are extracted to filter No 34.



Source: [143, DE 2019]

Figure 3.55: Examplary process scheme and volume flows

Shake-out process

With free-standing extraction shakers up to 2 m in width, for every m^2 of shaker surface 7 000 Nm^3/h to 9 000 Nm^3/h of air is extracted in the case of a one-sided ventilation screen. With a two-sided screen, 5 000 Nm^3/h per m^2 of shaker surface is installed.

If the extraction point is under the shaker in the sand-box, the amount of air extracted per m^2 of shaker surface is designed to be about 700 Nm^3/h.

In a Polish example foundry for large-size cast steel castings, a removable doghouse type cover was constructed over the shake-out grate. The doghouse consists of two sideways moving doors, which are opened and closed hydraulically, as shown in Figure 3.56. The cover reduces dust and noise emissions into the foundry hall. The exhaust is cleaned using dry de-dusting. The noise level for shake-out was reduced from 100 dBA to below 85 dBA.

Source: [107, Metalodlew s.a. 2003]

Figure 3.56: Doghouse cover for a shake-out grate, for large batch castings

Cross-media effects
Extraction of exhaust air consumes electrical energy. In the case of dust abatement, the emitted dust which is collected by the abatement system must be disposed of as a waste.

Technical considerations relevant to applicability
Applicability to existing plants of enclosed units or removable covers in the case of shake-out operations may be restricted by a lack of space.

Economics
Casting and cooling processes
For the example plant mentioned above, the implemented technical measures of enclosure required an investment of approximately EUR 180 000 for the reduction of noise, dust and CO emission in the hall. Efforts for maintenance of the exhaust hoods could be reduced by changing the supply air. Information on the level of operating costs is not available.

Shake-out process
For the doghouse in the Polish example foundry, as mentioned above, the investment cost was EUR 220 000 (2003 data), including some additional equipment.

Driving force for implementation
- Reduction of diffuse emissions.
- Legal requirements.

Example plants
Casting and cooling processes
The technique is commonly applied in large-series foundries (e.g. Miele & Cie KG, Gütersloh, Germany).

Shake-out process
Metalodlew s.a., Krakow (PL)

Reference literature
[14, CAEF 1997], [6, Gerber et al. 1981], [14, CAEF 1997], [107, Metalodlew s.a. 2003], [143, DE 2019]

3.2.1.10.3 Cyclone

More information on the technique
See Section 3.2.1.9.17

Environmental performance and operational data
Cyclones can be used alone, but are often used in combination with other waste gas treatment techniques.

Reported data from four plants (6 EPs) using cyclones show a range for dust emissions from 0.01 mg/Nm^3 to 43 mg/Nm^3 with 4 out of the 6 EPs with values lower than 2.7 mg/Nm^3. [169, TWG 2021]

Example plants
BE022, BE023, DE039 and PL135.

Reference literature
[169, TWG 2021]

3.2.1.10.4 Fabric filter

More information on the technique
See Section 3.2.1.12.7.

Environmental performance and operational data
Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from 75 plants (140 EPs) using fabric filters show a range for dust emissions from 0.07 mg/Nm^3 to 200 mg/Nm^3 with a median value of 0.5 mg/Nm^3 and an average value of 5.31 mg/Nm^3. [169, TWG 2021]

Example plants
Widely used.

Reference literature
[169, TWG 2021]

3.2.1.10.5 Wet scrubbing

More information on the technique
See Section 3.2.1.13.4.

Environmental performance and operational data
Wet scrubbing is used alone or in combination with other waste gas treatment techniques.
Reported data from five plants (7 EPs) using wet scrubbing show a range for dust emissions from 1.1 mg/Nm^3 to 84 mg/Nm^3 with 4 out of 6 EPs with emission levels below 17 mg/Nm^3 [169, TWG 2021]

Example plants
CZ026, DE043, DE062 and FR115.

Reference literature
[169, TWG 2021]

3.2.1.10.6 Electrostatic precipitator

More information on the technique
See Section 3.2.1.12.8.

Environmental performance and operational data
Reported data from four plants (14 EPs) using an ESP show a range for dust emissions from 0.14 mg/Nm^3 to 7.1 mg/Nm^3 with a median value of 3.35 mg/Nm^3 and an average value of 3.52 mg/Nm^3 [169, TWG 2021]

Example plants
AT005, CZ025, DE035 and ES087.

Reference literature
[169, TWG 2021]

3.2.1.10.7 Adsorption

See Section 3.2.2.2.1.12.

Further information is provided in the CWW BREF [179, COM 2016].

Reference literature
[179, COM 2016]

3.2.1.10.8 Biofilter

Description
The off-gas stream is passed through a bed of organic material (such as peat, heather, compost, root, tree bark, softwood and different combinations) or some inert material (such as clay, activated carbon, and polyurethane), where it is biologically oxidised by naturally occurring microorganisms into carbon dioxide, water, inorganic salts and biomass. The biofilter is sensitive to dust, high temperatures or high variations in the off-gas composition. Supplementary nutrient feeding may be needed.

Technical description
Biofiltration is based on the ability of microbes living in a fibre-peat filter bed to oxygenate malodorous gases and convert them into odourless compounds. The gas to be purified is blown by a fan through a bed of humid filter material, exiting odourless from the upper side. The odorous compounds are adsorbed in the water phase and are decomposed by microorganisms living on the filter material. The good performance of the filter depends on the balance between the supply of nutrient (compounds for abatement/decomposition) and the number of microorganisms.

In foundries, biofilters are applied for the removal of odorous gases, which mainly consist of amines from the off-gas from cold-box core-making processes and for the removal of VOCs (e.g. benzene) from casting shop exhaust gases.

Critical parameters for good functioning of the biofilter are:

- *Permeability of the filter layer*: Gases need to flow through the bed in good contact with the filter bed material. An excess of fine material in the filter bed may cause clogging, pressure build-up and blowout of bed material.
- *Wetting of the filter medium*: A water dispersion system may be installed for continuous or intermittent wetting of the bed material.
- *Conditioning of the exhaust gas*: The exhaust gases need to be moistened before entering the filter. For optimum operation, a constant temperature (30 ºC) has to be maintained. This may require preheating of the exhaust gas.
- *Adequate water treatment*: The biofilter produces residual water, containing phenol and cresol. This is treated in a waste water system before disposal or re-circulation. Re-circulation requires an additional salt removal step.

Introduction of the biofilter technique into a German foundry required a long optimisation period, until it was able to function satisfactory. It was found that the following characteristics appear to be important:

- Closure of the biofilter beds with a lid, in order to prevent CO- and condensation problems throughout the installation. The filtered air is evacuated through a centralised chimney.
- Close control of water quality (e.g. salt content), especially when applying a system not producing waste water.
- The addition of nutrient salts to the sprinkling water, to maintain bed activity.
- Control of the pH value of the bed material and the addition of lime to maintain a neutral pH value.

An updated biofiltering method (with additives) is applied in an example plant (Franz Kleinken GmbH, DE) which operates a bioscrubber micro cyclone system. Ambient air from the rooms first passes, in the cleaning installation, a spray chamber / water atomisation. The exhaust air (raw gas, a mixture of air and odour molecules) is treated with a water mist. The mist (fresh water with additives based on vegetable fatty acids) is produced by high-pressure nozzles. The active substance in the medium reacts with part of the odorous substances (sulphur compounds) and binds them.

At the same time, the water of the bioscrubber is sprayed into the air stream. The water, which is in a closed loop, contains natural enzymes and microorganisms as active compounds, which in the bioscrubber produce additional enzymes, and breaks down organic matter and biological odours.

The enzymes provide an improved transfer of the odour molecules into the water phase. A natural, herbal fragrance in the media is responsible for the change of plant-specific odour, without increasing the total odour load.

In a micro cyclone, drops and gaseous substances are separated from the gas stream. The separated liquid phase is collected and biodegradation of aromatic substances and media takes place. By added microorganisms, the organic ingredients are degraded mainly to CO_2 and water. In the demister unit, remaining drops are separated by the centrifugal deposition principle from the gas stream. They are then fed into the water circuit.

Further information on biofilters may also be found in the CWW BREF.[179, COM 2016]

Achieved environmental benefits

Reduction of odourous, amine and/or VOC emissions from the core shop and casting shop. The elimination of benzene and other VOCs takes place in biofilters but may not be regarded as reliable. The efficiency varies remarkably according to a wide spectrum of factors, such as weather conditions, age of substrates, etc. The use of biofilters alone is therefore not valid as a

stand-alone technique for the reduction of VOCs. Their main purpose consists in the reduction of odour.

In the example plant mentioned above (Franz Kleinken GmbH, DE), direct odour measurements above a casting mould showed odour minimisation efficiency in a range between 60 % and 80 %. The odour quality is thereby altered so that the plant-specific odour of the foundry is no longer perceivable. A long-term olfactometric measurement before installation of the system and during the plant operation (> 6 months) confirmed the achieved environmental benefits.

Environmental performance and operational data

TWG, please update this information

Pilot scale data for amine removal have been provided by Finland. A biofilter unit (diameter 0.8 m, height 1 m) was installed in a core-making off-gas line, after an acid scrubber. The equipment included a fan and a dewing unit, with which the dampness of the biofiltration unit was adjusted to an optimum level. The odour removal was measured using an olfactometer. Results for the odour and total hydrocarbon levels are given in Table 3.39. Variations in the input analysis are due to process variations. The results show that filtration results in a significant odour and hydrocarbon reduction.

Table 3.39: Operational data for the biofiltration of a cold-box core-making off-gas

Compound	Units	Before biofilter	After biofilter
Odour	OU/m³	410 – 3000	150 – 310
Total hydrocarbons	mg C/m³	20 – 35	5 – 10
OU = Odour units *Source* : [39, Salminen et al. 1999]			

Industrial scale data for VOC removal have been provided by Germany. A biofilter unit (specification: surface 300 m³, height 1 m, in 5 rectangular beds, with a total throughput of 32 330 Nm³/h dry gas) was installed for the treatment of exhaust gases from pouring and cooling in a green sand cast-iron foundry, using croning and cold-box cores. The emission data are given in Table 3.40. Olfactometric measurements showed an average reduction of odour emissions by a factor of 94.5 %.

Table 3.40: Emission data for the biofiltration of exhaust from green sand pouring and a cooling line

Parameter	Units	Before biofilter	After biofilter	Reduction %
O_2	%	20.74		
CO_2	%	0.17		
NO_x	mg/m³	3.65		
CO	mg/m³	382	299	21.7
Benzene	mg/m³	15.80	1.44	90.9
Toluene	mg/m³	9.37	0.92	90.1
Ethylbenzene	mg/m³	3.00	0.46	84.7
Xylene	mg/m³	4.90	1.54	68.6
Formaldehyde	mg/m³	0.37	0.01	68.6
Dust	mg/m³	13.63	2.03	85.1
Ammonia	mg/m³	8.97	0.16	98.2
Phenol	mg/m³	4.67	<0.02	>99.6
Cresol	mg/m³	3.73	<0.02	>99.5
PCDD/F	ng/m³	0.0056	0.0041	26.8
Benzo(a)pyrene)	mg/m³	0.0001	0.00003	70.0
Source: [9, Gapp, H. 1989]				

In the iron foundry using the micro cyclone system for odour abatement, products are made from gray and ductile iron with a weight up to 30 t. The foundry is divided into a hand moulding for large cast and a hand moulding for small castings (up to 4 tons weight). Both moulding facilities are supplied by its own core shops. The melting process consists of 2 MF induction furnaces, with a capacity of 2 tonnes and 4 tonnes and in 2 cupola furnaces with a melting capacity of 6 t/h.

The extracted exhaust per reference foundry plant is 25 000 m^3/h.

Cross-media effects
The biofilter produces a waste water flow. This may be recirculated internally after treatment, yielding a sludge cake for disposal.

Energy is consumed during the transfer of the off-gas to and through the filter, as well as for the surrounding equipment.

It has been reported that emissions of N_2O, a greenhouse gas, may be a problem.

Technical considerations relevant to applicability
In principal, bioscrubbers can be applied in new and existing plants. The required operating system depends on two conditions: the odour load and the hall suction. When the application of bioscrubbers is technically evaluated:

- the planned water flow and the amount of additives must be adapted to the odour load;
- uptime of the casting facility must be considered due to its consequence for energy consumption.

When no odours are generated (e.g. when no casting is done or during production downtime), it is possible to turn off the system manually. A time limit for downtime of the bioscrubber does not exist. The plant can operate continuously 24 hours a day.

It has to be considered that the microorganisms require relatively constant environmental conditions.

~~This technique finds its application in green sand foundries and cold-box core making shops. The applicability is limited to 3-shift large series casting foundries, as biofilters need very stable conditions throughout the year. It should be noted in each known case of application great individual efforts of research and development have been required to achieve an acceptable performance.~~

Economics
TWG please update this information
Investment costs for the biofilter unit in the ~~German~~ example plant Halberg Guss (specification: surface 300 m^3, height 1 m, in 5 rectangular beds, with a total throughput of 32 330 Nm^3/h dry gas), including a water treatment unit to allow operation without the production of waste water, have been estimated at EUR 3 247 000 (1998 data). This includes EUR 233 3000 for the filter and surrounding equipment and EUR 914 000 for the exhaust capture and ductwork. With a design load of 40 000 Nm^3/h, operational costs are estimated at EUR 170 000/y (costs based on DEM for 1998).

These estimated operational costs are much higher than generally stated investment and operational costs for biofilter units. This is probably due to the large throughput and the extent of the surrounding equipment. In a 1998 paper the cost for an open-bed biofilter, treating 17 000 Nm^3/h was estimated at USD 70 000-100 000 for investment and a yearly operating cost for water, labour and overheads of USD 15 000-25 000.

For the second example plant, Franz Kleinken GmbH (biofiltration with additives), the investment cost of air conditioning systems like indoor air extraction and indoor cleaning techniques are between EUR 150 000 and EUR 200 000. It should be considered in the evaluation of the economics whether the indoor air extraction and indoor cleaning techniques, which might be necessary anyway, must be redesigned to the needs of a bioscrubber system. The operating costs for the bioscrubber are between EUR 6 and EUR 10 per hour of operation (2013 data).

Driving force for implementation

- Reduction of nuisance effects (mainly odour) on neighbouring locations.
- Legal requirements.

Example plants

Halberg Guss, Saarbrücken-Brebach, DE.
Metallwerk Franz Kleinken GmbH, DE.

Reference literature

[9, Gapp, H. 1989], [39, Salminen et al. 1999], [100, TWG 2002], [106, Devinny, J. S. 1998], [143, DE 2019], [179, COM 2016]

3.2.1.11 Emissions to air from alternative casting processes (i.e. Lost Foam, ceramic shell casting)

3.2.1.11.1 Extraction of off-gases generated from Lost Foam and ceramic shell casting

Description

In the Lost Foam casting processes, off-gases from the pyrolysis of the expanded polymer during pouring and shake-out are extracted using, for example, an enclosure or hood.

In the ceramic shell process, off-gases from the burning of the polystyrene model in the sintering furnace are extracted using enclosure.

Further information and emission data for the Lost Foam casting process can be found in Sections 2.2.5.9.1 and 3.2.1.4.3.9.

More information on the ceramic shell casting process can be found in Section 3.2.1.4.3.10.

3.2.1.11.2 Catalytic or thermal oxidation

Description

Abatement technique which oxidises combustible compounds in a waste gas stream with air or oxygen in a catalyst bed. The catalyst enables oxidation at lower temperatures and in smaller equipment compared to thermal oxidation. The typical oxidation temperature is between 200 °C and 600 °C.

More information on thermal oxidation is provided in Section 3.2.1.12.9.

Further information on both thermal and catalytic oxidation is provided in the CWW BREF [179, COM 2016].

Reference literature

[179, COM 2016]

3.2.1.11.2.1 Catalytic oxidation of off-gases in the Lost Foam process

Description
Off-gases from the Lost Foam process are captured (using vacuum) and treated using catalytic post-combustion.

Technical description
Exhaust gas capture using vacuum and a catalytic post-combustion system is used for treatment of waste gases in the Lost Foam process. A description of the Lost Foam process is given in Section 2.2.5.9.1.

In the catalytic thermal oxidiser (CTO), volatile organic pollutants are burnt. The catalyst reduces the amount of energy needed to crack the pollutants. The raw gas loaded with pollutants is led into the heat exchangers of the CTO by the process fan. Here the raw gas is preheated by the hot clean gas. When required, the blower heats the exhaust gas in the combustion chamber until the ignition temperature of the catalyser is reached. In the catalyser, the pollutants contained in the raw gas are converted mainly into CO_2 and H_2O. After the catalyser, the clean gas is led into the heat exchanger tubes. A compensation tank can be used to equalise concentrations of the gases.

Achieved environmental benefits
The benefit of the post-combustion is the reduction of emissions of organic pollutants (BTEX, TVOC).

Environmental performance and operational data
For the example plant (GussStahl Lienen GmbH & Co. KG, Lienen, Germany), the following operational data were reported:

- foundry processes: Lost Foam process and no-bake moulding;
- 1 300 t to 1 600 t (500 t Lost Foam castings) per year, steel castings, heat-resistant steel;
- weight per part: 1 kg to 1 t;
- turnover: EUR 15 million;
- employees: 75;
- two-shift operation.

The catalytic post-combustion system has the following charactersitics:

- volume: 1 300 Nm^3/h;
- the air cleaning system is operating roughly 15 min/day; the catalyst is preheated all day;
- after pouring there are emissions for some seconds; the ventilation system is operated for a minute.

Table 3.41: Operational post-combustion data

Compound	Emissions, without post combustion	Emissions, with post combustion
Benzene	596 mg/m^3; 320 g/h	0.04 mg/m^3; 0.047 g/h
Toluene	129 mg/m^3 ; 70 g/h	Not measured
Etylbenzene	23 mg/m^3; 13 g/h	Not measured
Xylene	43 mg/m^3; 23 g/h	Not measured
Styrene	863 mg/m^3; 466 g/h	Not measured
Methyl methacrylate	2 157 mg/m^3; 1 165 g/h	Not measured
Total organic carbon	Not measured	95 mg/m^3, 0.111 kg/h
Parameters		
Air pressure	1 000 hPa	988 mbar
Gas flow	540 m^3/h	1 167 m^3/h

H_2O content	21 g/m	25.6 g/m^3
O_2 content	-	18.9 Vol.-%
Gas temperature	24 °C	Not measured
Catalyst temperature	Not measured	394 to 626 °C
Clean gas temperature	Not measured	255 to 370 °C
Burner temperature	Not measured	420 to 437 °C
Source: [133, DE UBA 2014]		

Cross-media effects
Consumption of 400 m^3 natural gas per month.

Technical considerations relevant to applicability
Post-combustion can be applied in new and existing plants. It is advantageous in the case of exhaust gas with relatively high organic content, e.g. after pouring in the lost foam process.

Economics
- Investment costs for catalytic post-combustion plant: EUR 250 000.
- Running costs (maintenance etc.) – post-combustion plant: EUR 5 000/year.

Driving force for implementation
Reduction of emissions and compliance with the German regulation TA Luft.

Example plants
GussStahl Lienen GmbH & Co. KG, Lienen, Germany.
Other users of lost foam process with post combustion: BMW AG, Landshut, Germany.

Reference literature
[133, DE UBA 2014]

3.2.1.11.3 Fabric filter

More information on the technique
See Section 3.2.1.12.7.

Environmental performance and operational data
Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from one plant (4 EPs) using fabric filters show a range for dust emissions from 0.22 mg/Nm^3 to 1.24 mg/Nm^3. [169, TWG 2021]

Example plants
IT129.

Reference literature
[169, TWG 2021]

3.2.1.11.4 Adsorption

See Section 3.2.2.2.1.12.

Further information is provided in the CWW BREF [179, COM 2016].

Example plants
A study carried out by the Basque Government at two foundries in Spain using the Lost Foam process showed significant emissions of VOCs, in particular benzene, toluene and styrene. These emissions were occuring particularly during the moulding and casting processes as a result of the thermal decomposition of the expanded polystyrene. In both foundries, emissions were not not extracted and purified properly prior to being released into the atmosphere. Accordingly, corrective measures were introduced in these two foundries with the installation of effective extraction and abatement systems including adsorption with activated carbon. [181, ES 2019]

Reference literature
[179, COM 2016], [181, ES 12019]

3.2.1.12 Emissions to air from the casting process in permanent moulds

3.2.1.12.1 General techniques for gravity and low-pressure die casting

Description
Techniques include:

- appropriate selection of the lubricating material to prevent castings surface defects;
- optimised lubricant preparation and application to avoid excessive use.

Technical description
The release agent (lubricants) to be used in die-casting plays a very important role to prevent the molten metal becoming welded to the die. It should also facilitate the release and later extraction of the casting from the die, without any change in the size or the structure of the casting.

In principle, the release agent must maintain its main characteristics after being in contact with the molten metal. The main pronciples that should be considered for the selection of the lubricating material are:

- to allow a trouble-free casting ejection from the die (e.g. in the shape and the surface appearance of the casting);
- to prevent the molten metal becoming welded to the die;
- to facilitate the flow of molten metal into the die and the filling up of all cavities;
- to leave the die clean (without any residue).

Equally important are the lubricant preparation (e.g. dilution with water) and the application method (e.g. spraying).

Achieved environmental benefits
- Optimised material efficiency.
- Reduction in the consumption of lubricants and water.
- Limitation of associated emissions to air and water.

Environmental performance and operational data
The use of lubricants has various environmental impacts, e.g. use of energy for the water and lubricant sprayer, generation of waste due to the low percentage of lubricant mixture that finally deposits on the die surface, VOC and hazardous pollutant emissions to air as a result of the decomposition of lubricants due to the heat of the die.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Savings in material and water consumption.
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[184, Watkins et al. 2013]

3.2.1.12.2 General techniques for high-pressure die casting

Description
Techniques include:

- proper lubrication of the die and plungers using water-based emulsions of, for example, silicone oils, ester oils, synthetic waxes;
- minimisation of the release agent and water consumption by use of, for example, micro-spraying for application of release agents (see also Section 3.2.1.4.3.2).

Technical description
Generally, lubricants (release agents) are a mixture of a lubricant and a carrier material. Formulations may also include additives to inhibit corrosion, to increase stability during storage, and to resist bacterial degradation. Lubricating materials are typically mineral oils and waxes in water emulsions. Silicone oils and synthetic waxes are finding increased use. Water-based lubricants are preferred to solvent-based ones to avoid VOC emissions.

Proper lubrication of the dies and plungers is essential for successful high-pressure die-casting. The proper die lubrication has positive effect on all of the following:

- the casting quality, density, and surface finish;
- the ease of cavity filling and of casting ejection.

Proper lubrication can also speed up the casting rate, reduce maintenance requirements, and reduce the build up of material on the die face.

Achieved environmental benefits
See Technical description above.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Better product quality.
- Reduced VOC emissions.
- Legal requirements.

Example plants
Widely used.

Reference literature
[42, US EPA, 1998], [128, IHOBE, 1998], [175, Brown, 1999]

3.2.1.12.3 Optimisation of process parameters for centrifugal and continuous casting

Description
In centrifugal casting, important process parameters such as mould rotation, pouring temperature and mould preheating temperature are optimised (e.g. using flow simulation) to reduce the number of defects and minimise emissions.

In continuous casting, the casting rate and temperature are optimised and direct cooling with water is used for final solidification.

Technical description
In centrifugal casting, a set of important process parameters needs to be optimised in order to achieve the best possible product output (e.g. obtaining the minimum porosity). These parameters include:

- the material;
- the pouring temperature;
- the preheat temperature;
- the mould rotation.

The mould pouring temperature may be considered the most significant parameter that affects the quality of centrifugal casting components. Simulation software may also be used for the simulation of the density of casting and the visualisation of outputs of the cast products.

In continuous casting, the major challenge is to cast continuously without interruptions and without many kinds of defects. The solidification control is crucial for the surface and internal casting quality. Important control parameters in solidification include steel chemistry, casting speed, mould level, mould powder, mould oscillation, liquid steel temperature, and secondary cooling conditions, as well as parameters affecting the flow phenomena in the mould. Advanced control systems based on multiple sensor inputs are used to allow optimised operation with on-line quality prediction.

Achieved environmental benefits
Material and energy efficiency through the production of castings with less defects (internal scrap minimisation).

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
Better product quality with less defects.

Example plants
Widely used.

Reference literature
[185, Seetharaman 2014]

3.2.1.12.4 Separate spraying of release agent and water in high-pressure die-casting

See Section 3.2.1.4.3.1

3.2.1.12.5 Use of water-free release agents in high-pressure die-casting

Description
Water-free release agents (e.g. in a powdered form) are applied to the die using electrostatic deposition.

Technical description
A minimum amount of dry lubricant – about 0.3-0.5 grams for each kilogram of injected aluminium – is electrostatically applied to the mould at each production cycle (the consumptions were calculated at a mould temperature of 250 °C). When it comes into contact with the hot mould, the electrostatically distributed dry lubricant melts, expanding to the deepest points. In this way, it creates a highly efficient release film, without creating residual thickness and carbon formations, which are typical of water-based lubrication systems.

The major advantages of the dry lubrication system are as follows:

- Improved quality of the castings. Lack of water from the lubrication process, drastically reduces the formation of hydrogen, which causes porosity in the casting.
- No waste water generation.
- No oil mist generation.
- Drastically reduced suction.
- Reduced cycle times: lubricating with water-based products normally takes 10-15 % of the cycle time. Two thirds of the lubrication process are dedicated to the mould drying process, which is no longer necessary if water-free lubrication is used. The estimated overall time saving is of the order of 7-10 %.
- Longer-lasting moulds through the elimination of the thermal shocks and therefore the drastic reduction of dies expansion and thus the formation of cracks. In addition, the alloy remains smoother.

Achieved environmental benefits
- No waste water or oil mist generation.
- Reduced energy consumption because of reduced volume of sprayed lubricant and less need for blowing air to ensure that no water is left in the die cavity.

Environmental performance and operational data
See Technical description above.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Operational efficiency.
- No waste water or oil mist generation.

Example plants
No specific information on plants using water-free lubrication systems is available. Water-free lubrication systems are available in the market from various providers.

Reference literature
[186, Foundry (journal) 2021], [193, Neto et al. 2009]

3.2.1.12.6 Extraction of off-gases generated from the casting process in permanent moulds

Description
Off-gases generated from the casting process in permanent moulds including high-pressure / low-pressure / gravity die casting, centrifugal and continuous casting are extracted using enclosures or extraction hoods and are sent to an abatement system.

Technical description
The use of mainly water-based release agents generates emissions to air (mainly in the form of mist) with low concentrations of decomposition products. These emissions are collected using enclosures or extraction hoods and sent to an abatement system.

Achieved environmental benefits
Reduction in the emission of release agent containing organic compounds. Prevention of diffuse emissions.

Environmental performance and operational data
Operational data from an example plant are given in Table 3.42. The data refer to a water miscible release agent (1:40 dilution factor), based on synthetic polymer and polysiloxane. Each die-casting machine is equipped with a separate suction hood and an EP. The hot and cleaned air is blown back into the hall (i.e. for heat recovery).

Table 3.42: Emission data from ESP-cleaned HPDC off-gas

Compound	Half hourly measured values (mg/Nm^3)	Mass – flow (g/h)
Dust	1.5 – 4.3	5.5
Organic substances (values in total carbon) (mg/m^3)	4 -6	9
Source: [100, TWG 2002]		

Cross-media effects
Capture and collection of the mist requires the consumption of energy.

Technical considerations relevant to applicability
Generally applicable.

Economics
Extraction of off-gases entails energy consumption.

Driving force for implementation
- Legal requirements.
- Minimisation of diffuse emissions and legislation on the emission of oil mist (e.g. in Sweden).
- Local conditions.

Example plants
Widely used. In the SF data collection the following plants reported this technique:

- Continuous casting: DE072 and ES083.
- Gravity die casting and tilt casting: AT013, EL080, FR112, FR114 and IT127.
- High pressure die-casting: AT005, AT014, ES087, FR116, IT122, IT123, IT133 and SE148.

Reference literature
[100, TWG 2002], [120, TWG 2003], [169, TWG 2021]

3.2.1.12.7 Fabric filter

Description
Fabric filters, often referred to as bag filters, are constructed from porous woven or felted fabric through which gases are passed to remove particles. The use of a fabric filter requires the selection of a fabric suitable for the characteristics of the waste gas and the maximum operating temperature.

Technical description
This type of separator is widely applied in various parts of the foundry process, due to its good efficiency and low emission values. It can achieve good efficiencies in controlling the fine particulate matter found in melting operations. Sub-micron particles such as metallic oxides may be separated as well. For proper operation, the following measures need to be taken: flue-gas cooling (T = 130-160 ºC) and separation of sparks (using a cyclone). The post combustion of organic material (to reduce the fire risk) may be applied for an off-gas with a high VOC content. Post combustion as a 'firewall' for bag filter protection has been reported in some cases for off-gas from the unpacking of drums. This technique is not applied in general; instead waste gas streams with high dust loads are mixed with gas streams with increased VOC contents to prevent the filter and the exhaust ducts from becoming sticky. A view of the inside and outside of a bag filter unit is given in Figure 3.57.

Source: [132, HUT 2003]

Figure 3.57: Bag filter units; inside (L) and outside (C, R) views

Achieved environmental benefits
Reduction of emissions to air.

Environmental performance and operational data
Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from three plants using fabric filters show a range for dust emissions from 0.2 mg/Nm^3 to 3.4 mg/Nm^3 with all but one value lower than 1.2 mg/Nm^3. [169, TWG 2021]

See also Technical description above. Further information is provided in the CWW BREF [179, COM 2016].

Cross-media effects
- Energy consumption.
- Disposal of the dust, if it is not used.

Further information is provided in the CWW BREF [179, COM 2016].

Technical considerations relevant to applicability
Generally applicable.

Further information is provided in the CWW BREF [179, COM 2016].

Economics
Information is provided in the CWW BREF [179, COM 2016].

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
EL080, IT133 and SE148.

Reference literature
[169, TWG 2021], [179, COM 2016]

3.2.1.12.8 Electrostatic precipitator

Description
Electrostatic precipitators (ESPs) operate such that particles are charged and separated under the influence of an electrical field. Electrostatic precipitators are capable of operating under a wide range of conditions. Abatement efficiency may depend on the number of fields, residence time (size), and upstream particle removal devices. They generally include between two and five fields, but may contain up to seven fields for the most advanced ESPs. Electrostatic precipitators can be of the dry or of the wet type depending on the technique used to collect the dust from the electrodes. Wet ESPs are typically used at the polishing stage to remove residual dust and droplets after wet scrubbing.

Technical description
Electrostatic precipitation is used to remove dust, both as a recovery and as an abatement technique. Removal efficiencies for dust typically range from 97 % to more than 99 %. [179, COM 2016]

Further information is provided in the CWW BREF [179, COM 2016].

Achieved environmental benefits
- Reduced emissions to air.
- Possible material recovery.

Environmental performance and operational data
Electrostatic precipitation is used alone or in combination with other waste gas treatment techniques.

Reported data from two plants (4 EPs) using an ESP show a range for dust emissions from 1.3 mg/Nm^3 to 5.3 mg/Nm^3. [169, TWG 2021]

Cross-media effects
- Energy consumption.
- Disposal of the dust, if it is not used.

Further information is provided in the CWW BREF [179, COM 2016].

Technical considerations relevant to applicability
Generally applicable.
Further information is provided in the CWW BREF [179, COM 2016].

Economics
Further information is provided in the CWW BREF [179, COM 2016].

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
AT005 and ES087. [169, TWG 2021]

Reference literature
[169, TWG 2021], [179, COM 2016]

3.2.1.12.9 Thermal oxidation

Description
Abatement technique which oxidises combustible compounds in a waste gas stream by heating it with air or oxygen to above its auto-ignition point in a combustion chamber and maintaining it at a high temperature long enough to complete its combustion to carbon dioxide and water. The typical combustion temperature is between 800 °C and 1 000 °C.

Several types of thermal oxidation are operated:

- Straight thermal oxidation: thermal oxidation without energy recovery from the combustion.
- Recuperative thermal oxidation: thermal oxidation using the heat of the waste gases by indirect heat transfer.
- Regenerative thermal oxidation: thermal oxidation where the incoming waste gas stream is heated when passing through a ceramic-packed bed before entering the combustion chamber. The purified hot gases exit this chamber by passing through one (or more) ceramic-packed bed(s) (cooled by an incoming waste gas stream in an earlier combustion cycle). This reheated packed bed then begins a new combustion cycle by preheating a new incoming waste gas stream.

Technical description
Thermal oxidation is used as an abatement technique to reduce emissions of organic compounds (e.g. TVOC, benzene).

Further information is provided in the CWW BREF [179, COM 2016].

Achieved environmental benefits
- Reduced emissions to air.
- Possible energy recovery.

Environmental performance and operational data
Thermal oxidation is used alone or in combination with other waste gas treatment techniques (e.g. combined with pretreatment by condensation or adsorption or with post-treatment by absorption). Removal efficiencies for organic compounds typically range from 95 % to more than 99.99 %.

Reported data from one plant using thermal oxidation show a range for TVOC emissions from 1 mg/Nm^3 to 2 mg/Nm^3. [169, TWG 2021]

Optimisation of thermal oxidation can reduce the emissions of NO_X and CO. This is carried out by:

- optimising the design of the oxidiser:
    - residence time;
    - mixing of the flows (e.g. natural diffusion between turbulent streams, changes in flow direction);
    - combustion chamber;
- monitoring the combustion parameters:
    - oxygen content;
    - carbon monoxide concentration;
    - temperature;
- inspecting the burners regularly, and cleaning them when necessary.

When the oxidised VOCs contain sulphur and/or halogens, further emissions of sulphur dioxide and/or hydrogen halides might be expected. This might require an additional waste gas treatment after thermal oxidation (e.g. absorption).

Further information is provided in the CWW BREF [179, COM 2016].

Cross-media effects
- Generation of NO_X and CO and potentially of other pollutants (e.g. HCl, SO_2, PCDD/F).
- Consumption of fuel in the case of non-autothermal operation.

Technical considerations relevant to applicability
Straight thermal oxidation is generally applicable. Applicability of recuperative and regenerative thermal oxidation to existing plants may be restricted by design and/or operational constraints .

Further information is provided in the CWW BREF [179, COM 2016].

Economics
Thermal oxidation is relatively expensive in comparison with some other techniques. Further information is provided in the CWW BREF [179, COM 2016].

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
AT013. [169, TWG 2021]

Reference literature
[169, TWG 2021], [179, COM 2016]

3.2.1.13 Emissions to air from finishing

3.2.1.13.1 Extraction of off-gases generated from finishing

Description
Off-gases generated from finishing operations, such as deburring, abrasive cutting, fettling, slide grinding, shot blasting, welding, chiselling, needling, are appropriately extracted using, e.g.:

- enclosure of the finishing process area;
- roof ventilation or dome-shaped roofs;
- rigid or adjustable extraction hoods;
- extraction arms.

Technical description
Considerable amounts of fume have to be captured and extracted when using thermal separation techniques. The work area may be as enclosed as much as possible, but ensuring the freedom of movement and that the inhaled air supply of the worker can be assisted. Dust collection techniques during abrasive cutting and grinding are differentiated between stationary machines and hand machines. Rigid hoods are customary at stationary machines, partly in connection with partial housings.

For stationary grinding machines, the tightly limited abrasive blast goes into an extracting funnel and is extracted. In the case of abrasive cutting-off stations, it is sensible to additionally extract emissions from the cabin in the interest of worker's health and safety. Handheld machine emissions are occasionally extracted via the splint protection hood. This is an effective but unpopular method, as it increases the weight of the machine and impairs its manageability. Normally hand grinding and hand cutting-off machines are housed in cabins (i.e. partial housings).

Collection of the dust takes place via extracting walls, roof domes, moveable hoods or extraction work benches. An effective aid when collecting emissions are hot-air curtains which direct additional air into the cabin. The additional air used may be cleaned recycled extraction air, in order to economise on heating energy. However, it should be noted, that a portion of fresh air will still always need to be provided from the outside.

Dust or pollutant collection is in most cases not needed for sawing, rapping, pressing, chiselling, stamping and milling. Screens may sometimes be used to protect the operator against rough particles. Welding is divided into processes with and without additional materials. Work protection regulations requiring extraction exist for most processes.

A rough estimation of the emission levels by applied finishing technique is provided in the following paragraphs.

- *Blasting:* Blasting generates a lot of dust. Off-gas capture is unproblematic due to the total enclosure of the blasting process in a closed cabin. Customary exhaust air decontamination processes are wet washing and dry filters, usually with a cyclone as a pre-filter.
- *Slide grinding, drumming:* Both processes do not require emission reduction in normal conditions. Aerosols that can form in quickly moving drums can be neglected.
- *Cutting:* All thermal separation processes generate emissions. Exhaust capture is achieved through enclosing the work place and carrying out an intensive extraction of the arising fume. It is important to place the capture elements as close as possible to the emission source, but without hindering the operating process. In some cases it has

proven beneficial to combine a mobile arm for direct extraction and additional cabin extraction. By carefully arranging the extraction elements, the dust-filled air can be guided away from the breathing area of the worker. The usual exhaust air decontamination processes are wet washing and dry filters. It should be noted that the systems are set up for the smaller grain sizes of the emitted fumes. Inertia force separators are applied as pre-separators.

- *Abrasive cutting*: Stationary abrasive cutting installations are extracted. Customary exhaust air decontamination processes are cyclones, wet washing and dry filters
- *Sawing, rapping, pressing*: These handling processes cause few emissions and do not require reduction measures in normal conditions.
- *Chiselling, needling*: In these processes mainly coarse particles are produced which are difficult to remove through extraction. The work is mainly carried out in cabins for safety reasons. In special cases, e.g. when removing burnt-on sand, the generated dust may be extracted by an extraction arm. The exhaust air is decontaminated in cyclones, wet washing and dry filters.
- *Grinding*: Emission capture when grinding on stationary machines takes place in a similar way as with abrasive cutting, i.e. via fixed funnels into which the abrasive blast is directed. An enclosed work place is used for manual grinding and abrasive cutting. Extraction walls can then be applied in the housing. Air decontamination processes are cyclones, wet washing and dry filters.
- *Stamping, milling*: These handling processes cause few emissions and do not require reduction measures in normal conditions.
- *Welding*: More or less emissions occur according to the type of the selected welding process, which is usually be best collected by extraction arms. For exhaust air cleaning, wet washing and dry filters and occasionally electrostatic filters are used.

Achieved environmental benefits
Reduction of diffuse emissions of metallic particles and dust.

Cross-media effects
The collection and extraction of dust-laden off-gas consumes energy.

Technical considerations relevant to applicability
Generally applicable.

As indicated in Table 3.43, some finishing techniques ~~do~~ may not generate dust and consequently ~~do~~ may not necessitate an off-gas collection system.

Table 3.43: ~~Applicability~~ Use of dust capture techniques for various finishing operations

	Roof ventilation	Dome-shaped roof	Rigid hood	Adjustable hood	Housing
Abrasive cutting			x	x	x
Burning	x	x	x	x	x
Chiselling, needling	Off-gas collection seldom necessary				
Fettling		x	x	x	x
Milling	No off-gas collection necessary				
Rapping, pressing	No off-gas collection necessary				
Sawing	No off-gas collection necessary				
Slide grinding	x	x	x	x	x
Shot blasting					x
Stamping	No off-gas collection necessary				
Welding	x		x	x	x
Source: [14, CAEF 1997], [120, TWG 2003]					

Economics
Extraction of off-gases entails energy consumption.

Driving force for implementation
- Regulations on dust emissions and occupational health and safety.
- Legal requirements.
- Local conditions.

Example plants
The technique is applied in the vast majority of the European foundries.

Reference literature
[14, CAEF 1997], [79, Assofond 2002], [169, TWG 2021]

3.2.1.13.2 Cyclone

See Section 3.2.1.9.17

Environmental performance and operational data
Cyclones can be used alone, but are often used in combination with other waste gas treatment techniques (e.g. combined with post-treatment by absorption or filtration). Removal efficiencies for dust typically range from 90 % to more than 99 % [179, COM 2016].

Reported data from seven plants (14 EPs) using cyclones show a range for dust emissions from 0.2 mg/Nm^3 to 11.6 mg/Nm^3 with a median value of 3 mg/Nm^3. [169, TWG 2021]

Example plants
ES087, ES089, ES090, IT071, PL135, PT139 and PT139 [169, TWG 2021]

Reference literature
[14, CAEF 1997], [79, Assofond 2002], [169, TWG 2021], [179, COM 2016]

3.2.1.13.3 Fabric filter

More information on the technique
See Section 3.2.1.12.7.

Environmental performance and operational data
Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from 79 plants (192 EPs) using fabric filters show a range for dust emissions from 0.02 mg/Nm^3 to 62.3 mg/Nm^3 with a median value of 1.1 mg/Nm^3 and an average value of 2.8 mg/Nm^3 [169, TWG 2021]

Example plants
Widely used. The vast majority of plants that reported emissions from finishing reported the use of fabric filters as an off-gas treatment technique. [169, TWG 2021]

Reference literature
[169, TWG 2021], [179, COM 2016]

3.2.1.13.4 Wet scrubbing

Description
The removal of gaseous or particulate pollutants from a gas stream via mass transfer to a liquid solvent, often water or an aqueous solution. It may involve a chemical reaction (e.g. in an acid

or alkaline scrubber). In some cases, the compounds may be recovered from the solvent. This includes venturi scrubbers.

Technical description
Wet scrubbers are typically used to remove water-soluble organic and inorganic compounds as well as dust. Alkaline scrubbers are typically used to remove acid gases, such as hydrogen chloride, hydrogen fluoride and hydrogen sulphide, while acid scrubbers are typically used to remove ammonia.

Wet scrubbers are mostly used as an abatement technique, although they are sometimes also used to recover gaseous organic compounds (e.g. benzene) as well as dust. In most cases, packed-bed scrubbers and spray towers are used. Further information is provided in the CWW BREF [179, COM 2016].

Achieved environmental benefits
- Reduced emissions to air.
- Possible material recovery.

Environmental performance and operational data
Wet scrubbing is used alone or in combination with other waste gas treatment techniques.

Reported data from three plants (6 EPs) using wet scrubbing show a range for dust emissions from 0.2 mg/Nm^3 to 35.6 mg/Nm^3 with 4 out of 6 EPs with emission levels below 1 mg/Nm^3 [169, TWG 2021]

Cross-media effects
Absorption generates a spent scrubbing liquid that usually requires further treatment or disposal. Further information is provided in the CWW BREF [179, COM 2016].

Technical considerations relevant to applicability
Generally applicable. Generally, there are no technical restrictions to the applicability of this technique. The use of absorption is subject to the availability of a suitable scrubbing liquid. Further information is provided in the CWW BREF [179, COM 2016].

Economics
Absorption is relatively inexpensive in comparison with some other techniques, e.g. thermal oxidation. There is also the potential benefit of material recovery which depends on the concentration of the compound concerned in the waste gas. Further information is provided in the CWW BREF [179, COM 2016].

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
CZ025, DE035 and DE036. [169, TWG 2021]

Reference literature
[169, TWG 2021], [179, COM 2016]

3.2.1.14 Emissions to air from sand reconditioning and regeneration

3.2.1.14.1 Use of a fuel or a combination of fuels with low NO_X formation potential

More information on the technique
See Section 3.2.1.7.4.

3.2.1.14.2 Use of a fuel or a combination of fuels with low sulphur content

More information on the technique
See Section 3.2.1.7.5.

3.2.1.14.3 Extraction of off-gases generated from sand reconditioning and regeneration

Description
Off-gases generated from sand reconditioning and regeneration (e.g. secondary regeneration) are extracted using an enclosure or a hood for example. This includes extraction of the flue-gases generated from fluidised bed furnaces, rotary kilns or multiple-hearth furnaces, etc. used in thermal sand regeneration.

Technical description
Further information by applied sand reconditioning and regeneration technique is provided in Section 3.2.1.4.4.

Achieved environmental benefits
- Reduction of emissions to air.
- Possible material recovery.

Environmental performance and operational data
Further information by applied sand reconditioning and regeneration technique is provided in Section 3.2.1.4.4.

Cross-media effects
Extraction of off-gases consumes energy.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used. The vast majority of plants participated in the SF data collection reported this technique. [169, TWG 2021]

Reference literature
[169, TWG 2021]

3.2.1.14.4 Cyclone

More information on the technique
See Section 3.2.1.13.2.

Environmental performance and operational data
Cyclones can be used alone, but are often used in combination with other waste gas treatment techniques.

Reported data from six plants (8 EPs) using cyclones show a range for dust emissions from 0.04 mg/Nm^3 to 19.4 mg/Nm^3 with a median value of 1.54 mg/Nm^3 and an average value of 2.9 mg/Nm^3 [169, TWG 2021].

Example plants
BE023, BE028, DE028, DE039, FR109, PT139 and PT141. [169, TWG 2021]

Reference literature
[169, TWG 2021], [179, COM 2016]

3.2.1.14.5 Fabric filter

More information on the technique
See Section 3.2.1.12.7.

Environmental performance and operational data
Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from 75 plants (118 EPs) using fabric filters show a range for dust emissions from 0.03 mg/Nm^3 to 103.3 mg/Nm^3 with a median value of 1.7 mg/Nm^3, an average value of 4.6 mg/Nm^3, a 90th percentile value of 16.36 mg/Nm^3 and a 10th percentile value of 0.29 mg/Nm^3 [169, TWG 2021].

Example plants
Widely used. The vast majority of plants reported the use of fabric filter as off-gas treatment technique. [169, TWG 2021]

Reference literature
[169, TWG 2021], [179, COM 2016]

3.2.1.14.6 Wet scrubbing

More information on the technique
See Section 3.2.1.13.4.

Environmental performance and operational data
Wet scrubbing is used alone or in combination with other waste gas treatment techniques.

Reported data from four plants (8 EPs) using wet scrubbing show a range for dust emissions from 0.61 mg/Nm^3 to 27 mg/Nm^3 with a median value of 2.9 mg/Nm^3 and an average value of 7.18 mg/Nm^3 [169, TWG 2021].

Example plants
CZ026, DE043, DE062 and FR114. [169, TWG 2021]

Reference literature
[169, TWG 2021], [179, COM 2016]

3.2.1.14.7 Thermal oxidation

More information on the technique
See Section 3.2.1.12.9.

Environmental performance and operational data
Reported data from one plant using regenerative thermal oxidation show a TVOC emission level of 12 mg/Nm^3. [169, TWG 2021]

See also Section 3.2.1.12.9.

Example plants
AT011. [169, TWG 2021]

Reference literature
[169, TWG 2021], [179, COM 2016]

3.2.1.15 Odour

Odour emissions are mainly associated with processes involving sand binders. The actual odorous products of pyrolysis may vary according to the type of system used, but generally the phenolic breakdown products, i.e. cresols and xylenols, are the most common source of odour complaint, due to their very low odour detection thresholds. The dispersion of odours during casting, cooling and shake-out involves mixing with large volumes of air, which makes collection and treatment difficult. The use of inorganic binders, such as sodium silicate, can substantially reduce emissions. No totally effective proven method of eliminating foundry generated ~~smells~~ odour is known to be currently available. A general approach is to ensure good ventilation (see Section 3.2.1.15.4) and a rate of air change that ensures that emissions are quickly and efficiently dispersed to the atmosphere. Process-integrated measures include ~~the~~ substitution techniques (see Section 3.2.1.9) ~~of binders or binder solvents (see Section)~~. End-of-pipe techniques are discussed in Section 3.2.1.10. ~~aim to abate pyrolysis products (see Section) and amines (see Section). These include adsorption techniques, post combustion, wet scrubbers and biofilters (see Section).~~

3.2.1.15.1 Odour management plan

Description
An odour management plan (OMP) is part of the environmental management system (EMS) of the installation (see Section 3.1.1.1) and includes elements to prevent or reduce odorous nuisances.

Technical description
The OMP includes the following:

- A protocol containing actions and timelines.
- A protocol for conducting odour monitoring. It may be complemented by measurement/estimation of odour exposure (e.g. according to EN 16841-1 or -2) or estimation of odour impact.
- A protocol for response to identified odour incidents (including the management of complaints: identification of operations carried out, weather conditions such as temperature, wind direction, rainfall, communication with the authority and with complainant, etc.)
- An odour prevention and reduction programme designed to identify the source(s), to measure/estimate odour exposure, to characterise the contributions of the sources, and to implement prevention and/or reduction measures.

In foundries, there are a number of diffuse emission sources that may cause odourous nuisances. Typically, emissions originate from the moulding, core-making, casting, shake-out, and sand reclamation areas. The odours are caused by the diffuse emissions of organic chemicals which are used as binders in the moulding and core-making process, as surface treatment agents or other additives. Besides, odours may also originate from the breakdown of these chemicals

when molten metal is poured into the moulds. There are a very high number of binder formulations, but typical formulations contain phenol, furan, formaldehyde, urethane and sometimes oil. In core-making, some formulations require the use of tertiary amine catalysts. Other additives may include coal, cereals, starches, clay and refractory minerals. Due to the high number of possible diffuse emission sources, it is necessary to establish comprehensive measures in foundries that help to prevent and minimise odour emissions.

The potential impact of malodorous emissions arising from the plant should be evaluated from the nature, size and frequency of operation and the distance of neighbours from the plant. Identified sources of malodorous emissions can be further characterised by quantitative measurements of odour concentration, flow rate, temperature, humidity, chemical analysis and the pH.

Achieved environmental benefits
Prevention or reduction of the emissions of those odorous releases that may be offensive and detectable beyond the boundaries of the site.

Environmental performance and operational data
No information provided.

Cross-media effects
No information provided.

Technical considerations relevant to applicability
The applicability is restricted to cases where an odour nuisance at sensitive receptors is expected and/or has been substantiated.

Economics
No information provided.

Driving force for implementation
Legal requirements.
Local conditions.

Example plants
TWG, please provide information

Reference literature
No information provided.

3.2.1.15.2 Periodic monitoring of odour emissions

Description
Odour emissions can be monitored using:

- EN standards (e.g. dynamic olfactometry according to EN 13725 in order to determine the odour concentration or EN 16841-1 or -2 in order to determine the odour exposure);
- alternative methods (e.g. estimation of odour impact) for which no EN standards are available, ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

The monitoring frequency is determined in the odour management plan.

Technical description
The techniques include:

- for odour concentration determination (expressed in OU_E/m^3, to control limit values): dynamic olfactometry (measured according to the European standard EN 13725);
- for odour in ambient air: the grid method (according to the European standard EN 16841-1) or the plume method (according to the European standard EN 16841-2) to determine the odour exposure;
- for odour perception in the surrounding area (impact): odour surveys (see odour intensity mapping and odour wheels);
- electronic noses.

To determine the odour concentration, an air sample must be taken. The sampling techniques are similar to those used for measuring individual compounds. Techniques for odour monitoring are described in the ROM and CWW BREF documents.

Achieved environmental benefits
The achieved environmental benefit is the minimisation of odorous emissions.

Environmental performance and operational data
See the ROM and CWW BREF documents.

Cross-media effects
None.

Technical considerations relevant to applicability
The applicability is restricted to cases where an odour nuisance at sensitive receptors is expected and/or has been substantiated.

Economics
See the ROM and CWW BREF documents.

Driving force for implementation
The driving forces for implementation include legislation and complaints occurring in the vicinity of the installation/site.

Example plants
Odour emissions were reported by three plants (in total 5 emission points): DE041, DE062 and IT127. [169, TWG 2021]

Reference literature
[169, TWG 2021], [174, COM 2018], [179, COM 2016].

3.2.1.15.3 Substitution of chemicals containing alcohol-based or aromatic solvents

Description
This includes techniques such as:

- the use of water-based coatings;
- the use of alternative solvents in cold-box core-making.

Technical description
For further information on these techniques, refer to Sections 3.2.1.9.12 and 3.2.1.9.8.

Technical considerations relevant to applicability
Applicability of water-based coatings may be restricted due to the type of raw material or product specifications (e.g. big moulds/cores, water glass-bonded sands, Mg castings, production of manganese steel with MgO coating).

3.2.1.15.4 Good ventilation of areas where binders are used

Description
Where process air extraction and treatment is not applied, good ventilation and a rate of air change that ensures that odour emissions are quickly and efficiently dispersed to the atmosphere.

Technical description
No totally effective proven method of eliminating foundry generated ~~smells~~ odour is known to be currently available. However, a general approach is to ensure good ventilation and a rate of air change that ensures that emissions are quickly and efficiently dispersed to the atmosphere.

Achieved environmental benefits
The achieved environmental benefit is the minimisation of odorous emissions.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information reported.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
No reference literature provided.

3.2.1.15.5 Collection and treatment of amine emissions from the cold-box core-making process ~~Cold-box:capture of amine vapour and exhaust treatment~~

Description
Off-gases containing amines, generated from the gassing of cold-box cores, are extracted and treated using, for example, wet scrubbing, thermal or catalytic oxidation.

Technical description
The gassing of cold-box cores produces off-gases that need cleaning before emission into the atmosphere. In order to safeguard the working atmosphere, the core shooting machines are enclosed and cores are flushed with air to remove all the gas residues before the machine is opened up to take out the freshly made core.

Exhaust capture systems may be installed to secure good working conditions during the checking, handling and storage of the freshly made cores. For this, hoods or ~~evacuation~~ extraction systems are installed, for example at the checking table, above the handling area and above the temporary storage area (the waiting area for the tray of ready cores).

The exhausted amine vapour requires treatment to prevent an odour nuisance. One of the following methods may be used:

- *Adsorption on activated carbon*: This process is very efficient, but the operational costs are excessive, so it may only be feasible if the exhausted volume is small
- *Combustion*: For this process to be efficient, the afterburner chamber must be correctly designed, to ensure a temperature of at least 800 ºC, with a minimum dwell time of 2 seconds. Energy consumption is high and the process is therefore expensive to operate. In foundries operating a cupola furnace, the exhaust gas may be fed to the cupola for combustion.
- *Chemical scrubbing*: Amines are strong bases, and react with sulphuric or phosphoric acid. The pH of the solution is normally controlled to below 3. As a consequence, the scrubbing solution is replaced from time to time to remove concentrated salts, which subsequently require disposal as a hazardous waste. It is technically possible to process the scrubbing solution to reclaim the amine for re-use. This is discussed in Section 3.2.1.4.3.6.
- *Biofilter:* See Section 3.2.1.10.8.

In winter, it may be necessary to heat the exhaust air in order to prevent amine condensation inside the ductwork. This may be done using waste heat from compressors or from other nearby devices.

Achieved environmental benefits
Exhaust capture allowing a reduction in amine emissions and related odour emissions.

Environmental performance and operational data
Whatever the treatment method applied, amine emissions can be kept lower than 5 mg/Nm^3.

Emission data for a cold-box core-making shop using an acid scrubber are given in Table 3.44. The scrubber uses a 75 % phospohoric acid solution. In normal operation, 15 kg amine is disposed per day through the scrubber solution. The solution is saturated and stored in a tank for external treatment or disposal. The installation operates at 35.5 kW power and for 2 000 h/yr.

Table 3.44: Emission data for a cold-box core-making shop, using an acid scrubber

Compound	Emission level mg/m³
Dust	0.42
Amine	2.4
Phenol	0.53
Oxygen	21 %
Exhaust gas volume	25100 m³/h
Source: [13, Batz, R. 1986]	

Cross-media effects
When using acid scrubbers, the amine is transferred to the scrubbing solution, which then needs further treatment. However, recovery of the amine from the solution is possible. This is discussed in Section 3.2.1.4.3.6.

Technical considerations relevant to applicability
The technique applies for all existing and new cold-box core-making shops.

Economics
Operational costs for the installation mentioned in the ‘operational data’ section are EUR 6.3/tonne good casting.

The investment cost for an example installation, using a wet scrubber is given in Table 3.45.

Table 3.45: Specification and investment cost for an amine scrubber on cold-box core-shop exhaust data for Portugal, 2003

Property	Value
Exhaust airflow	30 000 m^3/h
Crude gas amine concentration	150 mg amine/Nm^3
Cleaned gas amine concentration	<1 mg amine/Nm^3
Power supply	45 kW
Investment cost	EUR 187000

Driving force for implementation

- To ensure workers health and to prevent odour emissions.
- Legal requirements.
- Local conditions.

Example plants

The technique is generally applied for foundries using cold-box binders.

Reference literature

[13, Batz, R. 1986], [14, CAEF 1997], [5, Gwiasda, F. 1984], [169, TWG 2021],

3.2.1.15.6 Collection and treatment of VOC emissions from chemically bonded sand preparation, pouring, cooling and shake out ~~VOC collection and removal~~

Description

Off-gases containing VOCs, generated from the preparation of chemically bonded sand, pouring, cooling and shake-out are extracted and treated using, for example, wet scrubbing, thermal or catalytic oxidation.

Technical description

VOC emissions (mainly solvents, BTEX, and to a lesser extent phenol, formaldehyde, etc.) result from chemically bonded sand preparation and also, further along the process, from pouring, cooling and shake-out (see Table 2.25 in Section 2.3). These compounds are noxious and generate odour emissions.

The abatement of VOCs is hindered by the fact that large volumes of ambient air are entrained by the collection systems (e.g. canopy hoods) used.

The following techniques are applicable for the removal of VOCs:

- adsorption to activated carbon;
- post-combustion;
- biofilter.

For adsorption to activated carbon, the exhaust gas flows through a carbon bed. Upon saturation, the carbon is thermally regenerated. Activated carbon has a very high adsorption (and abatement) efficiency. For benzene, the efficiency is > 99 %. Nevertheless, it has the following disadvantages:

- the high flue-gas volumes require large amounts of activated carbon

- dust and aerosols need to be filtered out of the off-gas before the carbon adsorption. Since very fine dust particles show a tendency to stick, the filtering is only possible using wet dedusting techniques and this thus generates a waste water flow.

To successfully exploit post combustion to eliminate VOCs from off-gases, specific minimum concentrations are necessary. These limit values are compound-specific and depend on the chosen technique. Post-combustion is possible for the exhaust gas from shell moulding. Generally, the exhaust gas from the casting shop does not have high enough VOC levels to operate post combustion. One alternative to post-combustion is to use exhaust air from the core blowers as combustion air for the cupola.

The use of biofilters is discussed in detail in Section 3.2.1.10.8.

Achieved environmental benefits
Reduction of VOC emissions to air.

Environmental performance and operational data
See Technical description above.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Cross-media effects
Energy is consumed in the collection of the off-gas flow, which may also involve entraining large volumes of ambient air.

Driving force for implementation
- ~~Legislation on the emissions of VOC.~~
- Legal requirements.
- Local conditions.

Example plants
The technique is widely applied.

Reference literature
[9, Gapp, H. 1989], [38, VITO 2001] [169, TWG 2021],

3.2.1.16 Water consumption and waste water generation

3.2.1.16.1 Water management plan and water audits

Description
A water management plan and water audits are part of the EMS (see Section 3.1.1.1) and include:

- flow diagrams and water mass balances of the plant as part of the inventory of inputs and outputs mentioned in Section 3.1.1.2;
- establishment of water efficiency objectives;
- implementation of water optimisation techniques (e.g. control of water usage, reuse/recycling, detection and repair of leaks).

Water audits are carried out at least once every year to ensure that the objectives of the water management plan are met.

Technical description
Some water optimisation techniques to consider are as follows:

a) Controlling water consumption
A prerequisite of any programme to prevent unnecessary use of water is to firstly collect information on the installation and the volumes consumed in the various processes, as part of the collection of information on types, quantities, composition and sources of all waste streams.

As with water consumption, data at site level are already a good benchmark in determining whether water consumption is excessive and is a good baseline against which to measure improvements. In order to allow a process-specific analysis, water use is monitored and recorded at machine/process level and water meters are regularly maintained and calibrated.

b) Reducing water consumption
By improved working practices
Production procedures are established and the personnel is trained, in order to avoid inappropriate working practices, especially when there are not automated control systems, that can lead to significant wastage of water.

By technical modifications
See for example techniques in Sections 3.2.1.16.5 and 3.2.1.16.6.

By optimising water supply and treatment system
See for example the technique in Section 3.2.1.16.2.

By reuse and/or recycling of water
See for example the technique in Section 3.2.1.16.3.

Achieved environmental benefits
Reduction in water consumed and waste water discharged.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
The level of detail of the water management plan and water audits will generally be related to the nature, scale and complexity of the plant.

Economics
- Staff time.
- Cost of any additional metering required.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
This technique is usually applied by the majority of IED plants.

Reference literature
No reference literature provided.

3.2.1.16.2 Segregation of water streams

Description
Water streams (e.g. surface run-off water, process water) are collected separately, based on the pollutant content and on the required treatment techniques. Waste water streams that can be recycled without treatment are segregated from waste water streams that require treatment.

Technical description
A detailed technical description of a waste water collection and segregation system can be found in the CWW BREF [179, COM 2016].

Achieved environmental benefits
Reduction in water consumption and waste water discharge.

Environmental performance and operational data
Separate discharge is recommended to avoid a dilution effect of the treated waste water. The more concentrated the effluents that result from separation, the more generally effective their downstream treatment.

Cross-media effects
None.

Technical considerations relevant to applicability
Applicability to existing plants may be limited by the layout of the water collection system.

Economics
Retrofitting costs associated with the separation/segregation of waste waters can be significant at existing plants. Waste water separation/segregation systems can be installed efficiently at new plants. Savings may be made from the reduction in the water-holding capacity needed on the site.

Driving force for implementation
- Cost savings for water-holding capacity and waste water discharge.
- Legal requirements.

Example plants
This technique is usually applied by the majority of IED plants. It was reported by 26 plants in the SF data collection. [169, TWG 2021]

Reference literature
[169, TWG 2021], [179, COM 2016]

3.2.1.16.3 Reuse and/or recycling of water

Description
Water streams (e.g. process water, effluents from wet scrubbing or cooling water) are reused and/or recycled in closed or semi-closed circuits, if necessary after treatment (see Section 3.2.1.17).

Technical description
In order to reduce costs, plants will strive to reuse and/or recycle water as much as possible. Hence, water streams (e.g. process water, effluents from wet scrubbing or cooling water) are reused and/or recycled in closed or semi-closed circuits. If necessary (based on the content of impurities), collected water is treated before recycling/reuse – see Section 3.2.1.17 where the waste water treatment techniques are discussed.

Achieved environmental benefits
- Reduction of water consumption.
- Reduction of the volume of waste water generated.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
The degree of water reuse and/or recycling is limited by the water balance of the plant, the content of impurities and/or the characteristics of the water streams.

Economics
- Investment and operation cost for the water recycling/reuse system.
- Savings due to the reduced water consumption and the reduced volume of discharged waste water.

Driving force for implementation
- Legal requirements.

Example plants
This technique is usually applied by the majority of foundries. In particular:

- 49 plants reported the internal recycling of process water
- 14 plants reported the multiple use of treated waste water.

[169, TWG 2021]

Reference literature
[169, TWG 2021], [179, COM 2016]

3.2.1.16.4 Prevention of waste water generation from process and storage areas

Description
See Section 3.1.1.4.2 related to 'Structuring and management of process areas and raw material storage areas'.

3.2.1.16.5 Use of dry dedusting systems

Description
This includes techniques such as fabric filters and dry ESP.

More information on the techniques:
See Section 3.2.1.12.7 (fabric filter) and Section 3.2.1.12.8 (ESP).

Achieved environmental benefits
No waste water generation from the off-gas treatment.

Example plants
Widely used. The use of dry dedusting systems was reported by 40 foundries in the SF data collection.

Reference literature
[169, TWG 2021].

3.2.1.16.6 Separate spraying of release agent and water in high-pressure die-casting

See Section 3.2.1.4.3.1.

3.2.1.16.7 Use of waste heat for the evaporation of waste water

Description
When waste heat is available on a continuous basis, it can be used to evaporate waste water.

Technical description
Use of excess (waste) heat to evaporate waste water; the evaporated waste water (water vapour) is then released to the environment. This is achieved by directing a portion of the flue-gases into the evaporator (usually a drying vessel). In the evaporator, the heat in the flue-gases is transferred to the waste water and evaporate it.

Achieved environmental benefits
Reduction of generation of waste water.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
- Investment and operation costs for the needed equipment (evaporator).
- Savings in terms of efficient use of waste energy and reduction of waste water volume.

Driving force for implementation
- Savings (see Economics above).
- Legal requirements.

Example plants
DE049 and DE051 [169, TWG 2021].

Reference literature
[169, TWG 2021].

3.2.1.17 Emissions to water

The identified waste water treatment techniques are mentioned in this section. Detailed data on the associated emissions to water are presented in Section 2.3 (Current consumption and emission levels).

3.2.1.17.1 Equalisation

Further information is provided in the CWW BREF [179, COM 2016].

Example plants
FI101, IT157 and IT158. [169, TWG 2021]

3.2.1.17.2 Neutralisation

Further information is provided in the CWW BREF [179, COM 2016].

Example plants
AT001, AT013, DE035, DE036, DE037, DE038, DE050, DE062, EL080, FR116 and SE150. [169, TWG 2021]

3.2.1.17.3 Physical separation, e.g. using screens, sieves, grit separators, grease separators, hydrocyclones, oil-water separators or primary settlement tanks

Further information is provided in the CWW BREF [179, COM 2016].

Example plants
AT001, AT008, AT010, AT015, BE021, DE035, DE036, DE037, DE038, DE050, DE051, ES087, ES098, FR102, FR105, FR113, FR114, FR115, FR116, IT127, IT128, IT131, IT132, IT134, IT155, IT158, SE152 and SE153. [169, TWG 2021]

3.2.1.17.4 Adsorption

Further information is provided in the CWW BREF [179, COM 2016].

3.2.1.17.5 Chemical precipitation

Further information is provided in the CWW BREF [179, COM 2016].

Example plants
DE033, DE035, DE036, DE037, DE038, DE051, DE062, EL080, ES087, FI101, FR114 and FR115. [169, TWG 2021]

3.2.1.17.6 Evaporation

Further information is provided in the CWW BREF [179, COM 2016].

Example plants
AT007, CZ025, DE033, IT123, IT154 and SE148. [169, TWG 2021]

3.2.1.17.7 Activated sludge process

Further information is provided in the CWW BREF [179, COM 2016].

Example plants
AT003. [169, TWG 2021]

3.2.1.17.8 Membrane bioreactor

Further information is provided in the CWW BREF [179, COM 2016].

Example plants
FR116. [169, TWG 2021]

3.2.1.17.9 Coagulation and flocculation

Further information is provided in the CWW BREF [179, COM 2016].

Example plants
AT001, AT013, AT015, DE035, DE036, DE037, DE038, DE050, DE051, DE062, EL080, ES087, FR114, FR115, FR116, FR119, IT129 and SE144. [169, TWG 2021]

3.2.1.17.10 Sedimentation

Further information is provided in the CWW BREF [179, COM 2016].

Example plants
AT001, AT005, AT015, BE020, BE022, DE035, DE036, DE037, DE038, DE046, DE050, DE051, DE060, DE062, DE065, EL080, FI102, FR118, FR119, IT071, IT125, IT154, IT155 and PT140. [169, TWG 2021]

3.2.1.17.11 Filtration, e.g. sand filtration, microfiltration, ultrafiltration

Further information is provided in the CWW BREF [179, COM 2016].

Example plants
AT001, DE033, DE035, DE036, DE037, DE038, DE051, DE060, EL080, FR114, FR115, FR116, IT154, PT143 and SE148. [169, TWG 2021]

3.2.1.17.12 Flotation

Further information is provided in the CWW BREF [179, COM 2016].

Example plants
FR116. [169, TWG 2021]

3.2.2 Techniques to consider in the determination of BAT for iron foundries

3.2.2.1 Energy efficiency

3.2.2.1.1 Increase of shaft height in CBC furnaces

Description
Increasing the shaft height in cold blast cupola furnaces enables combustion gases to remain in contact with the charge for longer, resulting in a higher heat transfer.

Technical description
The required shaft height for cupolas at various melting rates is given in Table 3.46. These shaft heights optimise the preheat for the descending burden. However, if the gas is to be burned at the charge-hole, a shorter shaft height may be considered. In general, the shorter the shaft, the hotter the top gas and the greater the ease of combustion – either spontaneous or assisted by an afterburner.

Table 3.46: Shaft height requirements

Melting rate of Cupola (tonne/h)	Height from tuyères to charging door sill (m)
Up to 5	4.9
5 – 8	5.8
>8	6.7

The thermal efficiency of the cold blast cupola furnace can be improved by increasing the shaft height. In general, the higher the furnace shaft, the longer the combustion gases remain in contact with the charge, and the more heat is transferred to the charge.

Depending on the installation type, optimised shaft heights in CBC furnaces allow burn-out of the gases and efficient heating of the charge.

Achieved environmental benefits
Increased energy efficiency.
~~Depending on the installation type, the height must be optimised to allow burn-out of the gases and efficient heating of the charge.~~

Environmental performance and operational data
Operational data are given in Table 3.47. The modification involves a doubling of the upper zone volume. This results in a reduction of coke consumption from 140 kg/tonne to 115 kg/tonne, which is a relative reduction of 18 %. It should be noted that in general an optimal shaft height follows the rule-of-thumb: 'height = 5 x diameter at tuyères'. The initial situation in the example furnace was therefore sub-optimal.

Table 3.47: Example data for the change in coke consumption upon shaft height increases

	Cupola before modification	Cupola after modification
Diameter		
- melting zone (m)	1.4	1.4
- upper zone (m)	1.4	1.7
Heigth over tuyères (m)	5	6.5
Coke ratio (kg/tonne)	140	115
Source: [100, TWG 2002]		

Cross-media effects
None. ~~No cross-media effects apply.~~

Technical considerations relevant to applicability
Optimisation of the furnace height needs to be performed at the design stage of the furnace, otherwise height increases will usually only be performed during major re-building works of the furnace.

Driving force for implementation
To increase the efficiency of the furnace operation.

Example plants
Operational data are taken from an example plant in France.

Reference literature
[14, CAEF 1997], [20, ETS 1993], [100, TWG 2002], [169, TWG 2021]

3.2.2.1.2 Installation of secondary row of tuyères for a cold blast cupola (CBC)

TWG, please note that this technique is proposed for deletion by industry based on the following information: "According to the manufacturers of cupola furnaces, secondary blast operation is no longer state of the art and is hardly used in foundries. Its development was based on false assumptions (neglect of important process engineering principles of melting in cupola furnaces) so that the desired effects did not occur. In furnaces that were equipped with secondary blast operation in the past, these nozzle rows were shut down and in many cases removed again. Reason: Increased top gas temperatures, shift of the melting zone towards the top. Today it is generally accepted that operation with one row of nozzles and oxygen injection gives the best results".

~~**Description**~~

~~Installation of a secondary row of tuyères to reduce emissions of CO and to improve the thermal efficiency of the cold blast cupola furnace.~~

~~**Technical description**~~

~~The thermal efficiency of the cold blast cupola furnace can be improved by the installation of a secondary row of tuyères. These provide extra oxygen above the combustion zone, which induces the oxidation of the CO in the combustion gases, the CO being formed by the endothermic reduction of CO_2 by C (coke). This technique liberates the "latent" heat of the combustion gases, thus improving the thermal efficiency of the cupola.~~

~~The divided blast cupola is equipped with two rows of tuyères, each supplied with a measured and controlled quantity of blast air. Compared with a normal cupola, fitted with a single row of tuyères, the divided blast cupola enables:~~

- ~~a higher metal tipping temperature and higher carbon pick-up to be obtained for a given charge coke consumption~~
- ~~the charge coke consumption to be reduced and, if required, the melting rate to be increased, whilst maintaining a given metal tapping temperature.~~

~~To obtain the maximum benefit from divided blast operation, the blast should be divided 25 - 50 % top and 75 – 50 % bottom. The 2 rows should be spaced about 1m apart (cold blast) to 0.5 m (hot blast). Each row of tuyères needs to be provided with its own blast supply system.~~

~~**Achieved environmental benefits**~~

~~A reduction in coke consumption and an increase in thermal efficiency.~~

~~**Environmental performance and operational data**~~

~~By the use of two rows of correctly spaced tuyères with the blast equally divided between them, the metal tapping temperature can be increased by approximately 45 – 50 ºC for a given coke consumption. Alternatively, the coke consumption can be reduced by 20 – 32 % and the melting rate increased by 11 – 23 %. When operating with a divided blast but without reducing the coke charge, so that a higher melting temperature is obtained, the carbon pick-up tends to increase slightly (by approx. 0.06 %), and the melting loss of silicon tends to also increase, by approximately 0.18 %.~~

~~With divided blast operation, the lining burn-out extends further into the furnace shaft. At the start of a melt it is therefore necessary to measure and adjust the coke bed height. On melts of short duration, i.e. those less than about 2 – 3 hours, the saving in coke charge does not usually compensate for the additional requirements of bed coke. Nevertheless, even on short melts, the higher tapping temperature and the higher carbon pick-up obtainable with divided blast operation can be an advantage to many foundries.~~

~~Other reported advantages are:~~

- ~~the exit gas temperature is only 250 ºC, compared to the conventional cupola, where the temperature is 450 ºC~~

~~- it can take 100 % bigger chunks of re-melting scrap~~
~~- it is possible to increase the steel scrap ratio in the metal charge.~~

~~Additional operational data are given in Annex 1.~~

~~**Cross-media effects**~~
~~No cross-media effects apply.~~

~~**Technical considerations relevant to applicability**~~
~~The second row of tuyères is applied as a standard technique for new cold blast cupola installations and may be applied to existing installations during reconstruction. This technique is not normally applied for hot blast operation~~

~~**Economics**~~
~~The divided blast cupola has been well proven in practice as a means of obtaining economic operation for a modest investment cost.~~

~~The capital cost of converting existing cupolas to divided blast operation is low compared to the savings obtained. BCIRA quoted one British foundry where the payback period was only fourteen weeks. A large Canadian foundry saved CAD 170000 in one year for a conversion cost of only CAD 18000. An additional benefit from a lower coke use per tonne of iron is the lower sulphur content, this saves on the desulphurisation plant and gives a higher quality iron.~~

~~Additional economic data are given in Annex 1.~~

~~**Driving force for implementation**~~
~~To increase the efficiency of the melting operation.~~
~~Legal requirements.~~

~~**Example plants**~~
~~In France, all the recent cold blast cupolas use 2 rows of tuyères: STAUB (Merville), FONTE ARDENNAISE (Vivier au court), BERNARD HUET (Vivier au court). There is also 1 hot blast with 2 rows: FIDAY GESTION (Chassey les Scey)~~

~~**Reference literature**~~
~~[14, CAEF 1997], [94, Unido 2002], [100, TWG 2002], [120, TWG 2003]~~

3.2.2.1.3 Oxygen enrichment of the combustion air

Description
Oxygen enrichment of the combustion air is realised either directly at the blast supply or through injection of oxygen into the coke bed, or via the tuyères.

Technical description
The thermal efficiency of the cold blast cupola furnace can be improved by oxygen enrichment of the combustion air. This gives rise to a higher combustion temperature of the coke. In this way coke consumption can be decreased or higher temperatures of the tapped metal can be obtained.

Compared with normal operation, the continuous use of oxygen enables one of the following improvements to be made:

- a higher metal temperature, higher carbon pick-up and lower melting loss of silicon for the same coke consumption, or
- a lower coke consumption for a given metal temperature, with no increase in carbon pick-up or reduction in the melting loss of silicon, or

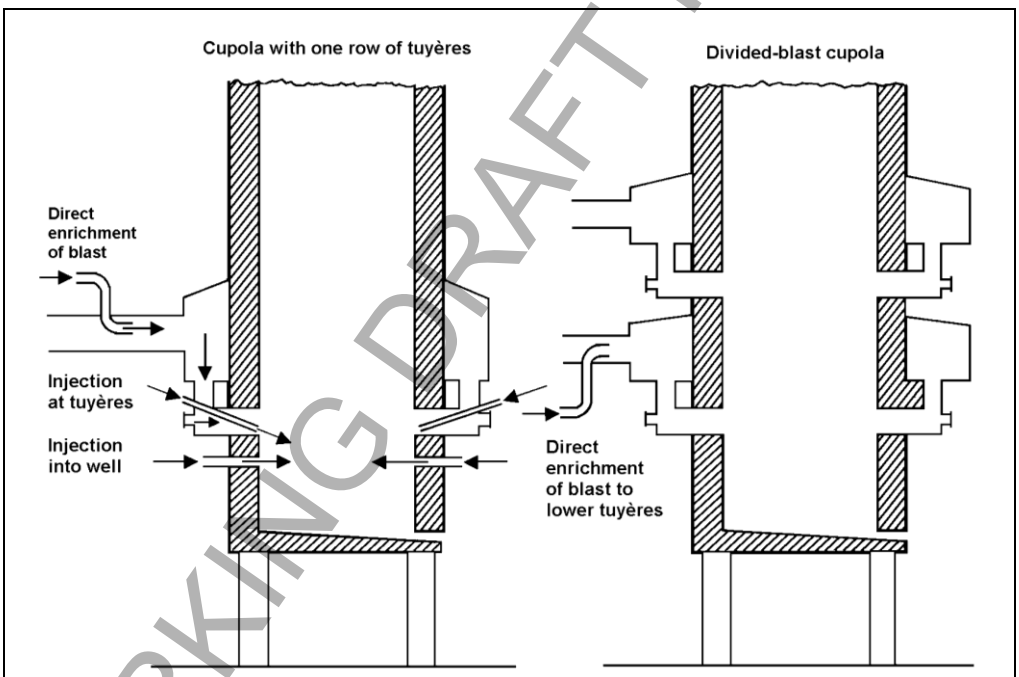
- an increased output from an existing cupola, as a result of the increased melting rate.

Oxygen injection provides the possibility of reacting quickly to process drifts, and then compensating for small changes in process conditions. Thus, oxygen injection is often used intermittently, usually whenever the process requires adjustment.

The effectiveness of the oxygen depends on the method by which it is introduced into the cupola. Three processes have been developed:

- *Direct enrichment of the blast supply*: Oxygen is fed into the main blast, this technique is applied in the majority of the cold blast cupolas.
- *Injection into the well*: Oxygen is injected into the coke bed from a ring-main which supplies water-cooled injectors, whose number depends on the cupola size. Oxygen used in this way is at least twice as effective as when it is used to enrich the blast supply directly. However, this type of injection is confined to continuously-tapped cupolas, since with intermittent tapping there is a risk that slag and or metal may rise to the level of the injectors. The technique was developed in the UK but it has not found widespread application.
- *Injection at the tuyères*: Oxygen is introduced into the cupola through injectors inserted into each tuyère or into alternate tuyères. The effectiveness of this method lies between direct blast injection and well injection methods. This technique is used in 20 – 30 % of cases, but more in hot blast operation.

The principles of oxygen injection are depicted in Figure 3.58.



Source: [20, ETSU 1993]

Figure 3.58: Various methods of oxygen injection

Achieved environmental benefits

The application of oxygen results in a reduced coke consumption and a better process control. Additionally, a reduction in the emission of dioxins and furans from cold blast cupolas have been reported.

Environmental performance and operational data
Compared to conventional cold blast operation with one row of tuyères, the increase in tapping temperature obtained for a given charge of coke, can be expected to be as follows:

- blast enrichment + 15 ºC;
- well injection + 85 ºC;
- tuyère injection + 40 ºC.

Divided blast operation with a direct enrichment of blast air, results in an increase in the tapping temperature of 85 ºC compared to cold blast operation. In divided blast operation, neither well injection nor tuyère injection give any greater benefit than the simple method of direct injection.

An important application of oxygen has been to increase the melting rate of an existing cupola, well beyond its usual optimum melting capacity. In divided blast cupolas, the melting rate increases by around 6.8 % and the tapping temperature by about 20 ºC for each 1 % of direct oxygen enrichment in the blast air. If an increase in temperature is not required and the coke charge is reduced, an even greater increase in the melting rate can be obtained for the same blast rate and oxygen enrichment.

Additional operational data are given in Section 9.1 (Annex 1).

Cross-media effects
The technique requires oxygen which is produced off site and involves a consumption of electric energy.

Technical considerations relevant to applicability
Today, almost all European hot blast cupolas inject oxygen through the tuyères. For cold blast furnaces, the use of oxygen enrichment can be considered as the standard technique. In this case, enrichment of the blast supply is usually applied, if applicable. The oxygen level of the oxidising air mixture is usually between 22 % and 25 % (i.e. an enrichment of 1 % to 4 %).

Economics
The effect that using oxygen has on melting costs greatly depends on the price of oxygen, which in turn is related to the amount used. Foundries with larger outputs can generally buy oxygen more cheaply. The economic case for using oxygen has to be established on a case-by-case basis.

The substantial increase in outputs obtainable has enabled foundries to increase outputs without high capital investments in new plant, and to reduce costs and overtime payments, so much so that the overall reduction in costs amply justify the cost of oxygen. Such improvements must take into account the related core and mould making capacity.

Driving force for implementation
- To optimise the efficiency and control of the melting process.
- Legal requirements.

Example plants
This technique is commonly applied in European foundries using cupola furnaces.

Reference literature
[14, CAEF 1997], [59, Godinot 2001]

3.2.2.1.4 Superheating of HBC blast air

Description
Increase of the flame temperature by superheating the blast air to 800-900 °C either by injection of air plasma or by using resistance heaters.

Technical description
An alternative technique for increasing the flame temperature is to superheat the blast air to 800-900 ºC. For this, injection of an air plasma, or heating in tubular resistance heaters is applied. Experience has shown that increasing the blast temperature by 200 ºC, from 550 ºC to 750 ºC, which takes 60 kWh per tonne of iron, saves 10 kg of coke per tonne melted. The main benefit, more important even than saving coke, is the flexibility: the hourly output can be increased by 30 % without modifying the melting bed. Additionally, the application of (plasma) superheating allows a change in raw material from clean cast iron to steel, with a subsequent positive economic effect.

Achieved environmental benefits
Reduced coke consumption and increased efficiency of the process.

Environmental performance and operational data
Operational data are given in Section 9.1 (Annex 1). The heating of the blast air produces a lower flue-gas volume as compared to hot blast long campaign operation. As compared to oxygen injection, the flue-gas volume and electricity consumption is larger.

Cross-media effects
Electrical heating causes an increase in electricity consumption (58 kWh/tonne).

Technical considerations relevant to applicability
The technique applies to new and existing HBC furnaces.

The technique (both with electrical and plasma heating) achieves a similar effect as injection of oxygen through the lances, but can be applied in a more complex installation and produces a larger flue-gas volume. Additionally, oxygen injection allows make-up for leaks in the air circuit.

Economics
Economic data are given in Section 9.1 (Annex 1).
TWG, please update.

Driving force for implementation
- To optimise the efficiency and to control the melting process.
- Legal requirements.

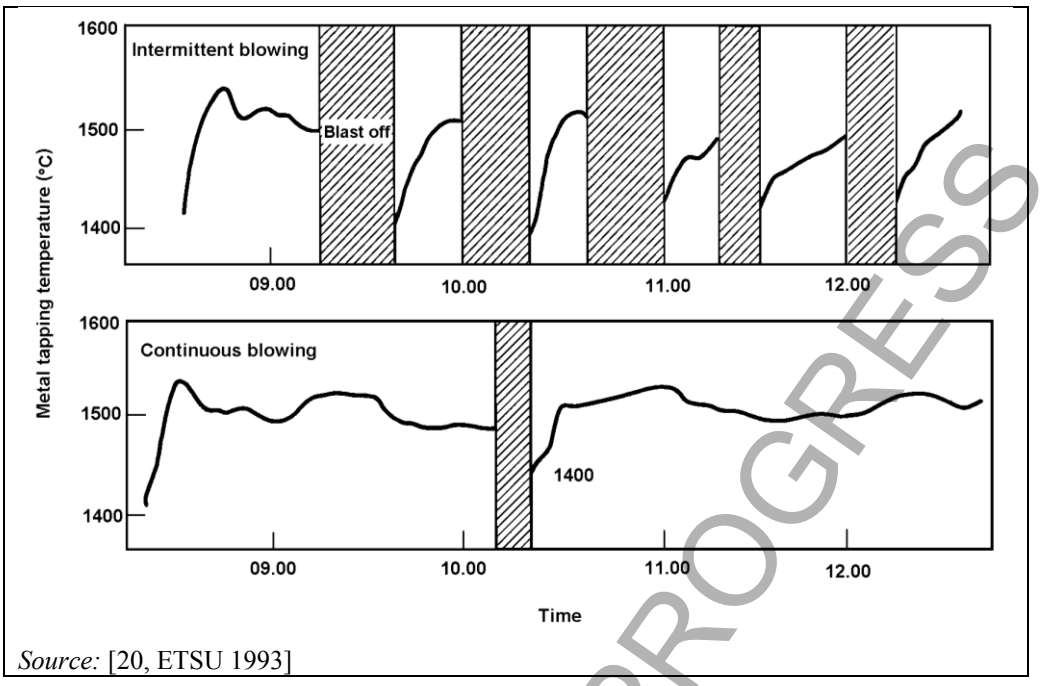
Example plants
PSA, Sept-Fons, France
Three foundries in France apply tubular resistance heating.

Reference literature
[59, Godinot 2001]

3.2.2.1.5 Minimal blast shut-off periods for HBC furnaces

Description
Minimisation of blast shut-off periods by programming the schedules of the moulding and casting processes to ensure a reasonably constant demand for metal.

Technical description
A cupola blown just intermittently will not operate efficiently, and will result in a reduced metal tapping temperature, as shown in Figure 3.59.



Source: [20, ETSU 1993]

Figure 3.59: Effect of blast shut-off periods on tapping temperature in a post-blast cupola

Frequently shutting off the blast due to only intermittent demands for metal:

- reduces the average tapping and pouring temperatures and increases the extent of their variations, with a consequent risk of producing defective castings;
- increases the variation in metal composition, particularly the carbon and silicon content, with a danger of then producing 'off-grade' metal;
- increases the coke consumption, through the operators' attempt to improve the tapping temperature;
- affects the degree of nucleation in the iron and increases its shrinkage tendencies.

Moulding and casting schedules are therefore programmed to produce a reasonably constant demand for metal, thereby minimising or even eliminating the need for blast shut-off periods or for large variations in the blast rate.

Where large fluctuations in demand are unavoidable, the installation of an electric holding furnace might be considered. This can provide a large buffer reservoir for metal, to take up variations in demand, so that the cupola can be operated continuously at a reasonably consistent blast rate. It can also be used to help even out variations in temperatures and composition.

Achieved environmental benefits

- Reduction of coke consumption.
- Higher process energy efficiency.

Environmental performance and operational data

No information provided.

Cross-media effects

Operating the electric holding furnace incurs a higher energy consumption.

Technical considerations relevant to applicability

This technique is applicable to all new and existing cupola furnaces.

Economics
The economics of installing a holding furnace must be very carefully considered, particularly in foundries with relatively low production rates.

Driving force for implementation
- To increase the efficiency of the foundry process.
- Legal requirements.

Example plants
The applicable blasting regime is part of the operational considerations in all European foundries using cupola furnaces.

Reference literature
[20, ETSU 1993]

3.2.2.1.6 Long-campaign cupola

Description
The cupola furnace is set up for long campaign operation to minimise maintenance and process changes. This may be achieved by using more resistant furnace refractory linings in the shaft, bottom and hearth, by using water cooling of the furnace wall and with water-cooled blasting pipes penetrating deeper in the furnace shaft.

Technical description
This is a long-term cold blast cupola which also has oxygen injection. The adjustment of the amount of blasted air to the current operating conditions is done with the aid of an air flow volume measurement, an air flow control system and a frequency control for the air fan. Unlike the pre-existing furnace, the molten iron is not continuously stored in the interior of the long-campaign cupola. For this purpose, a non-heated forehearth has been installed, which absorbs the leaking melt.

In normal operation, molten iron is continuously leaking. Here it is collected over iron gutters in the unheated tray forehearth with a crane ladle and then transported to the already existing, electrically heated furnace or heat-retaining memory furnace, or, if necessary, transported directly to the mould system for casting. The slag is separated in the siphon and then flows into a slag bucket below the furnace platform, which cools it before it is directed to the next step in solid form for recycling/disposal.

The main difference between the two former shaft furnaces, whose feed had to be replenished every day, is that the long-time cupola furnace has a water-cooling system for the blast furnace that the blast nozzles extend into. The water-cooling system prevents the nozzle from melting quickly due to the high temperature in the furnace, which was linked in this area to a strong erosion of the furnace lining. This will prolong the life of the furnace lining considerably, so that the furnace can be operated over a period of several weeks before the furnace has to be relined.

The dust extraction consists of the radiator, two cyclones, the dry cleaning system and dust filter with radial fan, exhaust silencer and steel chimney. In the combustion process in a cupola furnace, stack gas is produced in all phases of operation (start-up, normal operation, low-melting). The gas is fully captured in the furnace head and fed to the cupola dust extraction.

The deposited dust in the filter bags is cleaned by backwashing, then collected in the dust collection hopper and fed to a dust container and disposed of therein. The cleaned air is discharged with a residual dust content of < 10 mg/m^3 in the atmosphere.

As an additional measure for improvement, the warehouse and the charge make-up of the starting materials are housed in a separate hall. This reduces the noise emissions and fugitive dust emissions greatly and, in addition, loss of starting material quality due to weather can be avoided.

Achieved environmental benefits

- Long-term cold blast cupola:
  - Protecting the environment by reducing the consumption of materials (furnace lining) and the amount of waste (furnace waste). Before changing furnace, the lining life time was 1 day; afterwards it was more than 2 months. The demand in terms of fire resistant lining before changing was 25-30 kg/t liquid iron and afterwards 1.6 kg/t liquid iron (data for an example plant (Hermann Reckers GmbH & Co)).
  - Reduced dust emissions and waste volumes due to the start-up and shutdown, and the renewal of the furnace lining (before: 1 day; afterwards: more than 2 months).
  - Reduction of odour emissions by 60 % (before: 167 MGE/h; 4 400 GE/m^3; afterwards: 65 MGE/h; 1 700 GE/m^3).

- Feedstock storage in a warehouse:
  - Reduction of fugitive emissions during storage and charge makeup of the starting materials.
  - Reduced moisture in feedstock and coke.

- Reduction of noise at the delivery and in charging/make-up of substances.

Environmental performance and operational data

The following operational data were reported for an example plant (Hermann Reckers GmbH & Co).

Table 3.48: Operational data for a long-campaign cold blast cupola

Operating times cupola furnace	Monday to Friday in 2-shift operation from 5:00 to 22:00
Melting capacity (liquid iron)	Before: Up to 8 t/h After: Up to 12 t/h
Furnace lining lifetime	Before: 1 day After: more than 2 months
Fire resistant demand	Before: 25 – 30 kg/t Liquid After: 1.6 kg/t Liquid iron
Odour emissions	Before: 167 MGE/h; 4 400 GE/m^3 After: 65 MGE/h; 1 700 GE/m^3
Exhaust gas volume cupola furnace, coke, oxygen demand, the amount of dust (waste disposal)	No changes
NB: MGE/h: mega odour units per hour, unit for defining the odour emission rate. GE/m^3: Dutch odour unit - 1 GE/m^3 corresponds to 20 ppbv of n-butanol according to the Dutch NVN2820:1990 standard. *Source*: [133, DE UBA 2014]	

Cross-media effects

No significant cross media effects (slightly increased power consumption from cooling equipment might occur).

Technical considerations relevant to applicability
Reconstruction requires a significant investment (reconstruction of the cupola furnace and warehouse).

A long-term cold blast cupola should be operated in at least two shifts, because during non-operating time (night shift) it is not completely shut down. This phase takes too long (i.e. in one-shift operation) and the long-term cold blast cupola would be uneconomical.

Economics
The following economic data were reported for the example plant:

- investment storage hall: approximately EUR 900 000;
- investment long-term cupola: approximately EUR 1 200 000.

Table 3.49: Economic aspects for a long-term cold blast cupola

Operating costs:	Old cupola	New cupola
lining material	3.61 €/t Fe	2.10 €/t Fe
disposal costs	1.23 €/t Fe	0.04 €/t Fe
labour costs	5.76 €/t Fe	4.38 €/t Fe
Sum:	10.60 €/t Fe	6.52 €/t Fe
Source: [133, DE UBA 2014]		

Driving force for implementation
- Environmental benefits.
- Increased competitiveness by reducing costs related to refractory and furnace waste disposal.
- Possibility to extend the operating hours of the melting operation to three shifts.
- Improvement in workload and job security by significantly reducing physically stressful work in the hot and narrow furnace shaft.

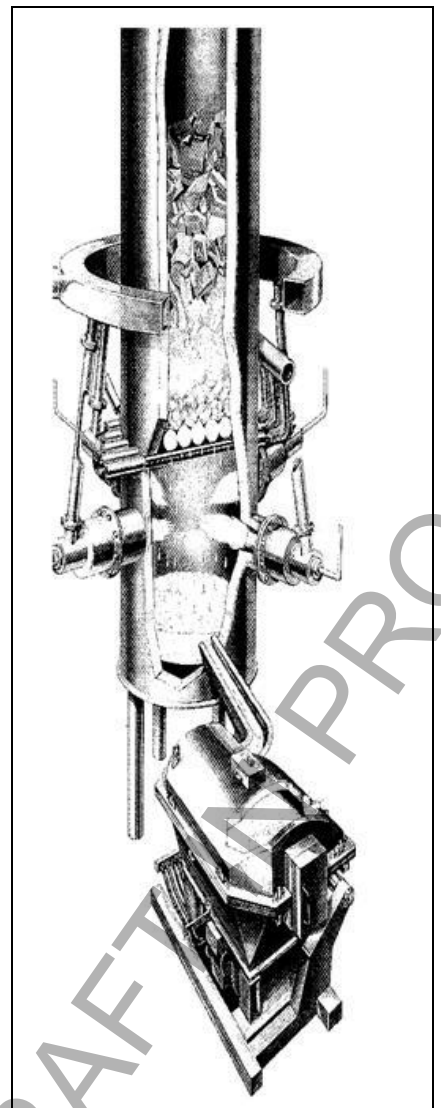
Example plants
Hermann Reckers GmbH & Co. KG Eisengießerei, 48432 Rheine – Mesum, DE.

Reference literature
[133, DE UBA 2014]

3.2.2.1.7 Cokeless cupola furnace

TWG, please note that this technique is proposed for deletion by industry based on the following information: "There is no new information available. The few cokeless cupolas in Europe were demolished"

~~**Technical description**~~
~~In the cokeless cupola, the metal charge is heated by the combustion of natural gas. Instead of the traditional coke bed, a bed of refractory spheres on a water-cooled grid supports the metal charge. The molten metal droplets run through this bed and are collected in the well at the bottom of the furnace. The life of the spheres exposed to the superheating temperatures of the metal is limited. A cokeless cupola is therefore run at a reduced temperature (1400 ºC instead of 1500 ºC) and superheating of the liquid metal is done in an attached gas-fired or induction furnace (duplex operation).~~



~~*Source:* [38, VITO 2001]~~

~~Figure 2.72: Cokeless cupola furnace in duplex operation [38, VITO 2001]~~

~~An important operational factor is that the cokeless cupola has to be run continuously. There is a high risk of clogging and blocking on the cooled grate bars. In case there is a need to stop the metal flow (e.g. due to problems in the moulding shop), the power of the burners can be reduced to 35 – 40 %, in order to compensate for wall heat losses. The need for continuity needs to be balanced with the usage of refractory in the melting zone. Therefore, melting campaigns of one week are typically used.~~

~~The oxidising atmosphere and relatively low flame temperature cause increased oxidation losses. This limits the possibility to feed in steel. A maximum amount of 35 % of steel is used in the production of nodular iron, though 20 % can be considered general practice. The quality of the feed needs to be well controlled since the cokeless cupola is more susceptible to bridging than the coke-fired cupola.~~

~~In the production of nodular iron, an important advantage of the cokeless cupola is that there is no resulphurisation, so the melt may be used immediately after recarburisation.~~

~~Achieved environmental benefits~~

~~Besides a higher thermal efficiency, this furnace has other environmental advantages. The combustion of natural gas instead of cokes has the following consequences for the flue-gas:~~

- ~~less dust (0.8 kg/t metal charge instead of 10 to 15 kg/t metal charge for cold blast cupola)~~
- ~~no CO or SO_2 and less CO_2 (120 kg/t metal charge instead of 450 kg CO_2/t metal charge for cold blast cupola)~~
- ~~the flue-gas rate is smaller (495 m³/t metal charge instead of 770 m³/t metal charge for cold blast cupola without water-cooled refractory), and hence the dedusting installation can be designed much smaller.~~

~~Environmental performance and operational data~~

~~Operational data are given in The furnace is generally operated at an air factor of λ = 1.15. The capacity of the furnace may be high (often in the range 10 – 12 t/m².h). The amount of spheres is 1 – 1.4 % of the metal charge. The energy efficiency of the cupola, without taking the coupled induction furnace into account, is in the range of 70 %.~~

	~~Units~~	**~~Consumption (per tonne of molten metal)~~**
~~Natural gas consumption~~		
~~Preheating of the furnace~~	~~m³~~	~~600~~
~~Melting~~	~~m³~~	~~48.0~~
~~Electrical energy consumption~~		
~~a) Superheater~~		
~~Superheating~~	~~kWh~~	~~64.0~~
~~Holding~~	~~kWh~~	~~15.0~~
~~b) Auxiliary equipment~~	~~kWh~~	~~25.0~~
~~Consumption of lining material~~		
~~Furnace shaft~~	~~kg~~	~~5 – 8~~
~~Syphon~~	~~kg~~	~~0.7~~
~~Superheater~~	~~kg~~	~~0.5~~
~~Water consumption~~	~~m³~~	~~0.4~~
~~Oxygen consumption~~	~~m³~~	~~19.7~~
~~Metallic charge~~	**~~Components~~**	~~Part (%/t)~~
	~~steel~~	~~25 – 35~~
	~~pig iron~~	~~20 – 30~~
	~~returns/cast iron scrap~~	~~35 – 55~~
~~Alloying and additives~~	**~~Components~~**	~~Part (%/t)~~
	~~Carburiser~~	~~1.1~~
	~~Briquettes – Si~~	~~0.8~~
	~~Ceramic balls~~	~~0.95~~
	~~Slag forming constituent~~	~~0.3~~

~~Typical operational data for a cokeless cupola furnace~~
~~[100, TWG 2002]~~

~~Due to the absence of cokes (and CO), no latent heat is lost from the cokeless furnace system. Full heat recuperation from the flue-gas occurs in the shaft. In duplex configurations (for example in conjunction with an induction furnace), efficiencies in the range of 40 to 60 % may be obtained. Thermal efficiencies for coke fired cupolas vary between 25 % (cold blast) and 45 % (hot blast, long campaign).~~

~~Emission data for cokeless and hot blast cupola furnaces are compared in These apply for the following configurations:~~

- ~~cokeless cupola: below-charge exhaust capture; oxidising atmosphere (λ = 1.15); no post combustion; dry filtration~~

- ~~hot blast cupola: below-charge exhaust capture; post combustion in separate chamber, followed by recuperation and dry filtration.~~

	~~Cokeless~~				~~Hot blast cupola~~			
	~~Working conditions~~		~~Nm³/t~~	~~kg/t~~	~~Working conditions~~		~~Nm³/t~~	~~kg/t~~
~~Gas~~	~~50 Nm³/tonne~~							
~~Energy~~	~~500 kWh/Nm³~~							
~~λ~~	~~1.15~~							
~~Coke~~					~~12 %~~			
~~Steel~~					~~50 %~~			
~~Recarburi-sation~~					~~1.9 %~~			
~~Total combustible carbon~~					~~9 %~~			
~~Flue gas~~			~~550~~				~~2930~~	
~~CO_2~~		~~9.1 %~~	~~50~~	~~98~~		~~6 %~~	~~176~~	~~346~~
~~H_2O~~		~~18.2 %~~	~~100~~			~~-~~		
~~O_2~~		~~2.7 %~~	~~15~~			~~15 %~~		
~~CO~~		~~<1 %~~	~~<5.5~~	~~<6.9~~		~~10 mg/Nm³~~		~~29 g/t~~
~~NO_x~~		~~155 – 375 mg/Nm³~~		~~85 – 210 g/t~~		~~205 mg/Nm³~~		~~150 g/t~~
~~SO_2~~		~~-~~				~~100 mg/Nm³~~		~~300 g/t~~

~~**Emission data for cokeless cupola and hot blast cupola [69, Godinot, P. et al. 1999]**~~

~~The following observations can be made:~~

- ~~the cokeless cupola emits five times less flue-gases than the hot blast cupola. This is mainly due to the post combustion, which brings excess air into the combustion chamber of the hot blast cupola. As a consequence, the cokeless cupola can be equipped with a smaller flue-gas treatment system~~
- ~~the cokeless cupola emits 3 to 4 times less CO_2 than the hot blast cupola~~
- ~~the cokeless cupola emits more CO, which is combusted in the case of the hot blast cupola~~
- ~~NO_x and SO_2 emission levels are low compared to current emission limit values (e.g. for France, 500 mg/Nm³ and 300 mg/Nm³ respectively)~~
- ~~if dry filtration is applied, both techniques have low dust emission values.~~

~~**Cross-media effects**~~

~~The use of cokeless cupola melting necessitates duplex operation, in order to allow superheating of the iron. For superheating in an induction furnace, there is an increased need for electrical power compared to the hot blast operation.~~

~~**Technical considerations relevant to applicability**~~

~~The technique applies to new installations, producing medium to large series. The cokeless cupola needs a constant and continuous working regime. Due to high oxidation losses and a high risk of bridging, the technique requires a clean feed with a steel content of max. 35 %. Since no sulphurisation occurs, the technique is of special interest for the production of nodular iron.~~

~~**Economics**~~

~~Data on operational costs (for 1999) are presented relative to operational costs of hot blast cupolas (set at 100%) in The values apply for a 12 tonnes/h equipment and have been based on a study of 3 cokeless cupolas operating in Europe.~~

		~~Raw materials (%)~~	~~Auxiliary materials (%)~~	~~Melting energy + Fluids (%)~~	~~Comparative index~~
~~Grey cast iron~~	~~Cokeless gas cupola~~	~~83~~	~~6~~	~~11~~	~~116~~
	~~Hot Blast coke cupola~~	~~69~~	~~8~~	~~23~~	~~100~~
~~Nodular cast iron~~	~~Cokeless gas cupola~~	~~81~~	~~6~~	~~13~~	~~104~~
	~~Hot Blast coke cupola~~	~~69~~	~~8~~	~~23~~	~~100~~

~~**Operational costs for cokeless cupola, relative to hot blast cupola (set at 100%) [100, TWG 2002]**~~

~~The tabled values were calculated in 1999, however since then, there has been an increase of the price of coke. From this table it may be concluded that, in Europe a 12 t/h cokeless cupola:~~
- ~~melts the more expensive grey cast iron~~
- ~~melts nodular base iron with a price very similar to hot blast cupola.~~

~~The comparison is very dependent on the local price of energy and materials.~~

~~**Driving force for implementation**~~
~~To reduce cupola emissions.~~

~~**Example plants**~~
- ~~Düker, Laufach (D): 15 tonne/h nodular iron~~
- ~~Düker-Kuttner, Lingotes Especiales, Valladolid (E): 16 tonne/h grey an nodular iron~~
- ~~Hayes Hydraulic Castings (GB), 5 - 6 tonne/h lammellar and nodular iron.~~

~~**Reference literature**~~
~~[14, CAEF 1997], [38, VITO 2001], [69, Godinot, P. et al. 1999]~~

3.2.2.1.8 Gas-fired coke-cupola

Description
Partial replacement of coke with natural gas in a cupola furnace.

Technical description
The principle of the coke-gas cupola is to replace part of the coke with gas. There are two techniques for burning natural gas in the cupola:

- using air-gas burners, located above the tuyères;
- using oxygas burners, located in the tuyères.

At present, the coke/air-gas cupola furnace finds limited implementation in Europe. This may be attributed to the difficulty in controlling the process and the increased complication of the furnace shell.

The oxygas burner was introduced in 1994. Besides oxygas firing, it allows the introduction of dust into the tuyères for recirculation, although in practice this option is not applied. The oxygas burners are placed in 1/3 – 1/2 of the tuyères. About 10 % of the coke energy is replaced by natural gas, leading to a gas consumption of 8 Nm³/tonne to 16 Nm³/tonne. This is associated with a total oxygen consumption (burners + lances) of 40 Nm³/tonne to 60 Nm³/tonne. The application of this technique allows a greater flexibility in the production and/or metallurgy.

The effect and use of the oxygas burner depends on the cupola concerned. In cold blast cupola furnaces, the technique is used to ensure easy restarts or to reduce the proportion of coke. In hot blast operation, the technique is used to increase the furnace capacity without modifying the

melting bed. The replacement of part of the coke with CH_4 results in a reduction in flue-gas volume. This is used as a means of increasing the furnace capacity, without over-saturating the installed flue-gas cleaning system.

The technique results in an increase in the carbon content of the melt and allows an increase in the amount of steel in the charge. The process provides a means of injecting FeSi, which is less expensive in powder form than as ore. These properties result in a beneficial economic effect.

Achieved environmental benefits
The replacement of part of the coke with CH_4 results in a reduction in the flue-gas volume. In addition, the flue-gas is made more combustible due to the higher CO and H_2 contents. If post combustion is present, the resulting flue-gases will show lower levels of organic compounds and CO.

The replacement of coke by natural gas reduces the emission levels of SO_2.

The technique allows the possibility of recirculating cupola dust into the melt. Although, after some initial trials, this application has not been fully developed.

Reducing the level of coke in the cupola increases the risk of bridging.

Environmental performance and operational data
The AGA-Rayburn Foundry (Coalbrookdale, UK) equipped 3 out of 8 tuyères of their cold blast cupola with oxygas burners. This allowed a reduction in the overall proportion of coke from 15 % to 10 %. There was a resultant drop in the sulphur content of the produced iron, this then allowing a reduction to be made in the amount of pig iron used, and thus yielding an economic gain.

Fritzwinter foundry (D) equipped three out of six tuyères of their 20-25 tonne/h hot blast cupola with oxygas burners. This allowed an increase in production capacity to 28 tonnes/h, without the need to change the melting bed, nor the flue-gas cleaning system. The effect on the flue-gas composition before burning is given in the following table.

Table 3.50: Effect of oxygas burners on the flue-gas composition for a hot blast cupola values in %

	With oxygen without oxygas burners	With oxygen with oxygas burners
H_2	0.8 – 1.2	2.2 – 2.4
CO	14 – 15	19
O_2	2	2
Source: [83, Godinot, P. et al. 2002]		

Cross-media effects
The production, storage and use of oxygen increases the safety risks. Oxygen production is done through cryogenic distillation or Vacuum (Pressure) Swing Adsorption, which both involve elctricity consumption. The consumption of the latter technique is 0.35-0.38 kWh/Nm³ O_2. Oxygen production is often done by an external supplier, who delivers the oxygen to a storage tank or directly through a pipeline.

Technical considerations relevant to applicability
The technique may be applied on both cold blast and hot blast cupolas in both new and existing installations. The advantages drawn from the application (increased flexibility, economical benefit, reduced flue-gas volume, increased capacity) will depend on the specific melting conditions of the installation under consideration. The technique has been reported to cause

difficulties for controlling the process and also increases the complication of the furnace shell required.

Economics
Operational costs before and after switching a cold blast cupola to oxygas operation for the above-mentioned Aga-Rayburn foundry (UK) are given in the following table. Prices are forecasts as calculated by CTIF (F).

Table 3.51: Operational costs for cold blast cupola with and without oxygas burners

Input	Units	Unit price	Without burners		With burners	
		EUR	Consumption per tonne	Cost EUR/tonne	Consumption per tonne	Cost EUR/tonne
Coke	Tonne	198	0.15	29.7	0.1	19.8
Gas	Nm³	0.15	0	-	16.5	2.5
Oxygen	Nm³	0.38	14	5.4		
		0.23			40	9.2
Pig iron	Tonne	164.6	0.2	32.9	0	-
Scrap iron	Tonne	125.8	0.2	37.7	0.5	62.9
Total	EUR/tonne			105.7		94.4

NB: All values per tonne of molten metal
Source: [83, Godinot, P. et al. 2002]

Operational costs decrease from EUR 105/tonne to EUR 94/tonne molten metal. The economic gain can mainly be attributed to the reduced proportion of pig iron. This also stresses the fact that the balance will differ for each specific foundry.

Driving force for implementation
To increase flexibility of the foundry and/or to increase the production capacity of existing installations without changing the installation layout.

Example plants
- AGA-Rayburn Foundry (Coalbrookdale, UK)
- Fritzwinter foundry (D)

Reference literature
[59, Godinot 2001], [83, Godinot, P. et al. 2002]

3.2.2.1.9 Post-combustion of off-gases

Description
Post-combustion of CO and other organic compounds contained in furnace off-gases is used to reduce emissions and for heat recovery. The generated heat is recovered with a heat exchanger and used for blast air preheating or other internal purposes. In HBC furnaces, post-combustion takes place in a separate post-combustion chamber preheated with a natural gas burner. In CBC furnaces, post-combustion takes place directly in the cupola shaft. In rotary furnaces, post-combustion is carried out using an afterburner installed between the furnace and before the heat exchanger.

Technical description
Post-combustion in cupola furnaces
Post-combustion of the waste gases is used to optimise heat recovery (chemically bonded as CO) and to provide cleaner exhaust gases. In burning CO, any residual carbonaceous material is simultaneously oxidised to CO_2 and H_2O. The generated heat can be recovered using a heat-exchanger and then transported to an internal user (e.g. blast air preheating).

Typical arrangements are:

- a post-combustion chamber placed before (bag filter) or after (wet filter) the dedusting unit (for below charge-hole offtake); ~~this is discussed in Section~~
- (natural gas) burners or controlled air injection in the cupola shaft (for above charge-hole offtake) ~~this is discussed in Section~~.

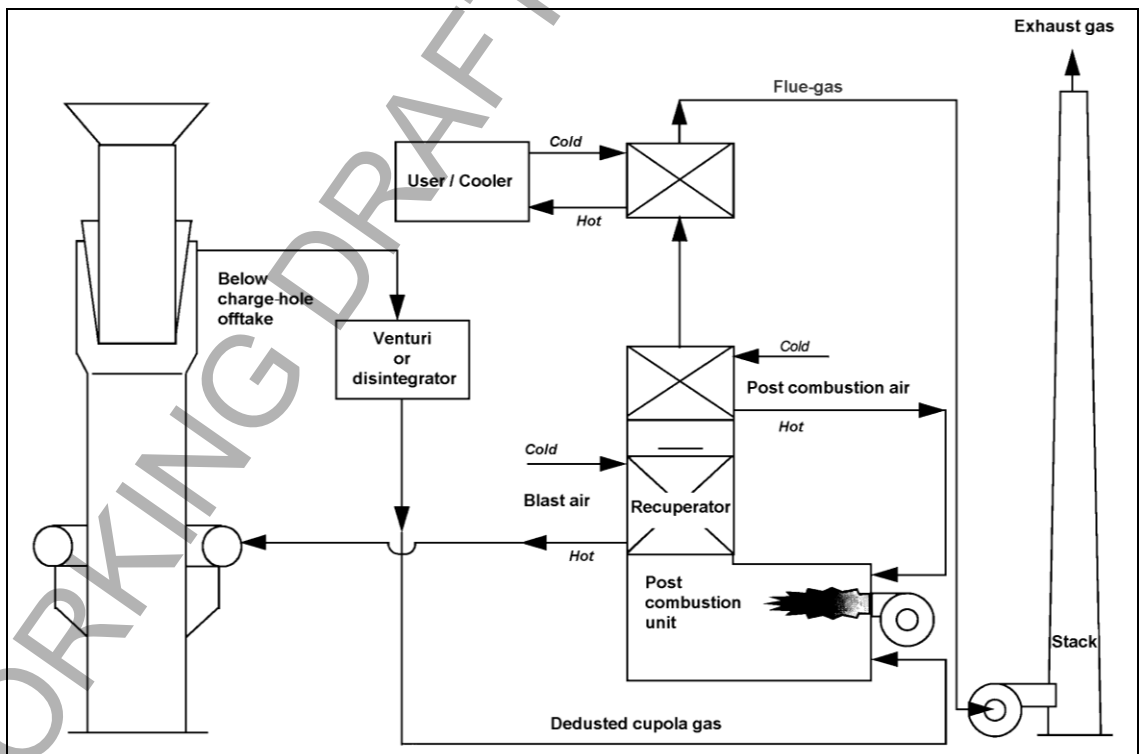
The design of the system needs to ensure that the waste gases remain at a temperature above 800 ºC and with a suitable residence time, i.e. 2 seconds, to guarantee the complete oxidation of the waste gases. The different systems are fully described and discussed below.

Post-combustion in HBC furnaces

A post combustion chamber with a burner is installed after the cupola. Normally a separate post combustion unit has to be preheated with a natural gas burner. Once the cupola is up and running either a smaller burner sustains the combustion of the waste gases or the gases self-ignite.

The type and position of the chamber can vary according to the process composition. Both horizontal and vertical combustion chamber types exist.

- *Hot blast cupola with a recuperator and wet scrubber* (Figure 3.60): In this arrangement, the gases are dedusted prior to combustion. This reduces dust build-up in the recuperator, which improves the rate of heat transfer. One disadvantage is the higher energy consumption in the post combustion unit, caused because the gases are cooled down in the wet scrubber. Early cooling of the offtake gases is continuously carried out to reduce the size of the dedusting unit.

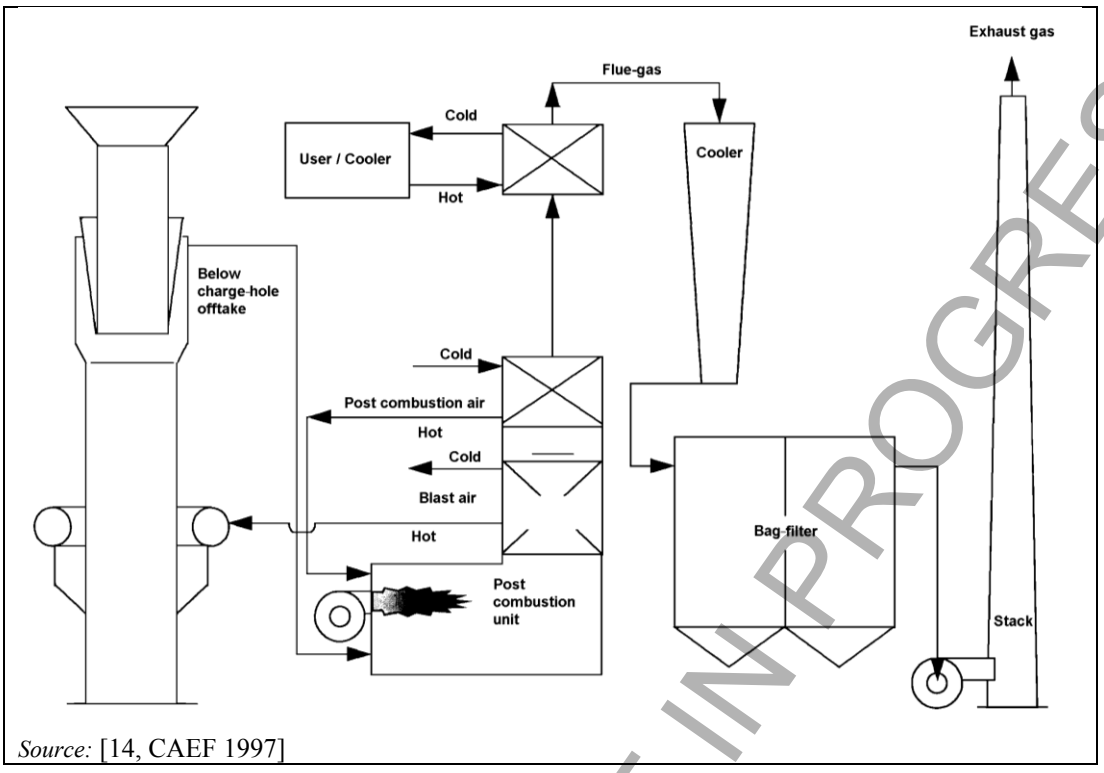


Source: [14, CAEF 1997]

Figure 3.60: Hot blast cupola with a recuperator and wet scrubber

- *Hot blast cupola with a recuperator and bag filter* (Figure 3.61): The hot, dust laden, top gases are fed directly into the post combustion unit. Close process control is necessary to prevent sintering of the dust particles to the walls of the recuperator, which need to be

cleaned regularly. The gases need further cooling before entering the bag filter since they leave the recuperator at temperatures of 500 ºC to 600 ºC.



Source: [14, CAEF 1997]

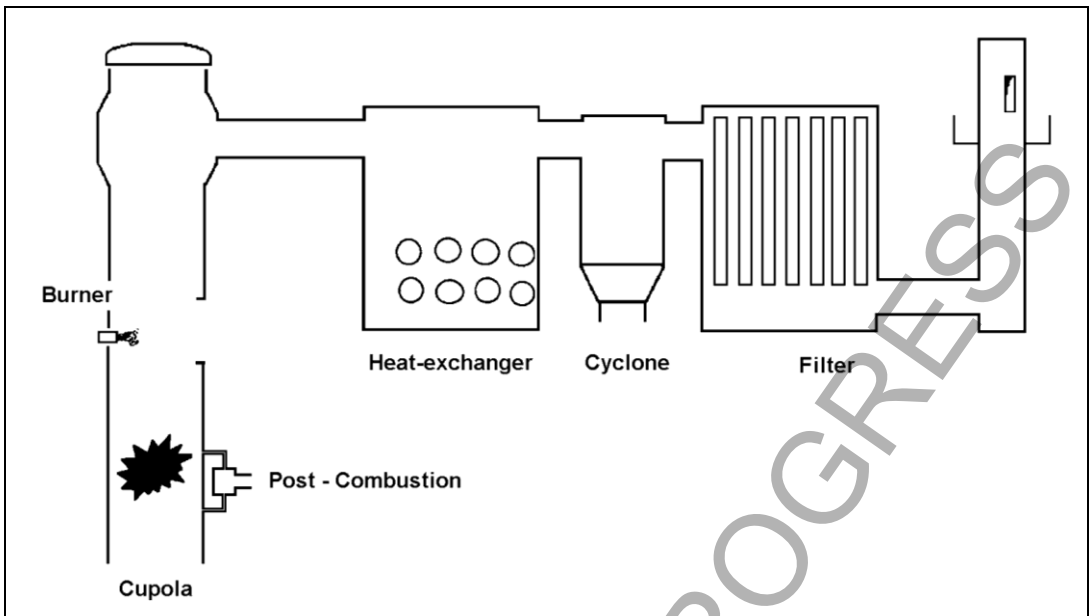
Figure 3.61: Hot blast cupola with a recuperator and bag filter

Post-combustion in the cupola shaft

The gases are combusted by an injection of air into the upper part of the charge or at a position above the charge top level. The airflow is adjusted so that the off-gases ignite spontaneously, due to their CO content and temperature. The injection nozzles can be placed on one or two levels. The partitioning of the airflow over the various levels, the choice of diameter and the position of the nozzles is based on experience. The goal of the optimisation is to burn the CO without ignition of the coke. The draught will also suck in air from the charge door. This air excess allows a more complete burn-out of the CO.

A supporting burner may be provided to maintain the flame. When using very low coke charges (i.e. < 6-8 %) the precautionary measure is reasonable.

Post combustion of the off-gas must be combined with a gas cooling, if a bag filter is used. For hot blast cupolas, the cooling is combined with a blast air preheating. In cold blast operation, a rapid cooling may be applied using water injection in the furnace shaft. Alternatively, an (off-gas – air) heat-exchanger may be used. This is illustrated in Figure 3.62.



Source: [60, Godinot et al. 1999]

Figure 3.62: Principle of post-combustion and off-gas cooling in cold blast cupolas

Installing post-combustion on cold blast cupolas can be combined with a full retrofit to hot blast operation. In general, this choice is based on operational considerations. The characteristics of hot blast and long campaign furnaces are discussed in Section 3.2.2.1.6.

Post-combustion in rotary furnaces

The application of an afterburner allows the reduction of organic carbon emissions and combustible particles. This technique may also be effective in reducing the risk of dioxin formation upon cooling of the gases. The afterburner is installed after the furnace and before the heat-exchanger. One of the following afterburner types may be used:

- thermal incinerator: combustion in an open flame;
- catalytic incinerator: combustion at lower temperatures through the use of a catalyst, resulting in a higher efficiency and lower NO_X emissions;
- recuperative incinerator: combustion with a heat recovery for preheating the combustion air, resulting in a higher thermal efficiency and lower fuel consumption;
- catalytic recuperative incinerator: a combination of the previous two types.

Achieved environmental benefits

Post combustion limits the emissions of CO and eliminates the majority of organic compounds. If not combusted, these would be captured in the dust or emitted through the chimney. Furthermore, post combustion reduces the risk of fire in the filter.

This technique is known to avoid explosion risks under certain circumstances. The positive environmental effect is limited to those cases when the off-gas is burning autothermally most of the time. Otherwise, the energy consumption will counterbalance the CO reduction.

Environmental performance and operational data

In Section 2.3, recent detailed information submitted in the frame of the SF data collection is presented.

In the following table, an overview of reported CO and TVOC emission concentrations from post-combustion in cupola furnaces (CBC and HBC) is presented.

Table 3.52: Reported concentrations of CO and TVOC for post combustion in cupola furnaces

Furnace type	Number of EPs	CO median/average of reported max. concentrations (mg/Nm^3)	TVOC median/average of reported max. concentrations (mg/Nm^3)
CBC	1	86/-	-/-
HBC	7	61/191	14/23
Source: [169, TWG 2021]			

Post-combustion in HBC furnaces

Operational data for hot blast cupolas are given in Table 3.53. Data for two example plants are given below:

1. Foundry G is a 3 shifts/days and 5 days/week operated foundry with a melting capacity of 50 t/h. The off-gas is collected below the charge-hole and combusted in a recuperator. The waste gas is then separated: one part goes to hot blast production (T = 600 ºC), another part goes to a steam boiler. The steam is fed into a turbine, which powers a generator or compressor. The residual heat is used for preheating the combustion air of the recuperator. Waste gas is then cleaned in a bag filter. A concept drawing and further discussion of the installation is given in Section 3.2.1.3.12. Dust is recycled into the cupola, after mixing with petcokes. This is discussed in Section 3.2.1.4.5.6.

2. Foundry H is a 3 shifts/day and 5 days/week operated foundry with a melting capacity of 70 t/h. The off-gas is collected below the charge-hole and washed in a disintegrator, before post combustion in a recuperator. Heat is used for blast air preheating and goes to a further heat recovery, before leaving through the stack at a temperature of 220 ºC. Further discussion of the heat recovery installation is given in Section 3.2.1.3.12. Waste water is re-circulated after settling. The circulating water volume is 440 m³/h. The sludge from the settling tank is dried in a filter press to a 50 % DS content, before disposal. Some 80 m³/day of waste water are disposed to the municipal waste water treatment.

Table 3.53: Operational data of hot blast cupola furnaces using a bag filter and a disintegrator for dust capture

	Units	Plant G	Plant H
Melting capacity	tonne/h	50	50
Waste gas flow	Nm^3/h	75000	55000
Hot blast temperature	ºC	600	570
Exhaust gas temperature	ºC	127	220
Year of construction of the flue-gas treatment		1989	1983
Date of the measurements		10/1990	Control measurement 09/1993
Emissions	mg/Nm^3		
- Dust			
• Raw gas		1300 – 4300	8000 – 20000
• Clean gas: average[1]		1.1	6.1
maximum		1.8	7.3
- Gaseous[2]			
• SO_2		33	15.6
• NO_x		44	52.5
• C_{total}		<5	28.6 (FID)
• CO		32	<100
• O_2	%	12.2	6.4
Heavy metal emission	mg/Nm^3	Clean gas[3]	Clean gas

- Cr - Cr_{total} - Pb - Zn - Ni		<0.001 <0.001 <0.001 <0.011 n.d	<0.0022 n.d 0.11 0.36 <0.004
PCDD/F-emissions[1] • Clean gas[4] • Emission factor	ng TEQ/Nm³ µg TEQ/tonne Fe	0.048 0.089	0.003 0.004
Filter dust/sludge - solitary quantity - PCDD/F-content	kg/tonne Fe µg TEQ/kg	Dust recycling 4.5 0.176	Filter cakes to disposal 5.5 1.4
Waste heat utilisation		Hot blast air, steam for electricity production up to 3 MW electric	Hot blast air, thermal oil for the conversion of the waste heat for heating and drying purposes up to 21 MW
Investment cost	DEM '000	26400	22700 in 1980/81
Operational cost	DEM/tonne good casting	See data in the text for foundry G	See data in the text for foundry H

1 Dust average is calculated on basis of 5 - 6 half-hour measurement data and 2x2 hour values for PCDD/F.
2 The concentrations of sulphur dioxide, nitrogen oxide, total carbon, carbon monoxide and carbon dioxide are calculated averages from continuous measurements over several hours during sampling for dust or PCDD/F.
3 At the time of measurement, the dust recycling was not operational.
4 Sampling time of 2 hours.
n.d: no data.
note: Raw gas sampling was performed before the bag filter in G and before the disintegrator for H; clean gas sampling was performed after the bag filter for G and after the recuperator for H.
Source: [7, Strauß 1983] [12, Kran, H.-P. et al. 1995] [100, TWG 2002]

Burning the fumes in the post-combustion chamber does not consume much energy, providing there is sufficient carbon monoxide in the fumes, which is generally the case. But the whole system for treating the fumes (combustion chamber + heat-exchanger + filter or wet scrubber + fans) also needs electrical energy and regular maintenance. Table 3.54 gives some examples of energy consumption for hot blast cupolas.

Table 3.54: Energy consumption of hot blast cupolas

Hourly rate of the cupola	Type of dedusting	Gas consumption for the combustion chamber (kWh/t charged)	Electricity consumption for the fume treatment system (kWh/t charged)
12	Filter	59	46
12	Filter	124	72
26	Filter	42	n.d
17	Electro filter (wet)	16	38

Post-combustion in the cupola shaft

Two configurations of (in-shaft post-combustion and) cooling on cold blast cupolas were studied on an industrial scale and compared by CTIF; cupola I was equipped with a water injection in the cupola shaft, a cyclone and a bag filter, cupola J was equipped with a gas-air heat-exchanger, a cyclone and a bag filter. Operational data are given in Table 3.55. Results of the measurement campaigns and reference to the applicable legislation are given in Table 3.56.

Table 3.55: ~~Operational data~~Environmental performance and operational data of two example configurations using post-combustion with water cooling (I), and air cooling (J)

Parameter	Units	Foundry I	Foundry J
Melting capacity	tonne/h	10.3	9.2
Primary + secondary airflow	Nm³/h	7389	6484
Post combustion airflow	Nm³/h	2372	1549
Water flow	l/h	2678	
Flue-gas flow (chimney)	Nm³/h	26780	39179
Residence time combustion to bag filter	s	10.5	12.3
Residence time cooling stage	s	<1.7	6.01
Overall CO combustion efficiency	%	66	96.5
Source: [60, Godinot et al. 1999]			

Table 3.56: Analytical results and applicable (French) legislation, for post-combustion in a cold blast cupola with water cooling (I), and the air cooling (J) of flue-gases

	Foundry I		Foundry J		Arrêté du 02/02/98	
Compound	**analysis**	**flux**	**analysis**	**flux**	**limit value**	**limit for consideration***
Dust	1.7 – 2.8 mg/Nm³ 3 – 5 g/t	0.04 – 0.07 kg/h	1 mg/Nm³ 34 g/h		100 mg/Nm³ 200 g/t	<1 kg/h melt = 8 tonne/h
CO	450 Nm³/h	560 kg/h	35 Nm³/h	44 kg/h		50 kg/h
HCl	22 mg/Nm³	0.4 kg/h	9.2 mg/Nm³	0.35 kg/h	50 mg/Nm³	1 kg/h
HF	13 mg/Nm³	0.24 kg/h	4.8 mg/Nm³	0.18 kg/h	5 mg/Nm³	0.5 kg/h
HCN	<0.007 mg/Nm³	0.13 g/h	<0.01 mg/Nm³	0.38 kg/h	5 mg/Nm³	50 g/h
NH_3	0.61 mg/Nm³	12 g/h	0.10 mg/Nm³	3.8 g/h	50 mg/Nm³	100 g/h
NO_x	9 mg/Nm³	0.17 kg/h	15 mg/Nm³	0.57 kg/h	500 mg/Nm³	25 kg/h
VOC non-methane	13 mg/Nm³	0.25 kg/h	6 mg/Nm³	0.23 kg/h	110 mg/Nm³	2 kg/h
*: If the flux is below the limit of consideration, the measured value may exceed the limit value. *Source*: [60, Godinot et al. 1999]						

The water spray cooling achieves a CO-destruction efficiency of 66 % and allows compliance with the applicable legislation. Flue-gas cooling over a heat-exchanger provides better efficiency (98 %). ~~For discussion on cooling performance~~

Post-combustion in rotary furnaces
~~Operational emission data are given in Section.~~
An afterburner can be expected to achieve between 80 % and 98 % efficiency for burning the combustible particulates emitted from the rotary furnace. Hot gases from the afterburner can be ducted through a recuperator and can assist in preheating the combustion air to the main furnace burner. Recuperators offer an energy saving of up to 15 %.

Cross-media effects
Dry dedusting techniques produce dust for disposal (4-12 kg/t liquid iron). The dust may be re-circulated into the cupola. ~~This is discussed in Section.~~ Wet systems produce a sludge fraction.

In cold blast cupolas, if the cupola off-gas does not ignite spontaneously, the installation of ignition or support burners is necessary. These incur a significant power use and increase the overall flue-gas volume.

Technical considerations relevant to applicability
Generally applicable.

During the design stage, considerable care has to be taken to minimise the total flow of the gases to be treated. The combustion air intake has to be kept to a strict minimum. This is the reason why a separate combustion unit is always installed in conjunction with a below charge-hole offtake.

For economic reasons (see below), the post-combustion chamber is only used on hot blast cupolas. However, ~~recently,~~ a post-combustion system for cold blast furnaces, without the complexity of a hot blast installation, has also been developed. This system is currently in operation in France. 'In-shaft' post-combustion therefore applies to both hot blast and cold blast cupola operation.

To change the offtake system of an existing cupola from above to below the charge-hole system is in most cases impossible. Post-combustion of the waste gases in the furnace shaft therefore is a more viable solution for cupolas with an above charge-hole offtake.

In the Czech Republic, the whole range of cold blast cupola installations was studied for applicability of in-shaft post-combustion. The combustion was not spontaneous in any of the set-ups over the whole melting period. In each case, it was necessary to install ignition burners of significant power. The cupola emission volume also increased.

Concerning rotary furnaces, this technique is applicable to all new and existing rotary furnace installations, both in ferrous and non-ferrous foundries.

Economics ***TWG, please update this information***
The high energy consumption of the post-combustion is only economically reasonable if the released heat of the waste gases can be re-used, as it is in the recuperative hot blast cupola. However, switching from a cold blast to a hot blast cupola for the sole reason of gas combustion might encounter economical limitations in certain situations. Hot blast cupolas, preferably in a long campaign configuration, involve higher investment costs and are only used with production rates of 10 tonne Fe/h or more. In smaller foundries, this production method might not be the right choice.

Table 3.53 gives economic data for the example plants. For foundry G, the investment costs for a hot blast cupola with bag filter and extensive heat recovery are given. The operational costs for 1994 (after refurbishment of the melting shop) were 25 % lower than those for 1985, i.e. with the old melting furnace. For foundry H, investment costs for 1980-1981 are given. After refurbishment, the operational costs went down by 2 % per tonne of liquid iron.

The investment cost for a twin cold blast cupola of 850 mm internal diameter, which produces 4.5 tonnes an hour, 10 hours a day, 5 days a week is in the order of EUR 300 000.

Driving force for implementation
Legal requirements: Emission limit values and continuous monitoring of CO and emission limit values for organic compounds.

Example plants
CBC: DE058 and DE067.
HBC: BE021, BE022, CZ024, DE046, DE051, DE061 and DE076. [169, TWG 2021]

Reference literature
[7, Strauß 1983] [12, Kran, H.-P. et al. 1995] [14, CAEF 1997] [60, Godinot et al. 1999] [100, TWG 2002] [54, ETSU 1998] [11, Brettschneider et al. 1992] [64, UK Environment Agency 2002] [169, TWG 2021]

3.2.2.1.10 Foamy slag practice

Description
Simultaneous injection of oxygen and carbon (in the form of coal dust) into the slag at the end of the melting cycle in electric arc furnaces. This injection generates CO bubbles, forming a layer of foamy slag which insulates the molten metal and protects the furnace refractory lining.

Technical description
The *foamy slag practice*, currently in use in the steel production industry, consists in simultaneously injecting oxygen and carbon (in the form of coal dust) into the slag at the end of the melting. The foam of slag is produced by the action of CO bubbles. The CO gas comes from the oxidation of carbon in the metal by the injected oxygen and also from the reduction of the iron oxides (FeO) by the injected carbon.

Creating a foamy slag improves the heat transfer to the charged units and protects the refractory material inside the furnace. Because of the better arc stability and less radiation effects, slag foaming leads to a reduction in energy consumption, electrode consumption, noise levels and increased productivity.

Achieved environmental benefits
Reduction of energy consumption and electrode consumption, lower noise levels and reduction of flue-gas volume.

Environmental performance and operational data
Table 3.57 gives the operational data for a 60-tonne arc furnace and indicates the mains savings in energy, time, refractory and electrodes.

Table 3.57: Energy and temperature data for EAF furnace melting with normal slag and foamy slag

	Units	Normal slag	Foamy slag
Total power	MW	25	30
Radiation loss arc to flue-gas	MW	6	0
Flue-gas flow	m³/h	41000	28000
Final temperature	°C		
- metal		1630	1630
- slag		1603	1753
- flue-gas		1463	1607
- refractory		1528	1674
Energy-input	kWh/tonne		
- electricity		50.8	37.7
- fossile (coal)		37.1	22.6
Energy-output	kWh/tonne		
- metal (ΔH)		10.4	10.4
- slag (ΔH)		1.1	9.4
- furnace losses		20.7	14.1
- flue-gas losses		53.6	24.8
- other losses		2.5	1.6
Heating time 1584 - 1630 °C	min	11min 45sec	7min 30sec
Heating rate	°C/min	3.9	6.1
Source: [100, TWG 2002]			

Slag density is reduced from 2.3 tonne/m³ to 1.15-1.5 tonne/m³.

Cross-media effects
As the volume of the slag rises so larger slag buckets may be needed. After tapping, the slag degasses again. There is no reported adverse impact on the possibilities for reuse of the slag.

Technical considerations relevant to applicability
This technique applies to new and existing EAF foundries that practice oxygen injection.

Driving force for implementation
- Increasing the efficiency of furnace operation.
- Legal requirements.

Example plants
No specific example plants were reported, but the technique finds application in several European foundries.

Reference literature
[14, CAEF 1997], [100, TWG 2002], [109, COM 2013]

3.2.2.2 Emissions to air from thermal processes

3.2.2.2.1 Emissions to air from metal melting and ladle preheating

3.2.2.2.1.1 Control of coke quality

Description
Important characteristics of the coke used (e.g. fixed carbon, ash, volatile matter, sulphur and moisture content, mean size diameter) are systematically controlled.

Technical description
The quality of the coke used has a direct bearing on the efficiency of cupola operations. It particularly affects the initial temperature carbon pick-up and the sulphur content of the iron. Specifying the foundry coke involves testing the following contents:

- *Fixed carbon*: The higher the carbon content, the higher the calorific value.
- *Ash content*: A high ash content is undesirable since it lowers the calorific value of the coke and generates a greater volume of slag in the cupola.
- *Volatile matter*: Volatile matter is undesirable since it reduces the fixed-carbon content, and thus the calorific value of the coke.
- *Sulphur*: Sulphur is well known as an unwanted element in any type of cast iron and leads to SO_2 emissions. The lower the sulphur content of the feedstock coke, the better. The sulphur content of the coke depends on the sulphur content of the feedstock coal. Unfortunately there is no known method to remove sulphur from coal.
- *Moisture*: Moisture in the coke when dispatched from the coke oven is undesirable, since it reduces the amount of carbon available by weight. However, it is necessary for the coke to contain some moisture, to avoid fires on conveyer belts and in lorries and wagons.
- *Size*: The size of the foundry coke directly affects the coke consumption per tonne of iron melted and also the melting rate. To achieve optimum performance the coke size dispatched from the coke oven generally needs to be sized such that the furnace coke has a mean size diameter greater than 90 mm, with no more than 4 % smaller than 50 mm. The content of fines will influence emissions of dust during (un)loading and handling.

Achieved environmental benefits
Optimising the coke input results in a higher process efficiency.

Environmental performance and operational data
Typical properties of foundry coke are given in Table 3.58.

Table 3.58: Typical properties of foundry cokes

Property	Typical value (%)	Limit value (%)
Ash	5.8 – 5.9	6.5 max.
Volatile matter	0.3 – 0.4	0.8 max.
Sulphur	0.68 – 0.70	0.75 max.
Moisture	1.5 – 2.5	3.0 max.
Strength		

M80 Micus index M10 Micus index	81 – 82 8 – 8.5	78.0 max. 9.0 max.
Fixed carbon	93.7 – 93.8	93.0 min.
Higher calorific value	32200 kJ/kg	31800 kJ/kg
Source: [95, Nalonchem 2002]		

The data in Table 3.58 are taken from supplier specifications. Local standards may use higher limit values.

Cross-media effects
None. ~~No cross-media effects apply.~~

Technical considerations relevant to applicability
The technique is applicable to all new and existing cupola installations.

Economics
In general, low-sulphur feedstocks are more expensive.

Driving force for implementation
- To improve the efficiency of the foundry process.
- Legal requirements.

Example plants
This technique is commonly applied in European foundries using cupola furnaces.

Reference literature
[20, ETSU 1993], [120, TWG 2003]

3.2.2.2.1.2 Adjustment of the slag acidity-basicity

More information on the technique
See Section 3.2.1.4.5.4.

3.2.2.2.1.3 Increase of shaft height in CBC furnaces

More information on the technique
See Section 3.2.2.1.1.

3.2.2.2.1.4 Oxygen enrichment of the combustion air

More information on the technique
See Section 3.2.2.1.3.

3.2.2.2.1.5 Superheating of HBC blast air

More information on the technique
See Section 3.2.2.1.4.

3.2.2.2.1.6 Minimal blast shut-off periods for HBC furnaces

More information on the technique
See Section 3.2.2.1.5.

3.2.2.2.1.7 Long-campaign cupola

More information on the technique
See Section 3.2.2.1.6.

3.2.2.2.1.8 Off-gas extraction and cooling

Description
In cupola furnaces, the off-gases are extracted either:

- above the charge-hole offtake at the end of the cupola stack using ductwork and a downstream fan; or
- below the charge-hole offtake using an annular ring.

After extraction, the off-gases are cooled using:

- long ducts to decrease the temperature by natural convection;
- air/gas or oil/gas heat exchangers;
- water quenching.

For induction furnaces, off-gases are extracted, for example using:

- hood extraction (e.g. canopy or side-draught hoods);
- lip extraction;
- cover extraction.

For rotary furnaces, off-gases are extracted, for example using hood extraction.

For EAFs, off-gases are extracted, for example using:

- roof-mounted hood extraction;
- canopy or side-draught hoods;
- partial furnace enclosures (mobile or fixed) mounted around the furnace and tapping area;
- total furnace enclosure using a complete room enclosure around the furnace and tapping area equipped with a moveable roof for charging/tapping operations.

Technical description
Collection, cooling and dedusting in cupola furnaces
The design of the collection and gas cleaning system is based on the conditions occuring during blow-down, as these are often the most severe conditions experienced during the system operation. At the end of a melting campaign, the furnace is no longer filled with charge materials. Gas temperatures will increase gradually since they are no longer cooled by a cold charge in the stack. In contact with oxygen, CO will burn automatically. Temperatures can therefore reach up to 1 200 ºC, or even higher. The off-gas collection and treatment system has to be able to cope with these severe conditions.

Collection
Two systems are in use for top gas collection:

- *Above charge-hole offtake*: The exhaust gases are withdrawn at the end of the cupola stack by means of ductwork and a fan placed downstream. The opening above the charge-hole allows an important inflow of air, necessary to prevent cupola gases being emitted from the area. This volume of extra air may be many times the cupola gas flow. This increases the size and cost of the collection and cleaning system. Reducing charge-hole sizes may have some merit but this option may be limited because of the explosion hazard present when too little oxygen is mixed with the CO containing cupola gases (pulsating combustion)

- *Below charge-hole offtake*: The cupola top gases are collected through an annular ring below the charge-hole. No air inflow is required since the gases cannot be emitted out of the hole, provided the control system is sensitive enough to function properly during the variation of the blowing rate of the cupola. Too little offtake rate can result in the emission of uncleaned gases through the cupola stack, too great an offtake flow can result in air ingress, leading to combustion and overheating of the gases (i.e. an explosion hazard).

Cooling
Following collection, the gases may need cooling depending on the dust abatement system used. In the hot blast operation, the heat recovered from cooling may be used for preheating the blast air.

Several options are possible for cooling the collected gases, including:

- *Using tube coolers*: Running the collected gases through long ducts, decreases the temperature by natural convection and radiation. This system is simple but takes up a lot of space and does not offer controlled cooling (therefore there is a risk of condensation).
- *Using a forced air/gas heat-exchanger*: Cold ambient air is forced through an arrangement of tubes or plates to cool down the gases. Dust collection and the subsequent need for cleaning the heat-exchanging surfaces may lead to a complex and expensive design of the system. One advantage of this system is the possible use of the heated air for external heating purposes. Recuperative hot blast cupolas are equipped with a post combustion unit and a heat-exchanger (recuperator) to heat the blast air.
- *Using an oil/gas heat-exchanger*: This is similar to the above system but more expensive because of the need for a secondary cooling system. The heat-exchanger is generally cooled with a circulation of mineral oil. Cooling with a water/gas heat-exchanger is not (or only very rarely) practised.
- *Saturation with water*: Here the gases are cooled by the evaporation of the water sprayed into the gas stream. Wet scrubbers perform better if the gases are cooled in a saturation chamber prior to cleaning. When using fabric filters only, partial saturation is possible to prevent clogging of the fabric due to the condensation of water. A good control system is necessary to guarantee correct functioning of the system. Quenching the gases has the advantage that rapid cooling reduces the risk of dioxin formation.

Dedusting
Dust capture equipment of various types can be used to remove particulate matter from the waste gases. Generally wet scrubbers have low capital costs and maintenance, but require a high energy input to achieve acceptable collection efficiencies. The removal of the sludge is difficult and the scrubber water has to be treated prior to discharge. Dry collection systems have more expensive capital costs and need better control of the inlet gas conditions (temperature, condensation of water or organic vapours, $CO:O_2$ ratio, sparks) but usually use less energy than that needed for wet scrubbing. Furthermore, dry cupola dust can be recycled into the cupola (see Section 3.2.1.4.5.6).

Both venturi scrubbers and disintegrators are used with cupola systems. Scrubber towers are used for dedusting of non-melting off-gas. Compared to dry systems, the wet systems have the following disadvantages: higher energy consumption, higher maintenance (corrosion, bacteria), and they result in waste water and a sludge for disposal. Advantages are the capture of water-soluble compounds (such as SO_2, chlorides), quick cooling - which prevents dioxin reformation, low investment costs, and less restriction on input temperature.

- *Venturi scrubbers*: Water is sprayed into the gases as they pass through a venturi. The acceleration of the gas flow in the venturi throat causes an intensive mixing of both media. The dust particles are damped, making them heavier, so that they can be separated in a cyclone or other system placed downstream. If the gas flow drops, the venturi throat is adjusted to maintain the collection efficiency

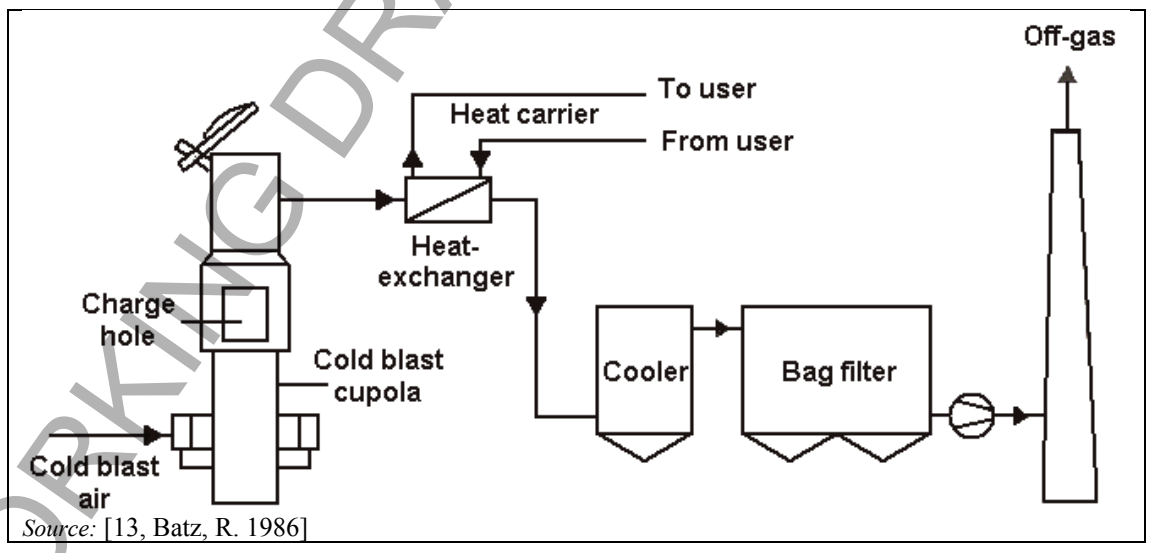
- *Disintegrators*: These so-called dynamic scrubbers consist of concentric rotor and stator mounted pins through which the gas stream is driven by means of a fan placed downstream or by fan blades at the outer end of the rotor. Water injected into the centre of the rotor, is broken into fine droplets by the pins and dispersed in the gas stream. The wet particles impinge on the stator walls and are collected at the bottom of the disintegrator. The system works efficiently when the gas flow is reduced.

A separator to remove small particles entrained in water droplets is located after the wet scrubber.

With regard to dry systems, the following remarks can be made:

- *Multicyclones*: These are often used in conjunction with a fabric filter, acting as coarse dust arrestors. They help to prevent incandescent coke particles reaching the filter cloth. Provided refractory lining and high grade steel are used in the design of the cyclone, they can operate at high temperatures. Note, the collection efficiency from cyclones alone is not sufficient to meet today's regulations, hence they are usually used in combination with other dedustung systems.
- *Bag filters*: These are ideal when the gases are burned prior to the dedusting. This avoids problems of the deposition of carbonaceous material or fire hazards. Bag filters can be designed to provide good efficiency for collecting metallurgical fume particles such as ZnO.
- *Electrostatic precipitators*: These systems are less common in the European foundry industry. This system is best suited to more or less constant working conditions, such as in long campaign cupolas, because of its sensitivity to variations in gas temperature, flow and humidity. There is an explosion hazard when dedusting unburned gases mixed with air, due to the relatively large volume of the precipitator. The precipitator therefore needs to be flushed before applying electrical power.

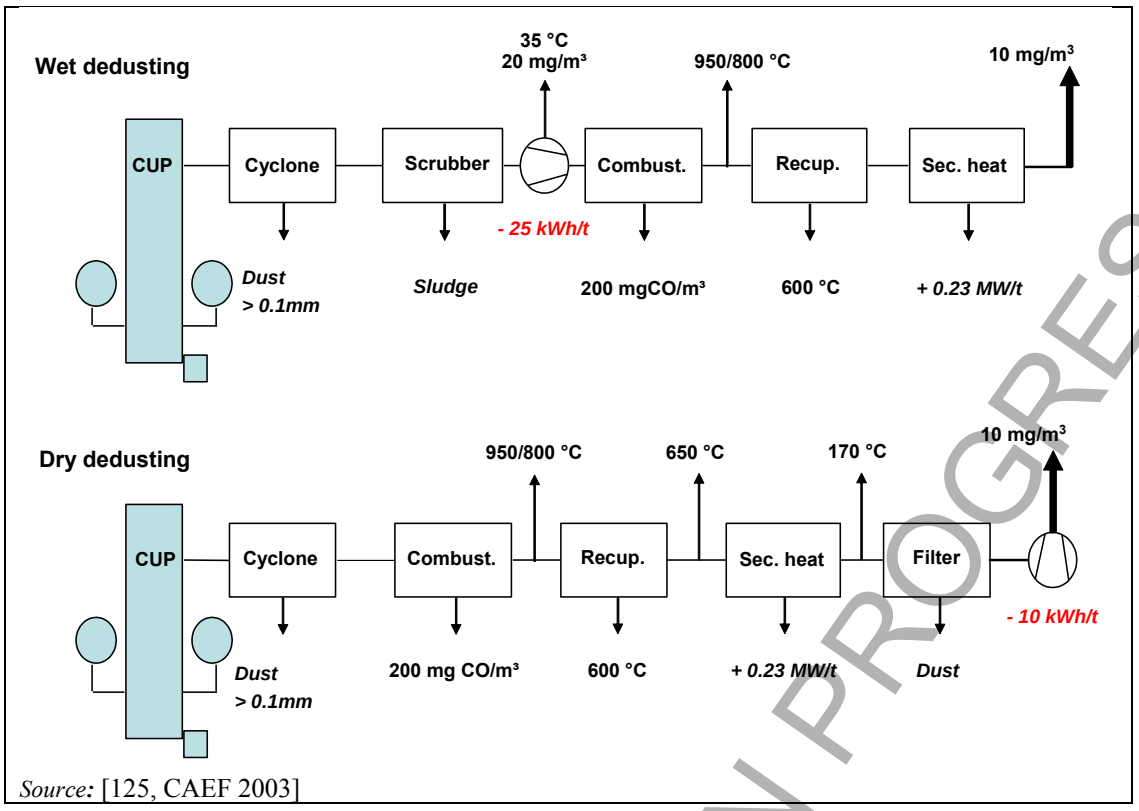
A schematic representation of a cold blast cupola with heat recovery and a bag filter is given in Figure 3.63.



Source: [13, Batz, R. 1986]

Figure 3.63: Flow sheet of cold blast cupola with heat recovery, cooling and a bag filter

In addition, Figure 3.64 gives a comparison of the operational conditions for hot blast cupola furnaces with a wet and dry dedusting system. The main differences are the temperature profile of the flue-gas and the energy consumption.



Source: [125, CAEF 2003]

Figure 3.64: Operational conditions for wet and dry dedusting of hot blast cupola off-gas

After dedusting, post-combustion of the waste gases in cupola furnaces is used to optimise heat recovery (chemically bonded as CO) and to provide cleaner exhaust gases. This is further described in Section 3.2.2.1.9.

Induction furnaces

The capture of smoke and dust is the most difficult problem to solve when installing an off-gas collection system on a coreless induction furnace, since there is no exhaust shaft. Several methods have been developed in the past decade, each with advantages and disadvantages.

- *General ventilation of the workplace*: A combination of wall mounted louvres and roof mounted ventilators situated over the furnace platform are used to increase the natural convection of smoke and fumes and to direct them outside. Even with baffles suspended from the roof and using high extraction rates the efficiency is often poor and easily disturbed by draughts.
- *Canopy hood extraction*: Since lower placed hoods will interfere with crane charging systems, larger hoods have to be installed above the charger. This creates a large gap between the furnace and the extraction system, making it difficult to control the rising smoke and dust, even when using high extraction rates. Cross-draughts can seriously distort the collection efficiency of the system. These disadvantages make the use of these collection systems unattractive.
- *Swing aside hoods:* These hoods are more efficient when used in conjunction with vibrating feeders. Cut-outs in the hood can facilitate charging. During tapping, the hood is swung over the ladle, allowing efficient fume extraction.
- *Side-draught hoods*: Placing the extraction hood beside the furnace offers the advantage of good furnace accessibility and no interference with the charging systems. Due to the high buoyancy of the exhaust gases, large extraction rates are achieved, therefore giving good efficiency, especially when the hood is placed outside the furnace platform. In this case extraction control is poor during tapping. Attachment to the furnace platform overcomes this problem but may interfere with charging operations. The efficiency can be improved by installing airjets at the opposite side of the hood to blow the dust and

fumes into the hood. Unfortunately, this facility does not work if there are any interferences in the airstream, which is the case during charging.

- *Lip extraction*: A suction ring is placed on top of the furnace and arranged so that it moves with the furnace during deslagging or tapping operations. This system does not interfere with the charging operations. With the lid closed, lip extraction offers very good control, since it is as near to the emission source as possible and involves the lowest extraction rates. The fumes do not pass through the breathing zone of the furnace operators. However, the extraction control decreases significantly when the furnace lid is opened, for instance during charging. The design of this extraction equipment has been subjected to many studies. Suppliers offer solutions to overcome some of the disadvantages.
- *Cover extraction*: The gas is exhausted through the furnace cover. This method is very effective. It is used by the majority of furnace producers. Exhaustion is managed according to furnace regime: melting, charging, pouring.

Attention has to be paid to the material used for hoods and ducts since the gases may be at high temperatures when the intake of the collection system is positioned close to the furnace. The heating required by radiation or convection from the molten metal bath needs to be taken into account in the design stage. Proper maintenance in combination with heat-sensors reduces the risk of fire.

Again scrap cleanliness plays an important role. When the scrap contains organic matter, collected gas temperatures may rise due to the combustion of the material, thus requiring the use of heat resistant steel or even refractory linings. Oily deposits, formed by condensation of oil vapour in the ductwork, accumulate dust and can present a fire hazard if not removed regularly. When using clean scrap, a mild steel construction is adequate and does not need accessibility for cleaning.

Rotary furnaces

In most cases, dedusting equipment is needed to meet the applicable regulations. Generally, bag filters are installed for this purpose, but it is also technically possible to use wet dedusting techniques.

In order to lower the temperature of the exhaust gases, they are diluted with ambient air. This is achieved by the intake of air through a gap between the furnace exhaust and the elbow shaped exhaust pipe. This gap is always present as it allows the furnace body to be able to rotate and tilt. Often the exhaust pipe is retractable. In general, dilution for emission reduction is unacceptable. If dilution is used (and is necessary) for cooling, the end-of-pipe technology should have the right dimension for the larger gas flow. Sometimes the diluted waste gases are then fed through an air-gas heat-exchanger for further cooling. This way the gas temperature is reduced from the initial 1 500 ºC to 200 ºC, or lower. At this temperature, the gases can be introduced into a bag filter for dedusting.

The application of an afterburner allows the reduction of organic carbon emissions and combustible particles. This is discussed in Section 3.2.2.1.9.

Electric arc furnaces (EAFs)

See Section 3.2.3.1.3.

Achieved environmental benefits

- Flue-gas capture allows the controlled evacuation and treatment of the flue-gas stream, and results in a minimisation of both fugitive and channelled emissions.
- In cupola furnaces, exhaust capture and cleaning is a necessary measure to reduce the emission products from coke combustion such as NO_X, SO_2, HF, PCDD/Fs and dust.
- To reduce dust and acidifying emissions from induction melting furnaces.

Environmental performance and operational data

Cold blast cupola furnaces

Fabric filters have an efficiency of over 99 %. Daily average dust emission values stay well below 10 mg/Nm^3. The sum of Pb, Zn, Cr, Cu, Mn,V, Sn, Cr, Ni, As, and Cd reaches about 20 % of the total dust content. The data represented in Table 3.59 were gathered within the framework of investigations of the Federal Environmental Agency in Germany of operational plants. Data for 3 example plants are given.

Table 3.59: Operational data of cold blast cupola furnaces with a bag filter for dust abatement

	Units	Plant D		Plant E	Plant F
		Initial	After rebuild		
Melting capacity - design value - actual value	 t/h t/h	 7.5 – 8 7.0	 12.0 11.0	 6 – 7 5.5	 4 – 5 3.7
Exhaust gas stream - design value - actual value	 Nm³/h Nm³/h	 25000 19800	 30000 22300	 20000 17400	 n.d 14300
Year of construction of the filter		1981	1995	1988	1985
Last filter cloth change		n.d	1995	1988	1993
Date of the measurements		07/1981	11/1997	03/1993	03/1993
Emissions - dust - raw gas - clean gas • average[1] • min. • max. - gaseous [2] • SO_2 • NO_x • C_{total} • CO • CO_2	mg/Nm^3 %	 1623 - 2674 21.5 18.0 25.4 288 43 n.d 700 7	 <1 <1 <1 n.d n.d n.d n.d n.d	 n.d 3 1 5 174 24 22 11890 4.9	 n.d 3 2 4 227 31 7 18980 3.9
Heavy metal emissions - Cd - Cr - Pb - Zn - Ni - As - Mo	mg/Nm^3	Raw Clean 0.0184 0.0019 0.7287 0.0384 29.895 0.2952 16.464 0.2862 0.2024 0.0077 0.7665 0.0149 0.2672 0.0420	Clean gas 0.00313 (ΣCu, Mn, Cr, V) 0.00057	n.d	n.d
PCDD/F-emissions - clean gas[3] - emission factor	 ngTEQ/Nm ^{3} µg TEQ/t Fe		n.d	 0.512 1.620	 0.085 0.330
Filter dust - collected amount - PCDD/F-Gehalt	 kg/t Fe µg TEQ/kg	 6.5 disposal	 8.2 re-use	 4.850	 0.960
Filter material		Polyester cloth with PA coating	Synthetic fibre	Polyester	Needle cloth
Filter cleaning		Pulse jet	Medium pressure counter flow	Pneumatical with pressure drop control	
Capital cost	EUR '000	385 (1981)	370 (1995/96)	n.d	350

Operating cost	EUR/tonne good casting	9.8 (1982) = 3 % of the casting costs	9.04 (1998) = 2.8 % of the casting costs	n.d	n.d

[1] Dust average is calculated on basis of 3 - 5 half-hour measurement data.
[2] The concentrations of sulphur dioxide, nitrogen oxide, total carbon, carbon monoxide and carbon dioxide are calculated averages from continuous measurements over several hours during sampling for dust or PCDD/F.
[3] Sampling time of 6 hours.
n.d: no data.
NB: Data taken from [19, Batz, R. 1996] and [100, TWG 2002], [120, TWG 2003]

Hot blast cupola furnaces
Data for hot blast cupolas are given in Section 3.2.2.1.9.

Induction furnaces
Cleaning of the captured gases is generally performed using filters. Daily average dust emission values stay well below 10 mg/Nm³. ~~Operational data are given in Section~~

Table 3.60 gives the operational data for a German cast iron foundry in which a centralised flue-gas capture system is installed, with dedusting carried out using a bag filter. The system collects exhaust gas from the various parts of the foundry, including: the four induction furnaces (each with lip extraction and canopy hood), the scrap storage and preheating, the metal treatment, the sand regeneration, and the casting areas. Data are given for the raw melting of the furnace off-gas, the raw combined gas flow and the cleaned gas flow.

Table 3.60: Emission data for a cast iron foundry, using induction melting and a centralised exhaust system with a bag filter

Compound	Melting off-gas	Combined exhaust gas	Cleaned gas*
Dust	89.3	237	<1
NO_x	1.6	8.3	7.9
CO	2.2	4.2	3.8
SO_2	3.5	3.9	3.7
Total C	21.8	34.7	34.9
PCDD/-F		0.036×10^{-6}	0.0027×10^{-6}

* NO_x, CO, SO_2 and total C are not captured in the bag filter. The difference between raw and cleaned gases are due to the slightly changed gas mix after the ID fan.
Melting capacity 14 tonne/h, total flue-gas flow 240 000 m³/h.
All data in mg/Nm³.
Source: [8, Rademacher, H. 1993]

Through the use of specific capture systems, such as side-draught hoods, movable extraction hoods and partial housing of the furnace, a capture efficiency of more than 95 % is possible.

Operational experience in a German cast iron foundry showed that the furnace lid is open on average during 25 % of the working time of the furnace. During the opening periods, dust-generating process steps such as the feeding of additives, deslagging and pouring are performed. The lip extraction system installed on the furnace lid, does not allow extraction of the generated fumes. Installation of a telescopic canopy hood allowed an efficient exhaust capture during the opening of the furnace lid.

Rotary furnaces
For ferrous rotary furnaces operating with simple air/fuel burners and an afterburner, dust emissions peak at about 250 mg/m³ for short periods (between 3 seconds continuously but also intermittently over a period of a minute) during the solid phases of the melt cycle. Thereafter, once the charge starts to become liquid, the dust emissions reduce to less than 30 mg/m³ during normal running. Emissions may remain as high as 150-200 mg/m³ continually during the solid phase of the melt. 40 % combustible emissions are common. Peak emissions from rotary

furnaces consist of at least 80 % unburned fuel and occur during charging operations when the main furnace burner is extinguished and then re-lit. The mentioned emissions only apply if at all times, including during charging, the fumes are ducted via the afterburner, which is kept fully operational [64, UK Environment Agency 2002]. The following raw gas dust levels have been reported for an oxygas rotary furnace without an afterburner: an average dust load of 400 – 450 mg/Nm^3 over the two distinct melting phases. These phases are a solid phase with dust emission levels of 150 mg/Nm^3, and a liquid metal phase with peak levels up to 1 500 mg/Nm^3 at the start of the rotation and 600-700 mg/Nm^3 during normal operation. [102, Carnicer Alfonso, P. L 2001]

Operational emission data after abatement are given in Section 2.3 and in the following table.

Table 3.61: Reported dust emission levels from rotary furnaces

Plant/ Emission Point	Abatement technique applied	Minimum	Average	Maximum	ELV
		mg/Nm^3			
BE020_a {1}	Fabric filter + cyclone	0.1	1.3	2.0	20
ES088_a {1}	Fabric filter	1.0	1.4	2.0	20
AT005_a {1}	Fabric filter	2.1	2.1	2.1	10
IT127_a {7}	Fabric filter	0.8	1.4	2.1	20
IT132_a {5}	Fabric filter	2.3	3.0	4.2	10
BE020_a {2}	Fabric filter + cyclone	0.9	10.1	26.0	20
Source: [169, TWG 2021]					

Cross-media effects

Cupola furnaces

Dedusting systems produce a residual dust for disposal. 5-13 kg of dust are produced per tonne of liquid iron. The dust may be recirculated into the cupola. This is discussed in Section 3.2.1.4.5.6.

Technical considerations relevant to applicability

Generally applicable.

Economics

TWG, please update this section if more recent information is available

Cupola furnaces

Table 3.59 shows emission values and economic data. The most important operational cost factors are the electrical energy requirements for overcoming the pressure drop and for the filter material.

For a melting installation incorporating two cold blast cupolas with a melting rate of 4.5 t/h, a sales quotation was made with the following details:

- abatement equipment to treat up to 12400 m^3/h blast, with combustion chamber at a temperature of 820 ºC accepting up to:
  - VOC – 1 g/Nm^3;
  - CO – 59100 g/Nm^3;
- two burners to be used with methane – Power/burner 390 kW

Installation and start-up price: EUR 350 000.
Foreseen running cost, considering a 4 500 tonne casting production, 5-year payment period plus 10 % for energy and maintenance per year: EUR 23.3/t.

Induction furnaces

The cost and consumption data for a bag filter installation on a melting unit of crucible induction furnaces, melting 15 t/h, able to treat 120 000 Nm^3/h are given in Table 3.62.

Table 3.62: Investment cost and power consumption for a bag filter unit on induction furnaces, with varying final dust emission levels

Dust emission level (mg/Nm³)	Investment cost (EUR)	Power consumption (kW)
<5	350 000	250
<20	200 000	150
NB: Data for Portugal 2003. *Source*: [120, TWG 2003]		

Driving force for implementation
~~Regulation of air emissions from foundries.~~
Legal requirements.

Example plants
The mentioned techniques are generally applied in all European foundries.

Reference literature
[13, Batz, R. 1986] [14, CAEF 1997] [38, VITO 2001] [100, TWG 2002] [120, TWG 2003] [8, Rademacher, H. 1993] [102, Carnicer Alfonso, P. L 2001] [11, Brettschneider et al. 1992] [64, UK Environment Agency 2002]

3.2.2.2.1.9 Primary control measures to minimise PCDD/F emissions

Description
Primary control measures to minimise PCDD/F emissions (dioxins) in metal melting include the following:

- *Maximisation of the off-gas residence time and optimisation of the temperature in the post-combustion chamber*: The temperature of the post-combustion chamber (T > 850 °C) is continuously monitored and the off-gas residence time is maximised (> 2 s).
- *Rapid off-gas cooling*: The off-gas is cooled rapidly from temperatures above 400 °C to below 250 °C before dust abatement to prevent the *de novo* synthesis of PCDD/F. This is achieved by appropriate design of the furnace and/or the use of a quench system.
- *Minimising dust build-up in heat exchangers*: The build-up of dust along the cooling trajectory of the off-gas is minimised, especially in the heat exchangers, e.g. by using vertical exchanger tubes, efficient internal cleaning of the exchanger tubes, high-temperature de-dusting.

Technical description
Dioxins are relevant for thermal processes which have metals present. Dioxins or their precursors may be present in some raw materials and there is a possibility of *de-novo* synthesis in furnaces or abatement systems. Dioxins are easily adsorbed onto solid matter and may be collected by all environmental media as dust, scrubber solids and filter dust. Field tests have shown that the formation of dioxins in cupola furnaces cannot be correlated to one (or a few single) operational parameter(s). A combination of measures is needed to minimise the risk of dioxin formation.

In-process or primary measures to prevent dioxin emissions include the following:

- Post combustion of the furnace off-gas in the CBC shaft or in a HBC combustion chamber. Combustion of cupola off-gas is fully described in Section 3.2.2.1.9.
- Continuous temperature monitoring and control in the HBC combustion chamber (T > 850 ºC) and maximising of the residence time (preferably >2s).
- Maintaining the particulate matter concentration in the recuperator at a level < 20 mg/m³, this is possible for HBC when using wet dedusting.
- Providing quick quenching of the dust laden off-gases, through the *de-novo* synthesis temperature range of 250-450 ºC.
- Preventing or minimising the build-up of dust along the cooling trajectory of the flue-gas, especially in the heat-exchanger, e.g. using vertical exchanger tubes, efficient internal cleaning, high temperature de-dusting.
- Melting clean scrap. This technique is described in Section 3.2.1.7.2.
- Using oxygen injection to ensure complete combustion. This technique is described in Section 3.2.2.1.3.

Although dioxins are destroyed at high temperature (i.e. above 850 ºC) in the presence of oxygen, the process of *de-novo* synthesis is still possible as the gases are cooled through the reformation window (250-450 ºC). This window can be present in heat-exchangers or abatement systems and in cooler parts of the furnace, e.g. the feed area. Care must be taken in the design of cooling systems to minimise the residence time in the window and to avoid dust build-up, in order to prevent *de-novo* synthesis. An alternative is to dedust the off-gas by quick quenching using a wet system. Sufficient oxygen also needs to be present in the hot gases and for this oxygen injection can be used to ensure complete combustion. Nevertheless, excess oxygen should be prevented since this may support *de-novo* synthesis.

Sulphur has an inhibiting effect on the formation of dioxins, through depletion of molecular chlorine. The use of coal with a higher sulphur content in large combustion plants has been shown to provide lower PCDD/F concentrations. The reducing inhibiting effect is related to the S/Cl ratio, with a critical ratio of 0.64. A further increase does not result in less dioxins and furans. This effect has not been demonstrated in foundries, but may be studied. [231, UNEP, 2003]

The great spreading and big variability in the dioxin emission levels (even for the same installation) show that primary measures alone may not allow a stable and low dioxin emission value. Therefore, besides primary measures, secondary measures such as adsorption (see Section 3.2.2.2.1.12) may be employed.

Achieved environmental benefits
Reduction of the emission of dioxins and furans to air.

Environmental performance and operational data
In-process measurements of dioxins in a hot blast cupola with dry dedusting have shown that high PCDD/F levels (5 ngTEQ/Nm³) occur in the heat-exchanger. Other parts of the flue-gas system show much lower values. Reduction measures should therefore aim at minimising the contact between dust and flue-gas in this zone, by minimising dust or reducing the dust residence time.

For a flue-gas rate of 8 000 m³/h at a blast rate of 3 000m³/h, quick quenching of the cupola off-gas from 800 ºC to 150 ºC requires a water consumption of 4 m³/h.

A PCDD/F emission level of 0.5 ng TEQ/Nm^3 can be achieved by using primary measures; and better than 0.5 ng TEQ/Nm³ can be achieved by using one or more of these techniques. A German survey concluded that without secondary measures the level of 0.1 ng TEQ/Nm³ is passed only in a limited number of installations and then only by a limited extent. ~~The operational data as given in however show that the level should be evaluated on a plant-by-plant basis.~~

Cross-media effects

None.

Technical considerations relevant to applicability
Generally applicable.

Economics
Primary measures do not involve additional investment costs. Operational costs are restricted to the use of oxygen or a higher price for cleaner scrap.

Driving force for implementation
- Regulation limiting ~~dioxin and furan~~ PCDD/F emissions from the melting of metals.
- Reduction of organic and other hazardous gases in cupola emissions.
- Legal requirements.

Example plants
Widely used.

Reference literature
[1, COM 2017], [63, UK Environment Agency 2002], [100, TWG 2002], [119, Helber et al. 2000], [125, CAEF 2003] [169, TWG 2021]

3.2.2.2.1.10 Post-combustion of off-gases

More information on the technique
See Section 3.2.2.1.9.

3.2.2.2.1.11 Cyclone

More information on the technique
See Section 3.2.1.13.2.

Environmental performance and operational data
Cyclones can be used alone, but are often used in combination with other waste gas treatment techniques.

Reported data from 23 plants (30 EPs) using cyclones show a range for dust emissions from 0.1 mg/Nm^3 to 62 mg/Nm^3 with a median value of 1.4 mg/Nm^3 and an average value of 3.31 mg/Nm^3. [169, TWG 2021]

Example plants
Widely used.

Reference literature
[169, TWG 2021]

3.2.2.2.1.12 Adsorption

Description
The removal of pollutants from a process off-gas or waste gas stream by retention on a solid surface (activated carbon is typically used as the adsorbent). Adsorption may be regenerative or non-regenerative.

In foundries, this technique concerns in particular the end-of-pipe abatement techniques used to reduce PCDD/F emissions from metal melting.

General information on this technique is also provided in the CWW BREF [179, COM 2016].

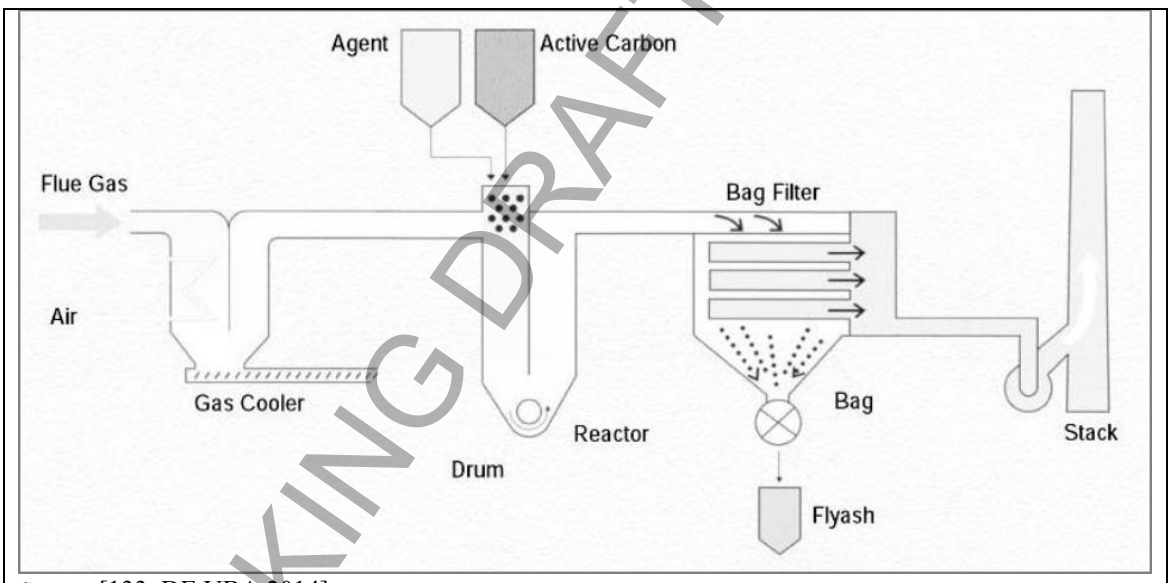
Technical description

Besides primary measures to control PCDD/F emisssions from metal melting, the following abatement measures may be considered:

- *Injection of additive powders* into the gas stream, such as activated carbon, open-hearth furnace coke or zeolite, so that dioxins are absorbed onto the surface. High efficiency dust filtration is then used to remove the dust and dioxins. The additive is injected into the off-gas stream before filtration. The adsorption process mainly takes place while the absorbents adhere to the filter bag. The filter dust may be recirculated back to the flue-gas to attain a higher efficiency. When using a carbon-based additive, special measures should be taken to prevent fire and explosion risk. The collected dusts may have high dioxin concentrations and will need to be disposed of or treated carefully (a detailed example is presented below).
- *Catalytic oxidation* systems are available for the destruction of dioxins. Fabric filters that incorporate a catalytic layer are used for the destruction of dioxins. In other sectors (e.g. steel, municipal waste incineration) this technique has been implemented successfully and implementation in the foundry industry is considered feasible. However, in order to prevent deactivation of the catalyst layer, a prior removal of coarse dust particles may be needed.

Example of adsorbent injection (activated carbon) in an iron foundry in Germany

Adsorbents can be injected directly into the flue gasses upstream of a bag filter. Figure 3.65 shows such a plant (an iron foundry in Germany). The adsorbents are composed of a mixture of activated carbon and calcium hydroxide.



Source: [133, DE UBA 2014]

Figure 3.65: Injection of adsorbents

The injection system consists of a hopper with a dosing screw, which regulates the amount of adsorbent dosed to the gases. To facilitate the installation, the dosing system is placed at ground level. By means of a small blower and a flexible pipe, the adsorbents are transported into the flue-gas (Figure 3.66).

Source: [133, DE UBA 2014]

Figure 3.66: View of an installation for adsorbent injection

Achieved environmental benefits
Reduction of the emissions of PCDD/Fs ~~dioxins and furans~~ to air.

Environmental performance and operational data
The injection of additives into the flue-gases of a cupola furnace results in a significant reduction of PCDD/Fs in the off-gases. In addition, the concentration of other hazardous substances such as heavy metals is also reduced due to the subsequent fabric filter dust abatement system.

The dose of additives were optimised during a research project (DIOFUR) where the addition dose was fixed at 150 mg/Nm³ (dry). In particular, activated carbon injection was tested in the project using a coke-based adsorbent with a high ash content suitable for high-temperature applications. PCDD/F emissions were measured after the heat exchanger (before adsorbent injection) and at the stack (after adsorbent injection). The results are summarised in Table 3.63.

Effective adsorption of PCDD/Fs was achieved; in addition, the adsorbent did not induce any safety issues (e.g. glow fires). The burning behaviour of this material at 20 °C and 100 °C was reported as 'brief ignition and rapid extinction' and its ignition temperature was 800 °C. This material was not glowing at temperatures up to 450 °C, therefore minimising potential safety concerns from the use of organic substances in high-temperature waste gas streams. [180, DIOFUR, 2010]

Table 3.63: PCDD/F and dust emission measurements after the heat exchanger and at the stack in the case of active carbon injection for a cupola furnace

Measurement date	13/11/2007		14/11/2007		15/11/2007	
Parameter	After heat exchanger	Stack	After heat exchanger	Stack	After heat exchanger	Stack
Total PCDD/Fs (ng I-TEQ/Dry Nm^3)	6.7	0.11	2.7	0.04	11.9	0.21
Dust (mg/Dry Nm³)	NI	32	NI	107	NI	106

In the case of the German iron foundry (presented above) with a cold blast cupola and a capacity of 12-14 t liquid iron per hour, the injection rate of additive was 0.1 kg to 0.4 kg per tonne of liquid iron. The energy consumption was 4 kW for blowing 500 m^3/h air containing the adsorbents into the raw gases of the cupola furnace.

Cross-media effects
The adsorption of dioxins and furans on activated carbon generates a PCDD/F-loaded dust stream. In order to prevent the explosion risk in the bag filter, mixing of the activated carbon with lime may be needed. This will increase the total amount of residue for disposal (in the case of the German iron foundry described previously, the amount of dust for disposal rose from 0.1 kg to 0.4 kg per t of liquid iron) and limits the possibility to reuse the filter dust.

The DIOFUR project concluded that the contribution of adsorbents to the overall dust amount originating from the gas cleaning is negligible. This means that the disposal costs for filter dust do not rise significantly from the use of adsorbent.

Technical considerations relevant to applicability
General additive injection is considered a technique that is compact, efficient and can be easily integrated in new and existing installations when space requirements are fulfilled. It is also applicable in hot and cold blast cupolas.

The application of catalytic filtration involves the least technical modification for existing plants, since only the filter bags need to be replaced by the catalytic type.

Economics
Economic data from the DIOFUR project showed that the investment costs for the installation of an activated carbon injection unit (2009 prices) were estimated at EUR 35 000 for a plant with a production capacity of 45 000 t per year. In this estimation, the following elements were not included:

- work of civil engineering such as the building of concrete bases, mural drilling etc.;
- protection of the material (electric instruments, detections etc.);
- the access for the crane and the elevators (nacelles) on the building site;
- the cable of power for electrical equipment box.

Driving force for implementation
- Regulation limiting PCDD/F emissions from the melting of metals.
- Reduction of organic and other hazardous gases in cupola emissions.
- Legal requirements.

Example plants
Foundry Fiday Gestion (France) [180, DIOFUR, 2010]

Reference literature
[1, COM 2017], [63, UK Environment Agency 2002], [100, TWG 2002], [119, Helber et al. 2000], [125, CAEF 2003] [133, DE UBA 2014], [180, DIOFUR, 2010]

3.2.2.2.1.13 Dry lime injection

Description
Dry lime is injected and dispersed in the off-gas stream. The material reacts with the acidic gaseous species (e.g. SO_2) to form a solid, which is removed by filtration (e.g. fabric filter).

Further information is provided in the CWW BREF [179, COM 2016].

Environmental performance and operational data
Reported data from two plants (2 EPs) using dry lime injection show a range for SO_2 emissions from 57 mg/Nm^3 to 214 mg/Nm^3. [169, TWG 2021]

Example plants
DE076, FR111 and FR120.

Reference literature
[169, TWG 2021], [179, COM 2016]

3.2.2.2.1.14 Fabric filter

More information on the technique
See Section 3.2.1.12.7.

Environmental performance and operational data
Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from 81 plants (112 EPs) using fabric filters show a range for dust emissions from 0.02 mg/Nm^3 to 26 mg/Nm^3 with a median value of 1 mg/Nm^3 and an average value of 2.1 mg/Nm^3 [169, TWG 2021].

Example plants
Widely used.

Reference literature
[169, TWG 2021]

3.2.2.2.1.15 Wet scrubbing

More information on the technique
See Section 3.2.1.13.4.

Environmental performance and operational data
Wet scrubbing is used alone or in combination with other waste gas treatment techniques.

Reported data from nine plants (12 EPs) using wet scrubbing show a range for dust emissions from 0.8 mg/Nm^3 to 62 mg/Nm^3 with two outlier values of the order of 1 120 mg/Nm^3 and 2 560 mg/Nm^3 [169, TWG 2021]

Example plants
AT015, DE041, DE046, DE050, DE051, DE062, DE070, PL138 and SE150.

Reference literature
[169, TWG 2021]

3.2.2.3 Emissions to air from nodularisation of cast iron

3.2.2.3.1 Nodularisation with no magnesium oxide emissions

Description
Use of the in-mould process whereby the magnesium alloy is added as a tablet, directly into the mould cavity, and the nodularisation reaction takes place during moulding.

Technical description
The in-mould process is the only nodularisation technique without flue-gas production. In this process, the magnesium alloy is added as a tablet in the mould cavity. The reaction takes place *in situ* and no magnesium oxide emissions are generated.

Achieved environmental benefits
No emissions of magnesium oxide during the nodularisation of cast iron.

Environmental performance and operational data
No data reported.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
Reduction of magnesium oxide emissions from nodularisation of cast iron.

Example plants
BE021, IT 126

Reference literature
[63, UK Environment Agency 2002] [38, VITO 2001]

3.2.2.3.2 Off-gas extraction as close as possible to the emission source

Description
When magnesium oxide emissions are generated from the nodularisation technique used (e.g. sandwich, ductilator), off-gases are extracted as close as possible to the emission source using a fixed or movable extraction hood.

Technical description
The type of exhaust collection applied depends on the technique used for nodularisation (see Section 2.2.4.12.4). Depending on the technique, significant amounts of MgO can be released as a white smoke. Properties of the various nodularisation techniques are given in Table 2.15. In general techniques with a higher take-up efficiency result in lower emissions. ~~This is the case for the 'in-mould' process, where the nodularisation takes place during pouring.~~

For 'in-crucible' nodularisation, techniques using a lid or cover result in a significant reduction of the emission.
If the nodularisation off-gas is not captured, this could result in the melting shop filling-up with a white smoke, and MgO dust drop out. Exhausting without filtration can result in a visible emission from the foundry. A large volume of visible particulate can be generated in a relatively short period of time, but usually only lasts for a short duration (5 to 10 minutes for each batch treated).

In-crucible nodularisation may be performed at a specific stand or location in the melting shop. The crucible with the molten metal is brought to this point after pouring, but before taking it to the casting furnace or station. This allows the installation of a fixed hood for exhaust capture.

The collection of the MgO fume is hampered by the fact that the gases are very hot and that the intensive Mg reaction causes sparks. Due to the high upward velocity and temperature large quantities of surrounding air need to be extracted as well. This requires a large sized, and high cost, installation.

Dry filtration (using bag filters) of the exhaust gas results in a MgO powder that may be re-used in pigments or for refractory material production.

Achieved environmental benefits

- Reduced emissions of magnesium oxide during the nodularisation of cast iron.
- Mg has no harmful effect on the environment and is an essential nutrient for animals and plants in small concentrations. In the UK, the occupational exposure limits give a long-term exposure limit (8-hour TWA) of 4 mg/m³ for MgO dust and respirable fume (expressed as Mg).

Environmental performance and operational data

A typical addition rate for magnesium to the melt is around 0.1 % of the melt weight, measured as magnesium (the actual addition of magnesium containing alloy, such as magnesium ferrosilicon, could be up to 2 % of the melt weight according to the alloy used).

This addition provides about 0.05 % of the magnesium in the melt, most of the remainder oxidises and escapes to atmosphere as MgO, where it will agglomerate fairly rapidly in the air. Where there is no fume capture, the fumes can spread through the foundry and a proportion will drop out in the foundry as dust. There is no accurate information available on this amount but a reasonable figure may be 50 % of the fume released. Therefore, for each tonne of metal treated there would be around 500 g of magnesium released to air at the ladle as MgO (i.e. 833 g of MgO released per tonne of metal treated) and about 400 g of MgO released to the external atmosphere.

Emissions data from plants in the data collection are summarised in Section 2.3.

Cross-media effects

Capture of the magnesium oxide fume requires an increased energy use and therefore results in increased emissions from energy production. ~~External re-use of the MgO powder leads to a reduced need for primary material.~~

Technical considerations relevant to applicability

The technique of exhaust capture and filtration applies for foundries using in-crucible nodularisation techniques.

Economics

In applying this technique, the extraction required to successfully capture most of the MgO emissions from the treatment ladle would be around 280 m³/min. The combined capital and installation costs per foundry would be around EUR 180 000.

Table 3.64 below summarises the financial data for an 'average foundry', with the costs amortised over the presumed 10-year lifespan of the extraction and abatement equipment.

Table 3.64: Cost calculation for MgO fume abatement

Extraction rate m³/min	Production rate tonne/h	Costs EUR		Power kW	Costs EUR/tonne of iron treated		
		Capital	Civil		Running	Financial	Total
280	0.5	180280	23514	50	21.95	29.35	51.30
	(1000 tonnes per year)						

Note:
Civil costs are taken as 15 % of capital costs. Running costs are based on maintenance and waste disposal costs and are equivalent to 10 % of capital costs and power at EUR 0.06/kWh. Financial costs are based on the plant being amortised over ten years with interest charges of 10 %.
Source: [63, UK Environment Agency 2002]

The costs for abatement of the magnesium oxide fume emissions are estimated at about EUR 51.30 per tonne of metal treated.

Driving force for implementation
Legal requirements.

Example plants
~~- Römheld & Moelle - Mainz (D)~~
~~- Fuchosa - Atxondo (E).~~
- Ductilator method: AT004.
- Core wire injection: AT017, IT132, PL138, BE022, BE023, DE042, DE045, DE056, ES100, FR110, IT071, IT124 and PL135.
- Sandwich method: PT141, PT140, IT130, FR104, ES095, DE060, FI102 and ES088.
- Tundish cover method: AT009, DE039, ES082, FR109, IT131, IT158, SE144, SE145 and SE152.
- G Fisher converter method: DE050, DE049 and DE051.
- Pour over method: BE019, CZ156, DE041, DE048, ES091 and IT 124.

Reference literature
[63, UK Environment Agency 2002] [38, VITO 2001] [169, TWG 2021]

3.2.2.3.3 Fabric filter

More information on the technique
See Section 3.2.1.12.7.

Description
The magnesium oxide collected may be reused for the production of pigments or refractory materials.

Environmental performance and operational data
Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from five plants (5 EPs) using fabric filters show a range for dust emissions from 0.4 mg/Nm^3 to 4.2 mg/Nm^3 with 4 out of 5 EPs with values lower than 1 mg/Nm^3 [169, TWG 2021].

Example plants
BE022, DE039, ES088, IT071 and IT132.

Reference literature
[169, TWG 2021]

3.2.3 Techniques to consider in the determination of BAT for steel foundries

3.2.3.1 Emissions to air from thermal processes

3.2.3.1.1 Rapid off-gas cooling

Description
The off-gas is cooled rapidly from temperatures above 400 °C to below 250 °C before dust abatement to prevent the de novo synthesis of PCDD/F. This is achieved by appropriate design of the furnace and/or the use of a quench system.

More information can be found in Section 3.2.2.2.1.9.

3.2.3.1.2 Minimising dust build-up in heat exchangers

Description
The build-up of dust along the cooling trajectory of the off-gas is minimised, especially in the heat exchangers, e.g. by using vertical exchanger tubes, efficient internal cleaning of the exchanger tubes, high-temperature de-dusting.

More information can be found in Section 3.2.2.2.1.9.

3.2.3.1.3 Off-gas extraction

Description
The off-gases from induction furnaces are extracted, for example using:

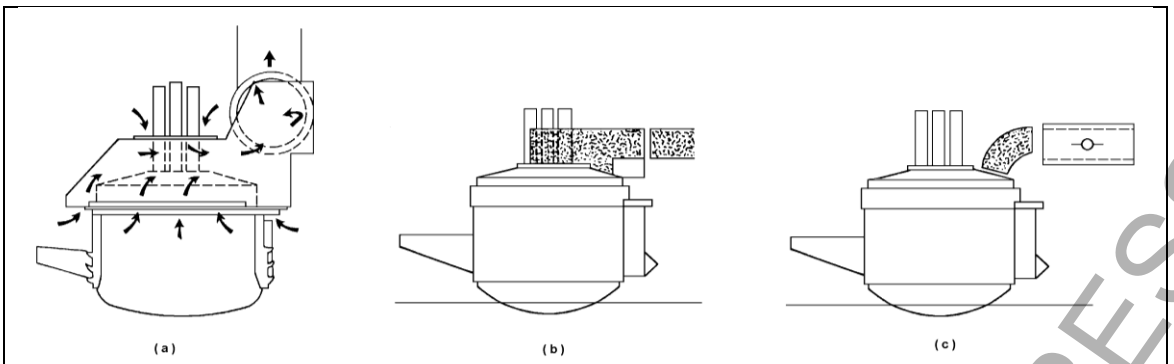
- hood extraction (e.g. canopy or side-draught hoods);
- lip extraction;
- cover extraction.

The off-gases from EAFs are extracted, for example using:

- partial furnace enclosures (mobile or fixed) mounted around the furnace and tapping area;
- total furnace enclosure using a complete room enclosure around the furnace and tapping area equipped with a moveable roof for charging/tapping operations;
- hood extraction (e.g. roof-mounted, canopy or side-draught hoods);
- direct extraction through the fourth hole in the furnace roof.

Technical description
<u>Induction furnaces</u>
Off-gas extraction systems for induction furnaces are described in Section 3.2.2.2.1.8.

<u>Electric arc furnaces (EAFs)</u>
Particulate matter from an EAF is very fine and difficult to capture. The capture of smoke and dust is the most difficult problem to solve when installing a dust arrestment system on an electric arc furnace. There are several methods that offer different advantages and disadvantages. Figure 3.67 depicts the principle of roof mounted hoods, side-draught hoods and fourth-hole evacuation.



Source: [72, Huelsen, W. B. 1985]

Figure 3.67: Principle drawings of (a) a roof mounted hood, (b) a side-draught hood, and (c) direct evacuation through a fourth-hole

- *Roof mounted hoods*: A hood is fixed on the furnace roof and collects fumes through a gap between the furnace shell and the roof. In addition, fumes arising from the working door and the tap-hole are also captured. Roof mounted hoods are heavy and subject to distortion from heat. If fitted to an existing EAF, problems may arise due to increased structural load of the roof lifting and rotating mechanism. Typical extraction rates for this system are 7 500 Nm^3/tonne to 15 000 Nm^3/tonne.
- *Side-draught hoods*: A hood is mounted on the furnace roof and collects the fumes emitted through the electrode ports. Vanes direct the airflow towards the hood. Additional hoods above the working door and the tapping-hole are used to capture emissions at these locations. Higher extraction rates are necessary here, compared to roof mounted hoods, as high air draught velocities are needed to capture the fumes. Some leakage of pollutants to the plant atmosphere can be expected, unless a tight seal is maintained. It has been reported that side-draught hoods increase electrode consumption.
- *Canopy hoods*: A large exhaust hood is placed over the complete furnace, and above the charging system. This creates a large gap between the furnace and the extraction system, making it difficult to control the rising smoke and dust, even when using high extraction rates. Cross-draughts can seriously distort the collection efficiency. These disadvantages make the use of these collection systems unattractive.
- *Direct furnace or 'fourth-hole'* ~~*evacuation*~~*extraction*: The fumes are collected through a water-cooled or refractory-lined duct connected to a fourth-hole in the furnace roof. Ambient air is aspirated through a joint in the ductwork, thus providing oxygen to burn the CO gas in the undiluted and hot offtake gas. This prevents explosions in the dust collecting system. The dimensions of the combustion chamber are very critical in order to guarantee sufficient combustion at all stages of the melting cycle. The burnt gas (900 ºC) is cooled downstream by dilution with ambient air, water injection, heat-exchangers (water jackets) or by the use of long ducts. This cooling process is needed to protect the dust filter equipment. The use of a pressure control system in the furnace allows a relatively small extraction rate at the furnace at 2 000 Nm^3/tonne to 4 000 Nm^3/tonne. Electrode consumption is generally higher due to the effect of oxidation. Direct furnace evacuation using a fourth-hole is usually limited to big electric arc furnaces, as the roof must be big enough to accommodate a fourth-hole without any structural weakening. The technique is not applied ~~applicable~~ for iron melting, because the in-flow of fresh air generates an excessive oxidation of carbon.
- *Partial furnace enclosure*: Mobile or fixed enclosures are mounted around the furnace and tapping area. The former are retracted in order to accommodate charging and tapping, while the latter are equipped with a mobile roof and side-walls for the same purpose. Exhaust gases are collected through a main exhaust duct at the top of the enclosure, assisted by fans inside the duct to guide the fumes to the exhaust. With these types of system collection, efficiencies of up to 98 % are possible.

- *Total furnace enclosure*: This system consists of a large fixed evacuated room completely surrounding the melting furnace and ladle pit. The enclosure is equipped with a movable roof and/or with side panels to accommodate both charging and tapping operations. These may be equipped with air curtains to reduce gas losses. Disadvantages of the technique are the high temperatures and noise levels inside the enclosure. However, the advantages include low outside noise levels and low energy consumption. The energy consumption is estimated to be 30 % to 50 % less than that required for a canopy hood.

Achieved environmental benefits
Flue-gas capture allows the controlled evacuation and treatment of the flue-gas stream, and results in a minimisation of both fugitive and channelled emissions.

Environmental performance and operational data
Table 3.65 provides typical exhaust flow rates and removal efficiencies for various capture systems.

Table 3.65: Typical exhaust flowrates (in m³/s) and particulate removal efficiency of EAF exhaust capture systems

	Exhaust flowrate for given furnace capacity			Particulate removal efficiency (%)	
	3.9 t/h	**9.1 t/h**	**22.7 t/h**	**Range**	**Typical max.**
Side-draught hood	12.9	19.8	50.00	90 – 100	99
Roof hood	7.7	11.9	30.00	95 – 100	99
Direct evacuation	3.2	5.0	12.5	90 – 100	99
Total enclosure			35 – 42		
Source: [72, Huelsen, W. B. 1985]					

In a Polish foundry, the installation of a total enclosure over two EAFs with a capacity of 8.5 tonnes each resulted in a reduction of the noise level from melting from 91 dBA to less than 85 dBA.

Cross-media effects
Capturing the exhaust increases the energy consumption. As it allows the cleaning of the exhaust gas, it will also generate dust for disposal or reuse.

Technical considerations relevant to applicability
Generally applicable.

Economics
TWG, please update this section with recent information.
The construction and assembly of a doghouse over two EAFs with a capacity of 8.5 tonnes each, involved an investment of EUR 275 000 (1996 prices), excluding costs for further refurbishment of the ducting and filtration system.

Driving force for implementation
- Workers-health-related prevention measures. It allows application of a gas cleaning technique by guiding the exhaust gas flow.
- Legal requirements.

Example plants
Doghouse: Metalodlew Foundry, Krakow (PL)
Off-gas collection: Metso Lokomo Steels and Sulzer Pumps Karhula Foundry (FI)

Reference literature
[13, Batz, R. 1986] [14, CAEF 1997] [72, Huelsen, W. B. 1985] [97, Metalodlew s.a. 2002] [169, TWG 2021]

3.2.3.1.4 Cyclone

More information on the technique
See Section 3.2.1.13.2.

Environmental performance and operational data
Cyclones can be used alone, but are often used in combination with other waste gas treatment techniques.

Reported data from two plants (2 EPs) using cyclones show a range for dust emissions from 8.7 mg/Nm^3 to 11.6 mg/Nm^3. [169, TWG 2021]

Example plants
ES089 and PL135.

Reference literature
[169, TWG 2021]

3.2.3.1.5 Fabric filter

More information on the technique
See Section 3.2.1.12.7.

Environmental performance and operational data
Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from 15 plants (18 EPs) using fabric filters show a range for dust emissions from 0.02 mg/Nm^3 to 8.7 mg/Nm^3 with a median value of 0.7 mg/Nm^3 and an average value of 1.24 mg/Nm^3 [169, TWG 2021].

Example plants
AT011, AT016, CZ156, DE043, DE044, DE068, DE069, DE073, ES097, FI103, FR104, IT129, PL135, SE146 and SE149.

Reference literature
[169, TWG 2021]

3.2.3.2 Emissions to air from steel refining

3.2.3.2.1 Off-gas extraction as close as possible to the emission source

Description
Off-gases from steel refining (e.g. from Argon Oxygen Decarburisation (AOD) or Vacuum Oxygen Decarburisation (VOD) converters) are extracted using for example a direct extraction hood or a roof canopy combined with an accelerator stack. Extracted off-gases are treated using a fabric filter (see Section 3.2.3.2.2).

Technical description
~~Pollution control equipment need to be designed to be able to handle the peak effluent condition, even though the peak may only persist for a relatively short period.~~

Fume control hoods for AOD vessels come in a great variety of shapes and sizes. The alternative to the direct extraction hood is the roof canopy. Roof canopies are in use in several AOD plants and efficiently capture both AOD process fumes and smoke from other operations such as charging and tapping. These roof canopies may be used in conjunction with accelerator stacks over the AOD mouth. The accelerator stack performs several useful functions, including forming a more coherent plume out of the AOD, reducing the size of canopy required, and shielding the surrounding equipment and personnel from the sometimes intense radiation of the AOD flame. The main advantage of the roof canopy is the capture of both process and fugitive effluents in the same hood.

Achieved environmental benefits
Flue-gas capture allows controlled evacuation and treatment of the flue-gas stream, and results in a minimisation of both fugitive and guided emissions.

Environmental performance and operational data
See data summarised in Section 2.3.

Cross-media effects
Exhaust gas cleaning increases the energy consumption. The dedusting of the exhaust gas generates dust for disposal or re-use.

Technical considerations relevant to applicability
This technique is applicable to all new and existing AOD installations.

Driving force for implementation
~~Regulations limiting the dust emissions from the melting of metals.~~
Legal requirements.

Example plants
~~Example plants are reported in Italy and Finland.~~
- AOD converters: FR104, DE068, AT017
- VOD converter: FI103

Reference literature
[100, TWG 2002]

3.2.3.2.2 Fabric filter

More information on the technique
See Section 3.2.1.12.7.

3.2.4 Techniques to consider in the determination of BAT for NFM foundries

3.2.4.1 Energy efficiency

3.2.4.1.1 Molten metal circulation in reverberatory furnaces

Description
A pump is installed on reverberatory furnaces to force the circulation of molten metal and minimise the temperature gradient throughout the molten bath (from top to bottom).

Technical description
The addition of a molten metal circulation pump can considerably improve the performance of reverberatory furnaces as heat is transferred from the surface of the metal bath throughout the bath more efficiently. Forcing circulation will result in lower temperature variations. It is claimed that the typical temperature variation (from top to bottom) in a 1-metre-deep reverberatory furnace without molten metal circulation ranges from 50 °C to 85 °C, and it can be decreased by 3-7 °C with the addition of a circulation pump. Since the metal is melted faster, energy can be saved or the capacity increased.

Another benefit from the use of a circulation pump is the reduced melt loss; dross formation will decrease due to the lower surface bath temperature. Metal melt loss can be decreased by about 1 %. In addition, sludge formation also decreases due to the greater temperature homogeneity.

Achieved environmental benefits
- Increased energy efficiency.
- Decreased dross formation.

Environmental performance and operational data
Molten metal circulation has the potential to decrease the energy use by 10-15 %.

Energy use in a well-designed and fully utilised fuel-fired, radiant roof-fired furnace with 100 % cold metal charging is about 830 kcal/kg (33 % efficiency). Enhancing the lining, adding a slow preheat hearth and molten metal circulation can decrease the energy use to about 680 kcal/kg (41 % efficiency). In addition, adopting recuperative burners will reduce the energy use to 600 kcal/kg (46 % efficiency) while adopting regenerative burners will reduce the energy use further to 520 kcal/kg (53 % efficiency).

In the case of an electric radiant roof reverberatory furnace with an energy use of 420 kcal/kg, the addition of molten metal circulation will reduce the energy use to about 380 kcal/kg.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
The typical cost of adding a pump well to a large furnace ranges between EUR 24 500 and EUR 31 500 (2011 data) depending on the size of the furnace. The cost of the circulation pump adds another EUR 24 500 to EUR 30 000 (2011 data). The return on investment for a typical circulation pump and a well is estimated from 24 to 28 months.

Driving force for implementation
Energy efficiency.

Example plants
No information provided.

Reference literature
[145, US EPA 2016]

3.2.4.1.2 Minimisation of energy losses by radiation in crucible furnaces

Description
Crucible furnaces are covered using a lid and/or equipped with radiant panel linings to minimise energy losses by radiation.

Technical description
About 60 % of the energy input in gas-fired crucible furnaces is lost due to radiation. In cases where furnaces are unsealed, covering the furnace with a lid would result in a significant reduction in energy losses. This measure is relatively easy to implement and will reduce melting time and energy use significantly.

Where radiation losses cannot be controlled by sealing the crucible furnace with a lid, an option is to equip the furnace with radiant panels. Radiant panels are made from alumina and reduce the radiation that leaves the crucible. The alumina panels have a special structure with a high surface area and need to be backed up with insulation material, such as alumina, that exhibits high thermal conductivity.

Achieved environmental benefits
Increased energy efficiency.

Environmental performance and operational data
It was predicted that radiant panels might improve furnace energy efficiency by 30 %. A study by Case Western Reserve University showed that the energy efficiency of a natural-gas-fired crucible was raised from 8 % to 16 % by installing improved gas burners and radiant panels. It was estimated that each of the two measures were equally responsible for the efficiency improvement. This means that the installation of radiant panels reduced natural gas consumption by 4-8 %.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
The installation costs for the panels were about EUR 2 800 per crucible (2007 data). Whether this can be economically justified needs to be evaluated on a case-by-case basis.

Driving force for implementation
Energy efficiency.

Example plants
No information provided.

Reference literature
[145, US EPA 2016]

3.2.4.2 Emissions to air from thermal processes

3.2.4.2.1 Emissions to air from metal melting and ladle preheating

3.2.4.2.1.1 Rapid off-gas cooling

Description
The off-gas is cooled rapidly from temperatures above 400 °C to below 250 °C before dust abatement to prevent the de novo synthesis of PCDD/F. This is achieved by appropriate design of the furnace and/or the use of a quench system.

More information can be found in Section 3.2.2.2.1.9.

3.2.4.2.1.2 Minimising dust build-up in heat exchangers

Description
The build-up of dust along the cooling trajectory of the off-gas is minimised, especially in the heat exchangers, e.g. by using vertical exchanger tubes, efficient internal cleaning of the exchanger tubes, high-temperature de-dusting.

More information can be found in Section 3.2.2.2.1.9.

3.2.4.2.1.3 Off-gas extraction

Description
Off-gases from shaft, crucible, resistance, reverberatory (hearth-type) and radiant roof furnaces are extracted using hood extraction (e.g. canopy hoods). The extraction is fitted in such a way that it enables the capture of emissions during pouring.

Off-gases from induction furnaces are extracted, for example using:

- hood extraction (e.g. canopy or side-draught hoods);
- lip extraction;
- cover extraction.

Off-gases from rotary furnaces are extracted, for example using hood extraction.

Technical description
Induction furnaces
See Section 3.2.2.2.1.8.

Shaft, crucible, resistance, reverberatory and radiant roof furnaces
Off-gases are collected using hood extraction (e.g. canopy hoods). For tilting furnaces (e.g. reverberatory, rotary), the extraction system is fitted to accommodate the capture of emissions when tapping the furnace.

Rotary furnaces
See Section 3.2.2.2.1.8.

Achieved environmental benefits
Flue-gas capture allows controlled evacuation and treatment of the flue-gas stream, and results in a minimisation of both fugitive and ~~guided~~ channelled emissions.

Cross-media effects
Some aluminium foundries melt material recovered from the electrolysis of aluminium. In this instance, inorganic pollutants such as hydrogen fluoride may be formed. These can be cleaned from the flue-gas using a chemisorption step, which can be added onto the dust abatement system. In this treatment, calcium hydrate or aluminium oxide can be used as the adsorbant.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Regulations concerning emissions to air.
- Legal requirements.

Example plants
~~These techniques are commonly used in induction furnaces in Europe. A specific example is Walter Hundhausen GmbH & co KG (DE).~~
Some NFM example plants from the SF data collection are summarised below [169, TWG 2021]:

- Induction furnaces (electric coreless): DE078, ES081, PL137 and SE148.
- Crucible furnaces: AT007, AT008, DE034, DE072, ES086, ES093, FI101 and PT142.
- Resistance furnaces: ES099, FR108 and FR116.
- Reverberatory (hearth-type): AT002, DE075, ES081, ES083, ES086, ES087 and IT133.
- Radiant roof: FR116 and IT154.
- Rotary furnaces: AT005 and IT127.

Reference literature
[169, TWG 2021].

3.2.4.2.1.4 Cyclone

More information on the technique
See Section 3.2.1.13.2.

Environmental performance and operational data
Cyclones can be used alone, but are often used in combination with other waste gas treatment techniques.

Reported data from three plants (5 EPs) using cyclones show a range for dust emissions from 0.6 mg/Nm^3 to 30.7 mg/Nm^3 with 3 out of 5 EPs with values lower than 4.7 mg/Nm^3 [169, TWG 2021].

Example plants
DE064, ES081 and SE148.

Reference literature
[169, TWG 2021]

3.2.4.2.1.5 Dry lime injection

Description
Dry lime is introduced and dispersed in the off-gas stream. It reacts with the acidic gaseous species (e.g. SO_2) to form a solid, which is removed by filtration (e.g. fabric filter).

Further information is provided in the CWW BREF [179, COM 2016].

Example plants
DE034.

Reference literature
[169, TWG 2021], [179, COM 2016]

3.2.4.2.1.6 Fabric filter

More information on the technique
See Section 3.2.1.12.7.

Environmental performance and operational data
Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from eight plants (18 EPs) using fabric filters show a range for dust emissions from 0.4 mg/Nm^3 to 15.4 mg/Nm^3 with a median value of 6.5 mg/Nm^3 and an average value of 6.12 mg/Nm^3 [169, TWG 2021].

Example plants
AT008, DE048, DE064, DE072, FR116, IT127, IT154 and PL137.

Reference literature
[169, TWG 2021]

3.2.4.2.1.7 Wet scrubbing

More information on the technique
See Section 3.2.1.13.4.

Environmental performance and operational data
Wet scrubbing is used alone or in combination with other waste gas treatment techniques.

Reported data from 1 plant (2 EPs) using wet scrubbing show a range for dust emissions from 14.5 mg/Nm^3 to 30.7 mg/Nm^3 [169, TWG 2021].

Example plants
ES081.

Reference literature
[169, TWG 2021]

3.2.4.3 Emissions to air from the treatment and protection of molten metal

3.2.4.3.1 Optimised degassing/cleaning of molten aluminium

Description
A mobile or fixed rotary impeller degassing station is used to remove hydrogen gas from the melt. In most cases, this is achieved through a simple degassing treatment using argon or nitrogen gas without chlorine gas.

In a combined degassing and cleaning process, gas mixtures of argon and chlorine or nitrogen and chlorine are introduced into the melt. In this case, the chlorine concentration in the carrier gas is optimised to ensure good cleaning and low chlorine emissions..

Technical description
The degassing of aluminium is needed to remove hydrogen from the melt. The removal or reduction of small amounts of undesirable elements and impurities necessitates treatment of the melt with halogens, such as chlorine, fluorine or bromine. This treatment is referred to as cleaning, and is usually combined with the degassing treatment.

Adequate degassing with physically operating treatment processes does not achieve sufficient cleaning in most aluminium castings. Vacuum degassing achieves a very low hydrogen content in the melt but, at the same time, the lower number of nuclei means that crystallisation is less effective.

In a combined degassing and cleaning process, gas mixtures of argon and chlorine or nitrogen and chlorine are introduced into the melt. The chlorine concentration in the carrier gas must be optimised in order to ensure good cleaning as well as low emissions. In most cases, only a degassing treatment is necessary. This treatment is done without Cl_2-gas. Depending on the treatment vessel, the efficiency of the degassing can be improved with porous plugs and impellers.

In some isolated cases, an Ar/SF_6-mixture has been used. The latter is a greenhouse gas with a high global warming potential, which falls under the Kyoto protocol.

Achieved environmental benefits
The use of an impeller with Ar/Cl_2 or N_2/Cl_2 avoids the use of hexachloroethane in the cleaning treatment of aluminium. The use of hexachloroethane ~~was~~ has been banned ~~from~~ since 30 June 2003 in the EU.

Environmental performance and operational data
A mixture of nitrogen with 3 % Cl_2 is generally used for combined degassing and cleaning. For degassing only, Cl_2 is not necessary.

A mobile impeller station can be used for holding furnaces and ladles of 50-250 kg of Al. The treatment takes 3 to 5 minutes. A metal treatment unit is used for capacities from 400 kg to 1000 kg Al. The melt is treated for 1.5 to 5 minutes with a gas flow between 8 litres/minute and 20 litres/minute. The graphite rotor has a life of 100-150 treatments, depending on the temperature of the melt.

Cross-media effects
None.

The application of this type of degassing unit has allowed an end to using hexachloroethane for degassing and cleaning purposes.

Technical considerations relevant to applicability
Generally applicable.

Impeller stations have been developed for holding furnaces and ladles from 50 kg to 1 000 kg of molten aluminium.

Economics
Investment costs are given Table 3.66.

Table 3.66: Investment costs for an impeller station

Description	Cost (EUR)
Impeller plant including accessories	15000
Facilities for mixing of argon gas with chlorine	40000
Total	**55000**
Source: [77, Wenk, L. 1995]	

Driving force for implementation
- European Directive 97/16/EC prohibiting the use of hexachloroethane in the manufacturing or processing of non-ferrous metals.
- Legal requirements.

Example plants
The technique is commonly applied in aluminium foundries.

In the SF data collection, the following information were reported: [169, TWG 2021]

- two plants (IT154 and SE148) reported the use of Ar-Cl_2 as a degassing agent;
- one plant (DE048) reported the use of N_2-Cl_2 as a degassing agent.

Reference literature
[74, Brown, J. R. 1999], [77, Wenk, L. 1995], [169, TWG 2021]

3.2.4.3.2 Selection of oxidation control agents with a low global warming potential in magnesium melting

Description
Oxidation control agents (covering gases) used in magnesium melting are selected by considering their global warming potential. Gas mixtures with a low environmental impact include:

- SO_2;
- gas mixtures of N_2, CO_2 and/or SO_2;
- gas mixtures of argon and SO_2.

The use of SO_2 results in the formation of a protective layer composed of $MgSO_4$, MgS and MgO.

Technical description
According to Article 13 of Regulation (EU) No 517/2014 on fluorinated greenhouse gases, the use of sulphur hexafluoride in magnesium die-casting and in the recycling of magnesium die-casting alloys is prohibited. As regards installations using a quantity of sulphur hexafluoride below 850 kg per year, in respect of magnesium die-casting and in the recycling of magnesium die-casting alloys, this prohibition has been valid since 1 January 2018.

~~Alternative covering gases for magnesium melting are of big interest due to the high global warming potential of the generally used SF_6. The substitution of SF_6 has been the topic of research for several years. A worldwide research project to develop and propose alternatives is~~

~~currently being co-ordinated by the International Magnesium Association and will be finalised in 2004.~~ Gas mixtures containing HFC-134a (CF_3CH_2F) and Novec 612 (perfluoroketone, $C_3F_7C(O)C_2F_5$) have been successfully tested. Research is on-going on the applicability of both compounds. HFC-134a falls under the restrictions of the Kyoto protocol. Both compounds show a lower global warning potential than SF_6: SF_6 GWP = 23900; HFC-134a GWP = 1300; Novec 612 GWP = 1.

Information from industry states that German foundries have applied the following cover gases/mixtures: N_2 + R134a, N_2 + CO_2 + SO_2, N_2 + SO_2, SO_2, S/Ar.

The use of R134a (1,1,1,2-tetrafluorourethane) results in a MgF_2 protective layer. The use of SO_2 (sulphur dioxide) to form $MgSO_4$, MgS and MgO phases. However, different companies have introduced different 'philosophies'.

~~At present~~Until 2005, SO_2 was a viable alternative. Some magnesium foundries have long experience with this gas, and never turned to SF_6 when this gas was first introduced at the beginning of the 1970s. SO_2 reacts with liquid magnesium and builds a protective film on the surface. A mixing unit for blending a low concentration SO_2-air mixture is available. Furthermore, handling procedures for SO_2 have been established to reduce workers exposure and risk.

The protective gas is supplied through a manifold with several outlets. The positions of the outlets are chosen to give protection to all areas of the metal surface. Areas closer to hatches that will be opened frequently during operation need a higher flow of gas than areas where interaction with the surrounding atmosphere is small.

In order to optimise safety and minimise gas consumption, totally encapsulated melting and casting processes are applied.

~~If replacement is not feasible, the following technical measures allow a reduction of SF_6 consumption and emissions:~~
- ~~improved sealing of furnaces~~
- ~~fully automatic cover gas dosage~~
- ~~electronic control of both gas mix and flowrate~~
- ~~reduction of overdosing.~~

Achieved environmental benefits
The replacement of SF_6 avoids using this greenhouse gas, which has a GWP of 22 200 over a 100-year time horizon.

Environmental performance and operational data
~~The consumption of SF_6 depends on the melting technique used, and varies between less than 0.1 and 11 kg/tonne of finished castings. Technical improvements and measures have resulted in a reduction in the average specific SF_6 consumption, from over 3 kg/tonne of casting to 0.9 kg/tonne. Application data are given in Section~~

In an undisturbed melt, the use of SO_2 would be typically 0.7 % in air at a flow rate of 5 litre/minute to 10 litre/minute. In closed (but not airtight) furnaces, such as the melting and dosing furnaces of die-casting machines, pure SO_2 is applied. Small amounts of air entering through the lid are needed to provide the covering action. If a carrier gas is used, nitrogen is the preferred gas because of its inertness. The SO_2 is then mixed in concentrations of 1-2 %.

Mass balance data for the fluxless re-melting of magnesium scrap are given in Section 3.2.1.4.1.2.

Cross-media effects

SO_2 is a toxic gas and exposure limit values for workers should be taken into account. The occupational exposure limit in most countries is 2 ppm (5 mg/m³) over 8 hours. Sulphur- and oxygen-containing deposits may form on the furnace wall. Under unfavourable conditions these deposits can be immersed into the molten metal where they cause reactions leading to metal eruptions from the surface. Frequent removal of scaling can prevent this from happening.

The technique results in emissions of small amounts of SO_2, the amount depending on the foundry capacity and the number of furnaces. ~~One estimate could be 50 – 500 kg per year for melt protection.~~

Technical considerations relevant to applicability

Generally applicable.

Economics

Conversion from SF_6 to another covering gas system entails an associated economic cost.
~~The price of SF_6 has increased dramatically over the last few years. Conversion from SF_6 to SO_2 will therefore have an associated economic cost. gives estimates for the running expenses for the use of SF_6 and SO_2 based on information from a die-caster running three die-casting machines and the results from industrial scale trials. Even though the figures are only rough estimates, they clearly show that there is a large cost saving potential when substituting SO_2 for SF_6.~~

~~**Property**~~	~~**Units**~~	~~**SF_6**~~	~~**SO_2**~~
~~Concentration of gas~~	~~%~~	~~0.4~~	~~0.7~~
~~Price~~	~~EUR/kg~~	~~36.5~~	~~4.5~~
~~Inverted density (at 0 ºC and 1 atm)~~	~~l/kg~~	~~153~~	~~350~~
~~Yearly consumption of gas~~	~~kg/yr~~	~~339~~	~~259~~
~~Cost/year~~	~~EUR~~	~~12373~~	~~1165~~
~~Data for 3 die-casting machines, run at 300 days/yr, 24 h/day with flowrate of gas to each machine of 10 l/min~~			

~~**Cost comparison between SO_2 and SF_6 used for protective gas atmospheres [89, Schubert et al. 0]**~~

~~If a new investment is considered, the SO_2 gas system, meeting all modern safety and dosage requirements, costs EUR 70 000, for a 1 000 tonnes/yr plant. A new SF_6 system costs EUR 23300. Operational data, accounting for this investment and for the use of 1.5 % of SO_2 and 0.2 % of SF_6, both in nitrogen, are given in The total annual cost for SO_2 is some EUR 2500 more than for SF_6, on the other hand 12300 tonnes of CO_2 equivalent emissions are avoided. The bigger the plant, the less the annual costs differ between the two systems. At an annual output of 1500 tonne/yr, the turning point is passed and the CO_2 reduction cost turns negative.~~

~~**General Casting Data**~~		
~~Capacity of the ovens~~	~~2000 kg~~	
~~Maximum smelting performance~~	~~1000 kg/h~~	
~~Casting time per day (Cold chamber)~~	~~13.2 h~~	
~~Working days~~	~~250/yr~~	
~~Utilisation~~	~~76 %~~	
~~Gross melting weight (shot weight)~~	~~2000 t/yr~~	
~~Scrap factor~~	~~50 %~~	
~~Net weight of the Mg parts~~	~~1000 t/yr~~	
~~Sales per year (EUR 15.00/kg)~~	~~EUR 15 million~~	
~~Surface of the Mg baths~~	~~6 m³~~	
~~Gas (carrier + cover gas) per m² surface~~	~~300 litres per hour, all year long~~	
~~Extra gas dosage while charging~~	~~+ 25 %~~	
~~**Gas Data**~~	~~**SF_6**~~	~~**SO_2**~~
~~Carrier gas~~	~~nitrogen~~	~~nitrogen~~
~~Cover gas concentration in carrier gas~~	~~0.2 vol. %~~	~~1.5 vol. %~~
~~Cover gas dosage per hour~~	~~46.9 g~~	~~154.2 g~~

~~Cover gas dosage per year~~	~~514 kg~~	~~1688 kg~~
~~Coefficient cover gas/net Mg output~~	~~0.51 kg/t~~	~~1.69 kg/t~~
~~Emissions in tonnes CO_2 equivalent~~	~~12278~~	~~-~~
~~**Cost Data**~~	~~**SF_6**~~	~~**SO_2**~~
~~1 kg cover gas~~	~~EUR 20.00~~	~~EUR 3.00~~
~~1 m^3 carrier gas (nitrogen)~~	~~EUR 0.20~~	~~EUR 0.20~~
~~Invest cost of new gas equipment~~	~~EUR 23333~~	~~EUR 70000~~
~~Discount rate per year~~	~~10 %~~	~~10 %~~
~~Depreciation period~~	~~10 yr~~	~~10 yr~~
~~Annualised invest cost of equipment~~	~~EUR 3797~~	~~EUR 11392~~
~~Operating cost of cover gas~~	~~EUR 10274~~	~~EUR 5065~~
~~Annual running cost (without nitrogen)~~	~~EUR 14072~~	~~EUR 16457~~
~~Additional total cost of using SO_2~~	~~-~~	~~EUR 2385~~
~~Specific emissions reduction cost~~	~~-~~	~~EUR 0.19/tonne CO_2 eq.~~
~~Share of additional cost in sales~~		~~0.02 %~~
~~Note: Most data are valid only for this 1000 tonne/yr plant and will change with plant size~~		

~~**Operational and cost data for a new die-casting plant of 1000 tonne/yr Mg output [116, Harnisch et al. 2003]**~~

~~For existing installations, the reduced cost for SO_2 consumption needs to pay back the investment cost for the conversion of the cover gas installation. The payback time is dependent on the actual cover gas consumption. Based on an SF_6 consumption of 0.9 kg/tonne, the turning point at which the total costs of using SO_2 get lower than the comparable cost of SF_6 is below 900 tonne/yr output. At 500 tonnes/yr the SO_2 is still more expensive, but the specific reduction cost of 1 tonne CO_2 eq. amounts to EUR 0.31. The share of additional costs in the plants sales amounts to 0.04 %. Therefore at this capacity, the technique can also be considered.~~

~~As a conclusion, it is found to be economic to use SO_2 instead of SF_6 as a cover gas in magnesium die-casting, at least in plants with an annual metal output of 500 tonnes and more, regardless of whether the plant is to be newly built or still runs with SF_6.~~

Driving force for implementation
Legal requirements related to the greenhouse gases.
~~Reduction measures for greenhouse gas emissions, in particular, the Kyoto climate protocol controlling the use of fluorinated gases: HFCs, PFCs and SF_6. These gases have a high global warming potential but are not ozone depletors. This will form the basis for the EU Directive on the use of fluorinated gases. Furthermore, some regions have already issued proposals to ban its use, such as e.g. Denmark, Germany and Austria.~~

Example plants
LM Leichtmetall Systemtechnik, Felbach (D)
~~In Austria, Denmark and Sweden SF_6 is no longer used as a cover gas.~~

In the SF data collection, of the three plants that produce magnesium castings, data for one plant (DE033) indicate the use of SO_2 as oxidation control agent.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
DE033.

Reference literature
[81, Closset 2002], [89, Schubert et al. 0], [90, IMA et al. 0], [91, Gjestland et al. 1996], [92, UNEP IPCC 2002], [116, Harnisch et al. 2003], [134, CAEF 2020], [169, TWG 2021]

3.3 Techniques to consider in the determination of BAT for smitheries

3.3.1 Energy efficiency

Heating and heat treatment processes generally account for a significant part of the energy consumption in smitheries. Furthermore, the machinery, heating and forging/hammering processes use a high amount of energy.

Techniques that were reported for minimisation of energy consumption are presented in Table 3.67 [169, TWG 2021]

Table 3.67: Reported techniques for the reduction of energy consumption in smitheries

Automation in heating furnace operation
Computer-based control of power consumption in critical points in the production process
Energy-efficient lighting
Energy management system
Improvements in heating system
Other (management system for air compressors)
Source: [169, TWG 2021]

In this context, more useful information can also be found in the Reference Document on Best Available Techniques for Energy Efficiency (ENE BREF). [177, COM 2009]

3.3.1.1 Optimum furnace design

Description
This includes techniques such as the following:

- optimisation of key furnace characteristics (e.g. number and type of burners (e.g impulse burner), air tightness and furnace insulation using suitable refractory materials);
- minimisation of heat losses from furnace door openings, e.g. by using several liftable segments instead of one in continuous reheating furnaces;
- minimisation of the number of feedstock supporting structures inside the furnace (e.g. beams, skids) and use of suitable insulation to reduce the heat losses from water cooling of the supporting structures in continuous reheating furnaces.

Technical description
Furnace design
The design of the furnace and the degree of insulation have a significant effect on thermal efficiency. The furnace together with the number and the capacity of the burners are carefully calculated starting from several realistic production scenarios. Different heating temperatures of the feedstock, and differences in production rhythm caused by changes in the dimensions of the feedstock are taken into account. [168, COM 2021],

The appropriate equipment is available to limit the emissions and the energy consumption in case of a sudden line stop. This means that the temperature can easily be lowered or burners switched off in certain furnace sections. In the latter case, a N_2 purge might be necessary for safety reasons. [168, COM 2021]

From March 2004 to the end of January 2009, new impulse burners were developed for the smitheries industry. These impulse burners are in use and show an optimisation of the heating

process, such as a better and optimised heat transfer to the steel parts in the furnace and a homogeneous temperature distribution in the furnace chamber is achieved. [169, COM 2021],

Furthermore, investigations were carried out regarding energy savings in forging operations through the optimisation of inductive heating processes. Based on experimental and numerical investigations on the use of induction systems, measures for the efficient use of energy in inductive heating of forging ingots have been derived. [137, Herbertz et al., 2013]

Furnace energy efficiency may be taken into consideration for the furnace selection, e.g. furnaces that allow the heating/reheating of incoming feedstock.

Optimisation of furnaces and furnace operation will yield major efficiency improvements because heating, reheating and holding account for the majority of total energy consumption. Energy consumption can also be reduced by optimising utilities such as air compressors, fans, motors, pumps and lights.

Process heat can be reused for heating processes.

Further information regarding energy efficiency along with measures and techniques for reduction and/or optimisation of energy consumption can be found in the Reference Document on Best Available Techniques for Energy Efficiency (ENE BREF). [177, COM 2009]

Achieved environmental benefits

- Reduced energy consumption.
- Reduction of NO_X and CO emissions.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Only applicable to new plants and major plant upgrades.

Economics
No information provided.

Driving force for implementation

- Reduction of costs.
- Natural resources savings by reduction of energy consumption.
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[137, Herbertz et al., 2013], [168, COM 2021], [169, TWG 2021], [177, COM 2009]

3.3.1.2 Furnace automation and control

Description
The heating process is optimised by using a computer system controlling in real time key parameters such as furnace and feedstock temperature, the air to fuel ratio and the furnace pressure.
Technical description

Furnace automation controls the combustion, the energy consumption, material handling, temperature control of the feedstock and process safety continuously. In addition, it enables adjustment of the air to fuel ratio for optimum combustion which in turn minimises NO_X emissions. [168, COM 2021]

With the help of a process computer, the heating process can be optimised (e.g. no unnecessary overheating of feedstock during interruptions, more accurate temperature control) in accordance with the material quality and dimensions. [168, COM 2021]

Achieved environmental benefits
- Reduced energy consumption.
- NO_X reduction.

Environmental performance and operational data
No information provided. ***TWG, please provide information.***

Cross-media effects
No negative effects on other media are known.

Technical considerations relevant to applicability
Generally, there are no technical restrictions to the applicability of this technique.

Economics
TWG, please provide information.

Driving force for implementation
Reduced energy consumption – energy savings.
Improved product quality and reduced maintenance costs.

Example plants
Widely used.
In the SF data collection: DE006, DE007, ES008 and PL009

Reference literature
[137, Herbertz et al., 2013], [168, COM 2021], [169, TWG 2021]

3.3.1.3 Optimisation of feedstock heating/reheating

Description
This includes measures such as:

- techniques related to the entire process, e.g. ensure that feedstock heating/reheating target temperatures are consistently met, switch off equipment during idle periods;
- furnace operation optimisation, e.g. furnace capacity utilisation, correction of the air/fuel ratio, improvement of insulation, use of covers to avoid heat losses, use of recuperators/regenerators, preheated feedstock loading.

Technical description
Gas furnaces, electric induction and conduction heaters are available for heating the material, which ensure a precise process temperature.
For both preheating and reheating, both indirect and direct heating processes are applied. Furthermore, there are two direct heating processes applied:
- inductive heating;
- conductive heating.

Achieved environmental benefits

Reduction of energy consumption.

Environmental performance and operational data
TWG, please provide information.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Legal requirements.
- Local conditions.
- Reduction of costs.
- Natural resources savings by reduction of energy consumption.

Example plants
In the SF data collection: DE004 and DE006

Reference literature
[169, TWG 2021], [177, COM 2009]

3.3.1.4 Preheating of combustion air

More information on this technique: see Section 3.2.1.3.13.

3.3.1.5 General processing techniques

Description
Energy-efficient processes by applying general processing techniques.

Technical description
General processing techniques and several different measures are presented here, which can be applied to the smitheries processes individually or in combination:

- automation in heating furnace operation;
- computer-based control of power consumption in critical points in the production process;
- energy-efficient lighting;
- energy management system;
- improvements in heating system;
- management system for air compressors; [169, TWG 2021]
- minimisation/reduction of process step, such as avoidance of reheating processes; [137, Herbertz et al., 2013]
- optimisation of processes, e.g. optimised heating processes and aggregates, heat recovery. [137, Herbertz et al., 2013]

Achieved environmental benefits
Increased energy efficiency.

Environmental performance and operational data

TWG, please provide information.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable to smitheries.

Economics
No information provided.

Driving force for implementation
- Legal requirements.
- Local conditions.
- Saving costs by saving energy.
- Reduction of CO_2 emissions.

Example plants
Widely used.
In the SF data collection: DE006, DE007, ES008 and PL009

Reference literature
[137, Herbertz et al., 2013]; [169, TWG 2021]

3.3.2 Material efficiency

3.3.2.1 Process optimisation

Description
Process optimisation leads to increasing material efficiency and energy efficiency.

This includes techniques such as:

- computerised management of processes, e.g. heating/reheating cycles, hammering sequences, hammer's impact loads;
- adjustment of raw material size, either in the forging line (fully automated) or in the organisational area of the material shredding (manual), in order to minimise the amount of modifications in the hammering process.

Technical description
Process optimisation leads to an efficient use of material and energy, and may result in targeted adjustment of various process parameters within the smitheries processes.

Computer-aided design software is used for the design of products. This results in the efficient and optimised use of raw materials and the reduction of generated residues (e.g. burrs). [169, TWG 2021]

Material size reduction can be achieved with either of the following two reduction methods:

- fully automatic, centrally in the forging line;
- manually decentralised in the organisational area of the material shredding.

[169, TWG 2021]

Furthermore, the use of material-efficient equipment (new equipment for productivity, safety and consumption improvements) was reported. [169, TWG 2021]
Achieved environmental benefits

Efficient use of material and energy.

Environmental performance and operational data
TWG, please provide information.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
The costs associated with monitoring the off-gas of a smitheries installation relate to personnel and equipment used for sampling and measurement.

Driving force for implementation
- Environmental legislation.
- Legal requirements.
- Local conditions.

Example plants
In the SF data collection: DE006 and ES008

Reference literature
[169, TWG 2021]

3.3.2.2 Optimisation of raw material consumption

Description
This includes techniques such as:

- use of computer-aided design of products to optimise the amount of raw material used and reduce the generation of burrs;
- use of high-strength raw materials;
- reuse/recycling of process residues;
- selection of an appropriate type of lubrication material in hot/warm forging, e.g. synthetic lubricant, water-based dispersions of graphite ;
- centralised distribution system for coolants/lubricants that reduce intermediate storage and consumption, and facilitates leak detection;
- systems for collecting and recirculating coolants/lubricants (see also Section 3.3.6).

Technical description
Different techniques and measures were reported for an efficient consumption of raw materials and prepared materials, which can be applied individually or in combination. By applying these techniques, materials are used efficiently. Furthermore, reused and recycled process residues can be used.

Improved material utilisation includes:

- reduced material consumption due to the use of high-strength materials;
- reduction of burrs through improved design as a result of powerful simulation;
- application of lightweight construction [137, Herbertz et al., 2013].

Process residues generated from the raw material preparation, hammering and/or treatment processes for example are recycled and internally reused within the smitheries processes. [169, TWG 2021]

Lubricants
Lubricants are used in hot and warm forging and often include water-based dispersions of graphite. Graphite can support the metal-forming process and can resist high pressures applied perpendicularly to the planes, avoiding metal-to-metal contact between the workpiece and dies, thus minimising die wear. The disadvantage is the effect of galvanic corrosion, which is supported by the conductivity of graphite.

There is a clear trend to replace graphite-based die lubricants with synthetic lubricants. This is driven by the need for cleaner work environments, easier handling and to avoid graphite-induced galvanic corrosion of equipment. [165, Odink, G. J. 2021]

Achieved environmental benefits
- Efficient use of material and energy.
- Minimisation of residues through recycling of process residues and reuse of recycled materials along with raw material savings.

Environmental performance and operational data
TWG, please provide information.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
TWG, please provide information.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
In the SF data collection: DE005, DE006, DE007, ES008 and PL009

Reference literature
[137, Herbertz et al., 2013]. [169, TWG 2021], [165, Odink, G. J. 2021]

3.3.2.3 Automation of forging machines

Description
Process optimisation is supported by automation of forging processes and machines, such as heating/reheating, hammering. [137, Herbertz et al., 2013]

Technical description
Automation is related to both the individual operation steps and the different parts of forging machines. It includes, for example, the production process, the process economy of the machinery, the operation unit and the control unit in order to regulate for example the efficiency of the operation steps, including energy consumption, energy efficiency and material efficiency. The controlling of temperature, heating conditions, hammering power, temperature of the material can be automated and optimised in order to produce an optimised product. Automation

can directly detect problems with the machinery and the process. Corrective measures are directly added by the automation procedure or can be carried out on demand.

Furthermore, robots are applied for special production steps or production processes.

A very flexible grabbing principle is combined with almost any web guide system. As a result, geometrically complex components can also be grabbed and transported on almost any web guides within the area, including across the boundaries of a machine. This principle enables robots to pick up the workpieces easily and securely.

Usually, the robots have a limit to their cycle time. The cycle time limit can sometimes be bypassed by increasing the number of robots used and by sharing the work.
[137, Herbertz et al., 2013]

Achieved environmental benefits
Optimisation of energy efficiency and material efficiency.

Environmental performance and operational data
TWG, please provide information.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
Investment and operating costs generally depend on both the type of automation and the parts of machinery that have to be automated. Labour expenses may be reduced.

Economically viable automation generally requires large batch sizes.
[137, Herbertz et al., 2013]

Driving force for implementation
- Reduction of labour expenses.
- Increase of production productivity.
- Legal requirements.
- Local conditions.

Example plants
In the SF data collection: DE005, DE006, DE007, ES008 and PL009

Reference literature
[137, Herbertz et al., 2013]

3.3.2.4 Integrated process monitoring system

Description
Integrated monitoring systems with adequate measuring equipment are used to track energy and raw materials consumption from input to the points of consumption.

Technical description
An integrated monitoring system is used to control the energy consumption, the temperature and heating conditions, from input to points of consumption. The system can obtain data directly from measuring equipment; however, this technique could also include a system of hardware and software for the automatic detection of electric energy for heating and reheating, machining,

hammer power and water consumption, if applicable. It allows monitoring of installation energy consumption (process consumption and utilities such as air compressors, air treatment units (if available), compressed air and lighting), the detection of deviations and the estimation of the consumption reduction.

Monitoring of energy consumption could include direct measurements, calculation or recording, e.g. using suitable meters or invoices. The monitoring is broken down at the most appropriate level (e.g. at process or plant/installation level) and considers any significant changes in the plant/installation.

Achieved environmental benefits
Benefits include the control and measurement of energy consumption in an integrated way. This permits the main points of consumption and potential points of savings to be identified, consumption levels to be controlled, points of losses or incorrect functioning to be identified, and achieved savings to be measured.

Environmental performance and operational data
An example of monitoring is to control temperature, by dedicated measurement and correction.

Cross-media effects
No cross media effects.

Technical considerations relevant to applicability
Generally applicable.

Economics
Investment and operating costs generally depend on the type of measurement and complexity of the installation.

Driving force for implementation
- The implementation of this technique is stimulated by the potential economic savings, rise in yield and efficiency, and improvement of operating conditions.
- Legal requirements.
- Local conditions.

Example plants
In the SF data collection: DE007, ES008 and PL009

Reference literature
[175, COM, 2021]

3.3.3 Vibrations

Description
Reduction of vibration occurring from the hammering process by using vibration-reducing and insulating techniques.

Technical description
Vibration-reducing and insulating techniques for the hammering equipment include:

- installation of vibration-damping components, e.g. layered elastomeric isolators or viscous spring isolators below the anvil or spring casings below the hammer foundation;
- optimisation of the hammer's impact loads (see Section 3.3.2.1).

Forging hammers are types of shock-producing machines and generate powerful brief impact loads and powerful dynamic effects that are relatively short in duration and can be characterised

as pulses. Only a part of the shock energy is utilised in the intended machine function and the rest is dissipated in the foundation, causing intense vibration. These impact loads on vibrations have significant effects on the surroundings and need to be reduced and minimised. Heavy shocks imparted to the foundation can cause alignment problems (i.e. reduce operating life), neighbour complaints and prohibit proper operation of adjacent equipment. The main objectives are to reduce the vibration amplitudes and the forces transmitted to the soil and/or to minimise any disturbance to the neighbourhood and surroundings. The supporting foundations need to be designed in such a way that the vibration amplitude is reduced and the force is transmitted to the soil. [164, Heidari et al. 2011]

Different measures are applied in the hammering process to reduce vibrations, such as:

- vibration-reducing and insulating measures for the equipment;
- vibration-damping components, e.g. elastomer below the anvil and spring casings below the foundation [162, Raju et al. 2017];
- suitable insulating base [139, Probst 2006];
- use of anti-vibration bases for vibrating equipment [169, TWG 2021].

It is important to install vibration isolation systems for modern forging hammers that are massive and powerful because of the improved work environment and to minimise the effect of vibration on surrounding equipment such as furnaces and machine tools. Die forgers and hammers are installed on layered elastomeric isolators or viscous spring isolators. [164, Heidari et al. 2011] Elastomer below the anvil and spring casings below the foundation are used for vibration absorption. [162, Raju et al. 2017] The correct application of a well-designed isolation system will result in a significant reduction of the ram's impact shock. [163, Veroeven 2010]

Achieved environmental benefits
Reduction of vibrations.

Environmental performance and operational data
For small hammers, the reinforced soil foundation can reduce the foundation response amplitude by up to 80 %. For large hammers and presses, the reinforced soil foundation can be designed to reduce the foundation response by up to 60 % of the case of no soil reinforcement. [164, Heidari et al. 2011]

Cross-media effects
None.

Technical considerations relevant to applicability
Applicable to new and existing plants.

Economics
No information provided. ***TWG, please provide information.***

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.
In the SF data collection: DE002, DE003 and DE005

Reference literature
[139, Probst 2006], [162, Raju et al. 2017], [163, Veroeven 2010], [164, Heidari et al. 2011] , [169, TWG 2021]

3.3.4 Noise emissions

3.3.4.1 Overview

Noise emissions and vibrations occur in the several steps during the smitheries process. Noise emissions and vibrations may occur throughout the whole smitheries process, such as preparing and processing raw materials, cutting, heating, forging/hammering, heat treatment, surface treatment, material transport and storage of products as well as from the dispatch and shipping of the final products. [139, Probst 2006], [169, TWG 2021]

The high level of noise is mainly caused by the production process itself. Metal requires large forces in the transformation process.

The heavy machinery and large fans used in various parts of the smitheries manufacturing/forging process can give rise to noise emissions and/or vibration, particularly from:

- forging/hammering vibrations and any operations involving hammering;
- exhaust fans;
- blowers;
- duct vibration.

A reduction of sound emissions can often be achieved by directly applying measures at the source of the noise.

Plants are required to comply with reduction standards in compliance with national legislation, and noise surveys are conducted and evaluated. At the process/hammering hall, the windows and doors are closed during proceedings. Natural noise barriers, such as office buildings, walls, trees or bushes, are used in the smitheries industry to reduce noise emissions.

Furthermore, sound-absorbing surfaces can be installed and construction measures can be applied. [139, Probst 2006]

In the machine shop, technical noise-absorbing devices and sound-absorbing surfaces can be applied, e.g. cement-bonded particleboards/wood fibre boards. Externally insulated trapezoidal sheet roofs in which the space-side plates are perforated and filled with mineral fibre wedges have also proved efficient as noise absorption roof structures. [139, Probst 2006]

Furthermore, low-noise machinery, equipment and tools can be applied, e.g. low-noise nozzles. For material transport, noise-reduced equipment is used.

In the event that the installation is located close to residential areas, the planning of new buildings at the site is connected with the necessity to reduce noise emissions and vibrations.

See also Section 3.1.5 for further techniques and measures which are applicable for reduction of noise emissions.

3.3.4.2 General measures

Description
Techniques and measures to reduce noise emissions.

Technical description
A reduction of noise emissions can often be achieved by directly applying techniques at the source of the noise. In addition, various techniques for noise abatement can be applied at

smitheries in order to reduce the noise levels for neighbourhood protection, such as:

- installation of noise walls and utilisation/optimisation of the noise-absorbing effect of buildings:
    - double walls or sheathing in a double-shelled construction are very efficient because, additionally, the air between the first and the second wall guarantees a higher noise protection level;
- enclosure of the noisy unit;
- enclosure or partial enclosure of noisy operations;
- full enclosure of the smitheries building;
- decoupling of machine foundations from the building structure;
- noise management measures (e.g. improved inspection and maintenance of equipment, closing of doors and windows);
- noise reduction measures for fans (e.g. using silencers, slow rotating fans);
- avoidance of noisy activities (e.g. transport) at night;
- encapsulation of material supply in the outside area and sealing of building fronts;
- soundproofing the building fronts including arrangement of soundproofed ventilation elements.

[169, TWG 2021]

If the above-mentioned noise prevention/reduction techniques cannot be applied, secondary noise reduction techniques, e.g. construction of buildings or natural barriers, such as growing trees and bushes between the protected area and the noisy activity, have to be carried out. Doors and windows of covered areas have to be kept closed during noisy operations.

The overall reduction of noise levels involves developing a noise reduction plan. Each source needs to be checked and evaluated. Alternative techniques with lower noise levels may be applied and/or point sources may be enclosed, as described above.

Achieved environmental benefits
Reduction of noise emissions.

Environmental performance and operational data
TWG, please provide information.

Cross-media effects
No issues.

Technical considerations relevant to applicability
Applicable to all new and existing installations.

Economics
Additional investment and maintenance costs can occur due to the noise protection techniques.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.
In the SF data collection: DE001, DE002, DE003, DE004, DE005, DE006, DE007, ES008 and PL009

Reference literature
[169, TWG 2021]

3.3.5 Monitoring

3.3.5.1 Overview

Real data are required on the precise effects of the activities of the industrial site on the environment. It is thus necessary to conduct a planned, regular sampling and monitoring programme. The parameters monitored include:

- point sources' channelled, diffuse and fugitive emissions to the atmosphere, water or sewer;
- wastes, particularly hazardous wastes, if applicable;
- contamination of land, water and air;
- use of water, fuels, energy, oxygen, nitrogen and other gases (e.g. argon);
- discharge of thermal energy, noise, vibration and dust;
- effects on specific parts of the environment and ecosystems;
- on-site accidents;
- staff injuries;
- transport accidents;
- complaints from community residents.

Monitoring, however, is not restricted to analytical measuring. It also includes regular maintenance, and visual and safety checks.

In parallel to this document, the reader is referred to the Reference Report on Monitoring of Emissions to Air and Water from IED installations (ROM) for further information. [174, COM 2018]

Preferably, the monitoring records for emissions to air and water shall be made available in an electronic format.

3.3.5.2 Monitoring of channelled emissions to air

Description
Regular monitoring of emissions to air.

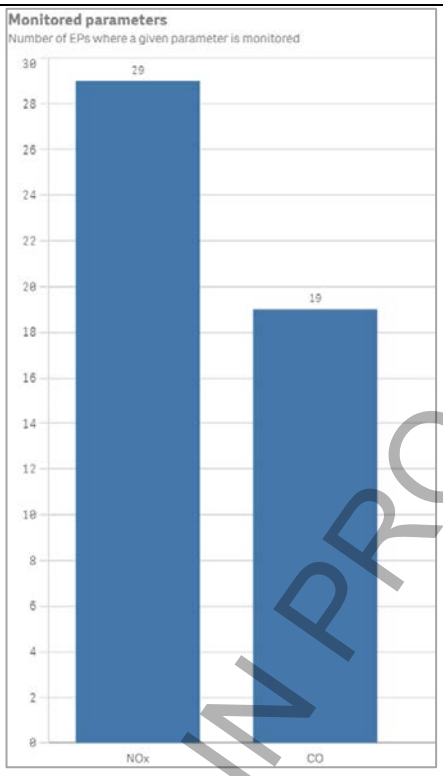
Technical description
Continuous and regular monitoring of emissions to air.

The monitoring of emissions is carried out in accordance with EN standards or, if EN standards are not available, ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality.

For heating/reheating and heat treatment processes, NO_X and CO emissions are usually monitored.

Achieved environmental benefits
Monitoring the off-gas characteristics and pollutant concentrations assist with the evaluation of the environmental impact from smitheries operation. In addition, it contributes to the process optimisation (e.g. combustion processes) and to detect accidental releases, helping to prevent any possible adverse environmental effects.

Environmental performance and operational data



[169, TWG 2021]

Figure 3.68: Reported number of emission points where a given parameter is monitored

Cross-media effects
No cross-media-effects.

Technical considerations relevant to applicability
Generally applicable to all smitheries plants where there are channelled emissions to air.

Economics
The costs associated with monitoring the waste gas of a smithery relate to personnel and equipment used for sampling and measurement.

Driving force for implementation
Environmental legislation.

Example plants
See the relevant sector sections for emissions in Section 1.3.4.

Reference literature
[174, COM 2018], [169, TWG 2021]

3.3.6 Emissions to air

3.3.6.1 Diffuse emissions to air

Various process steps in smitheries operation have the potential to produce dust, fume and other pollutants, e.g. material storage, handling and processing.

Diffuse emissions occur when emissions from specific process sources and process steps are not collected. Potential sources include:

- storage areas;
- the loading and unloading of transport containers;
- preparation of raw materials;
- moving of materials;
- an accidental loss of containment from a plant or equipment failure, including leakages;
- spills.

3.3.6.1.1 Operational measures

Description
This includes techniques such as:

- use of closed bags or drums to handle materials with dispersible or water-soluble components;
- minimisation of transport distances;
- efficient material handling;
- enclosure of storage areas;
- cooling line enclosure.

Technical description
Techniques to reduce emissions to air involve prevention, minimisation and collection of off-gas (see Section 3.3.6.1.2).

Several techniques are available to prevent or minimise diffuse emissions, e.g. from material handling and preparation, heating/reheating, heat treatment, hammering, finishing.

For information on efficient storage and handling of raw materials and reduction of diffuse emissions to air, see Section 3.3.6.1.3.

Achieved environmental benefits
- Reduction of diffuse emissions (mainly dust).
- By enclosure of storage areas, noise emission reduction is also possible.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Legal requirements.
- Local conditions.
- Health and safety requirements for the workplace.

Example plants
In the SF data collection: DE007, ES008 and PL009

Reference literature
[169, TWG 2021]

3.3.6.1.2 Extraction of off-gases from heating/reheating, heat treatment, hammering and finishing processes

Description
Off-gases from heating/reheating, heat treatment, hammering and finishing processes are extracted using enclosures or hoods. Extracted off-gases from finishing processes may be treated using techniques such as fabric filters.

Technical description
Extraction of off-gases from heating/reheating, heat treatment, hammering and finishing processes to prevent or reduce diffuse emissions to air.

The following techniques were reported for emissions to air:

- capture and treatment of off-gases from finishing processes (e.g. blasting);
- capture and treatment of off-gases from hammers;
- capture and treatment of off-gases from heating furnaces;
- collection and treatment of off-gases from finishing processes. [169, TWG 2021]

Off-gas treatment may be applied, e.g. by using fabric filters. More information on fabric filters is given in Section 3.2.1.12.7. The use of a fabric filter requires the selection of a fabric suitable for the characteristics of the off-gas and the maximum operating temperature.

Achieved environmental benefits
Prevention or reduction of diffuse emissions.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation
- Legal requirements.
- Local conditions.
- Health and safety requirements for the workplace.

Example plants
All plants reported extraction of off-gases from e.g. furnaces, hammers.
The following plants reported extraction and treatment:
- DE006_a{4}, DE006_a{5} and DE006_a{6}: Collection of off-gases from hand grinding processes. Permanent emission monitoring. Off-gas treatment using a gate filter and bag filter. Shutdown of the plant when emission limit values are exceeded.
- ES008_a{1}: Capture and treatment of emissions from mechanical processes, e.g. blasting. Mechanical filters for welding proccess,

Reference literature
[169, TWG 2021]

3.3.6.1.3 Storage and handling of raw materials

Description
Efficient storage and handling of raw materials and reduction of diffuse emissions to air. Structuring and management of covered storage areas.

Technical description
Different techniques and measures were reported for storage and handling of raw materials and prepared materials, which can be applied individually or in combination. By applying these techniques, raw materials are efficiently stored and handled. The materials are well sorted, remain in a dry area under the roof or in closed storage containers and can quickly be delivered to the heating furnace and the corresponding forging line. The personnel is trained to manage, handle and distribute the material in an efficient way. The raw material is prepared in an efficient way that is either automated or manually decentralised:

- Raw materials and auxiliaries materials classified and stored near the places where they will be used, in covered and paved locations.
- The storage area for material pieces has compartments according to length, on cement-paved floor.
- Storage personnel training, distribution of information materials and visible space signs.
- Sensible determination of the storage location for delivered raw material through consideration of the respective forging line; raw materials are preferably stored in the process hall. Minimisation of raw material transportation.
- Outdoor storage of raw materials in containers.
  [169, TWG 2021]

Achieved environmental benefits
- Efficient storage and handling of raw materials and reduced transportation distances.
- Reducing diffuse emissions to air.
- Reducing noise emissions.

Environmental performance and operational data
TWG, please provide information.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
TWG, please provide information.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.
In the SF data collection: DE007, ES008, PL009, DE001, DE002, DE003, DE004, DE005 and DE006

Reference literature
[169, TWG 2021]

3.3.6.2 Emissions to air (NO_X, CO) from heating and reheating

Description
Use of either electricity generated from fossil-free energy sources or an appropriate combination of the techniques given in Sections 3.3.6.2.1 to 3.3.6.2.8 below.

Technical description
In order to reduce or control NO_X and CO emissions, different techniques are considered suitable and one or a combination of primary and/or process-integrated techniques can be applied (see Sections 3.3.6.2.1 to 3.3.6.2.8).

Achieved environmental benefits
Reduced NO_X emissions.

Environmental performance and operational data
No information provided. ***TWG, please provide information.***

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
TWG, please provide information.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[169, TWG 2021]

3.3.6.2.1 Use of a fuel or a combination of fuels with low NO_X formation potential

More information on the technique
See Section 3.2.1.7.4.

3.3.6.2.2 Combustion optimisation

Description
Measures taken to maximise the efficiency of energy conversion in the furnace while minimising emissions (in particular of CO). This is achieved by a combination of techniques including good design of the furnace, optimisation of the temperature (e.g. efficient mixing of the fuel and combustion air) and residence time in the combustion zone, and use of furnace automation and control.

Technical description
Maximisation of the efficiency of energy conversion in the furnace while minimising emissions (in particular of CO).

Elevated CO emissions mainly result from poor combustion and improper burning conditions in furnaces.

See the LCP BREF for more information. [178, COM 2017]

Achieved environmental benefits
Reduced CO emissions.

Environmental performance and operational data
TWG, please provide information.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
TWG, please provide information.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
In the SF data collection: ES008, PL009 and DE006

Reference literature
[169, TWG 2021], [178, COM 2017]

3.3.6.2.3 Furnace automation and control

See also Section 3.3.1.2.

3.3.6.2.4 Flue-gas recirculation

Description
Recirculation (external) of part of the flue-gas to the combustion chamber to replace part of the fresh combustion air, with the dual effect of lowering the temperature and limiting the O_2 content for nitrogen oxidation, thus limiting the NO_X generation.

Technical description
Flue-gas recirculation is a technique for limiting peak flame temperatures. Recirculating flue-gases into the combustion air will reduce the oxygen and lower flame temperatures, hence limiting the formation of thermal NO_X. It implies the supply of flue-gas from the furnace into the flame to reduce the oxygen content and therefore the temperature of the flame.

More information is available in the FMP BREF. [168, COM 2021]

Achieved environmental benefits
Reduced NO_X emissions.

Environmental performance and operational data
TWG, please provide information.

Cross-media effects
None.

Technical considerations relevant to applicability
Applicability to existing plants may be restricted by a lack of space.

Economics
TWG, please provide information.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
In the SF data collection: DE006, DE007, ES008 and PL009

Reference literature
[168, COM 2021], [169, TWG 2021]

3.3.6.2.5 Low-NO_X burners

More information on the technique
See Section 3.2.1.7.6.

3.3.6.2.6 Limiting the air preheating temperature

Description
Limiting the air preheating temperature leads to a decrease of the concentration of NO_X emissions. A balance has to be achieved between maximising heat recovery from the flue-gas and minimising NO_X emissions.

Technical description
Emission levels of NO_X increase with increasing preheating temperatures of combustion air. Thus limiting air preheating can be a measure to limit NO_X emissions.

On the other hand, the preheating of combustion air is a commonly applied measure to increase the energy efficiency of furnaces and to decrease fuel consumption. Limiting air preheating means that the unused energy content in the flue-gas is wasted and has to be compensated with higher fuel consumption.

Generally, plant operators are interested in reducing the fuel consumption as this implies a monetary benefit, but the reduction of fuel consumption can additionally reduce other air pollutants, such as CO_2 and particulates. Thus a balance may need to be achieved between energy efficiency and decreasing CO_2 emissions on one hand and increasing NO_X emissions on the other. When keeping air preheating temperatures high, the application of secondary NO_X reduction measures might be necessary.

More information is available in the FMP BREF. [168, COM 2021]

Achieved environmental benefits
Reducing NO_X emissions.

Environmental performance and operational data
TWG, please provide information.

Cross-media effects
Reduced energy efficiency.

Technical considerations relevant to applicability
Generally applicable.

Economics
TWG, please provide information.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
No information provided.

Reference literature
[169, TWG 2021]

3.3.6.2.7 Oxy-fuel combustion

More information on the technique: See Section 3.2.1.3.7.

More information is also available in the FMP BREF. [168, COM 2021]

3.3.6.2.8 Flameless combustion

Description
Flameless combustion is achieved by injecting fuel and combustion air separately into the combustion chamber of the furnace at high velocity, to suppress flame formation and reduce the formation of thermal NO_X while creating a more uniform heat distribution throughout the chamber. Flameless combustion can be used in combination with oxy-fuel combustion.

Technical description
Flameless combustion can be achieved using conventional air-fuelled furnaces equipped with a flameless burner or using oxy-fuel flameless burners.

<u>Flameless combustion</u>
Flameless combustion can be achieved with intense mixing of the fuel gas, the combustion air and the recirculated exhaust gases. Fuel gas and combustion air are injected separately into the combustion chamber at high velocity. Inside the combustion chamber, a very intensive internal flue-gas circulation mixes the combustion air, the fuel gas and the products of combustion. Under these conditions, flameless combustion occurs provided that the combustion temperature inside the furnace is above the auto-ignition temperature of the mixture (e.g. > 800 ºC using natural gas and air) and the flue-gas recirculation ratio is higher than three. [168, COM 2021]

With flameless combustion, the temperature peak of the flame front does not exist, reducing to a large extent the formation of NO_X in comparison with conventional burners. Another additional benefit provided by flameless combustion is that the fuel oxidises throughout the entire volume of the combustion chamber, providing a very homogeneous furnace temperature. With the uniform distribution, it is possible to maintain a higher average combustion chamber temperature, resulting in reduced heating time, and lower CO emissions since complete combustion is achieved. Finally, flameless combustion results in lower noise emissions and reduced thermal stress for the burner. [168, COM 2021]

Flameless combustion in combination with oxy-fuel
Flameless technology can be used in combination with the oxy-fuel technique. This technique involves the replacement of the combustion air with oxygen (> 90 % purity) which means less nitrogen to be heated and a reduction of the total exhaust gas volume, leading to increased energy efficiency.

Flameless oxy-fuel combustion is achieved by separately injecting the fuel and oxygen at high velocities into the furnace. [168, COM 2021]

Achieved environmental benefits
- Reduced NO_X emissions.
- Reduced CO emissions.
- Reduced noise emissions

Environmental performance and operational data
TWG, please provide information.

Cross-media effects
None.

Technical considerations relevant to applicability
Applicability to existing plants may be limited by furnace design (i.e. furnace volume, space for burners, distance between burners) and the need for a change of the furnace refractory lining. This technique is not applicable to furnaces operating at a temperature lower than the auto-ignition temperature required for flameless combustion.

Economics
Application of oxy-fuel burners requires the additional purchase or on-site production of oxygen. Accordingly, the flameless oxy-fuel technique is often only economically viable at plants where oxygen is available at a low price. [168, COM 2021]

Driving force for implementation
- Increased productivity.
- Energy savings.
- Legal requirements.
- Local conditions.

Example plants
No information provided.

Reference literature
[168, COM 2021], [169, TWG 2021]

3.3.7 Water use and waste water generation

3.3.7.1 Use of closed cooling circuits

Description
In order to optimise water consumption and to reduce the volume of waste water generated, closed cooling circuits are applied.

Technical description
Techniques and measures were reported for efficient use of water, waste water prevention/minimisation and waste water treatment to reduce emissions to water, which can be applied individually or in combination, such as minimisation of waste water generation in cooling by using a closed cooling circuit [148, Euroforge 2021].

Achieved environmental benefits
- Efficient water consumption.
- Reduction of emissions to water.

Environmental performance and operational data
TWG, please provide information.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
TWG, please provide information.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
In the SF data collection: DE007, ES008 and PL009

Reference literature
[169, TWG 2021]

3.3.7.2 Segregation of water streams

Description
Water streams (e.g. surface run-off water, process water) are collected separately, based on the pollutant content and on the required treatment techniques. Waste water streams that can be recycled without treatment are segregated from waste water streams that require treatment.

Technical description
A detailed technical description of a waste water collection and segregation system can be found in the CWW BREF [179, COM 2016].

Achieved environmental benefits
Reduced emissions to water.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Only applicable when waste water generation is identified in the inventory of inputs and outputs mentioned in Section 3.1.1.2.

Economics
No information provided.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
In the SF data collection: DE006, ES008

Reference literature
[169, TWG 2021], [179, COM 2016]

3.3.8 Emissions to water

3.3.8.1 Waste water treatment

3.3.8.1.1 Water management plan and water audits

Description
A water management plan and water audits are part of the EMS (see Section 3.1.1.1) and include:

- flow diagrams and water mass balances of the plant as part of the inventory of inputs and outputs mentioned in Section 3.1.1.2;
- establishment of water efficiency objectives;
- implementation of water optimisation techniques (e.g. control of water usage, reuse/recycling, detection and repair of leaks).

Water audits are carried out at least once every year to ensure that the objectives of the water management plan are met.

Technical description
A prerequisite of any programme to prevent unnecessary use of water is to firstly collect information on the installation and the volumes consumed in the various processes, as part of the collection of information on types, quantities, composition and sources of all waste streams.

As with water consumption, data at site level are already a good benchmark in determining whether water consumption is excessive and is a good baseline against which to measure improvements. In order to allow a process-specific analysis, water use is monitored and recorded at machine/process level and water meters are regularly maintained and calibrated.

Improved working praxis is applied to reduce water consumption. Production procedures are established and the personnel is trained, in order to avoid inappropriate working practices and the absence of automated control systems that can lead to significant wastage of water.

Achieved environmental benefits
Reduced water consumption.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Only applicable when waste water generation is identified in the inventory of inputs and outputs mentioned in Section 3.1.1.2.

Economics
No information provided.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
No information provided.

Reference literature
[169, TWG 2021]

3.3.8.2 Techniques for waste water treatment

Description
Techniques are described in Section 3.2.1.17. The objective is to reduce the volume of waste water generated as well as to improve water recyclability.

Technical description
Techniques and measures were reported for waste water prevention/minimisation and waste water treatment to reduce emissions to water, which can be applied individually or in combination, such as:

- pH and oils/fats monitoring at the outflow of waste water;
- industrial waste water treatment;
- reuse/recycling of process residues for waste water treatment. [169, TWG 2021]

Achieved environmental benefits
Reduced emissions to water.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Only applicable when waste water generation is identified in the inventory of inputs and outputs mentioned in Section 3.1.1.2.

Economics
No information provided.

Driving force for implementation
- Legal requirements.
- Local conditions.

Example plants
In the SF data collection: DE006 and ES009

Reference literature
[169, TWG 2021]

4 BEST AVAILABLE TECHNIQUES (BAT) CONCLUSIONS FOR THE SMITHERIES AND FOUNDRIES INDUSTRY

This chapter has been completely rewritten compared to the original SF BREF

Scope

These BAT conclusions concern the following activities specified in Annex I to Directive 2010/75/EU:

2.3. Processing of ferrous metals:
(b) operation of smitheries with hammers the energy of which exceeds 50 kilojoules per hammer, where the calorific power used exceeds 20 MW.

2.4. Operation of ferrous metal foundries with a production capacity exceeding 20 tonnes per day.

2.5. Processing of non-ferrous metals:
(b) melting, including the alloyage, of non-ferrous metals, including recovered products, and operation of non-ferrous metal foundries, with a melting capacity exceeding 4 tonnes per day for lead and cadmium or 20 tonnes per day for all other metals.

6.11 Independently operated treatment of waste water not covered by Directive 91/271/EEC, provided that the main pollutant load originates from the activities covered by these BAT conclusions.

These BAT conclusions also cover the following:

- Ferrous metal foundries employing continuous casting processes for the production of grey or nodular iron castings at or near their final shape.
- Non-ferrous metal foundries using alloyed ingots, scrap, recovered products or liquid metal for the production of castings at or near their final shape.
- The combined treatment of waste water from different origins, provided that the waste water treatment is not covered by Directive 91/271/EEC and that the main pollutant load originates from the activities covered by these BAT conclusions.
- The coating of moulds and cores in ferrous and non-ferrous metal foundries.
- The storage, transfer and handling of materials, including the storage and handling of scrap and sand in foundries.
- Combustion processes directly associated with the activities covered by these BAT conclusions provided that the gaseous products of combustion are put into direct contact with material (such as direct feedstock heating or direct feedstock drying).

These BAT conclusions do not cover the following:

- The continuous casting of iron and/or steel (i.e. to produce thin slabs, thin strips, and sheets). This is covered by the BAT conclusions for Iron and Steel production (IS).
- The production of semi-finished non-ferrous metal products requiring further forming. This is covered by the BAT conclusions for the Non-Ferrous Metals industries (NFM).
- Cadmium, titanium and precious metal foundries, as well as bell and art casting.
- The coating of castings. This may be covered by the BAT conclusions for the Surface Treatment Using Organic Solvents including Wood and Wood Products Preservation with Chemicals.
- Forging presses.
- Rolling mills. This is covered by the BAT conclusions for Ferrous Metals Processing Industry (FMP).

Other BAT conclusions and reference documents which could be relevant for the activities covered by these BAT conclusions are the following:

- Large Combustion Plants (LCP);
- Surface Treatment of Metals and Plastics (STM);
- Waste Treatment (WT);
- Monitoring of Emissions to Air and Water from IED Installations (ROM);
- Economics and Cross-Media Effects (ECM);
- Emissions from Storage (EFS);
- Energy Efficiency (ENE);

These BAT conclusions apply without prejudice to other relevant legislation, e.g. on the registration, evaluation, authorisation and restriction of chemicals (REACH), on classification, labelling and packaging of substances and mixtures (CLP).

Definitions

For the purposes of these BAT conclusions, the following **definitions** apply.

General terms	
Term used	**Definition**
Casting	A metal workpiece, produced using a casting process, which is ejected or released out of a mould.
Casting process	Pouring molten metal into the cavity of a mould. The molten metal is subsequently allowed to solidify.
Centrifugal casting	Molten metal is poured into a preheated rotating mould, placed either vertically or horizontally depending on the product shape. After pouring, the mould rotates around its central axis creating a centrifugal force which displaces the molten metal towards the periphery forcing it to deposit on the walls.
Ceramic shell moulding	A polystyrene model is covered by a thin ceramic shell made with a mixture of ethyl silicate and refractory sand. The shell is hardened using ammonia and sintered at around 1 000 ºC to cure the shell and eliminate the polystyrene by pyrolysis. The molten metal is then poured into the ceramic shell.
Channelled emissions	Emissions of pollutants into the environment through any kind of duct, pipe, stack, etc.
Cold-setting processes	Curing processes for moulds and cores where the sand binder hardens at ambient temperature. Curing begins immediately after the last component of the sand binder formulation is introduced in the mix.
Continuous casting	Molten metal is cast into a water-cooled die that is open at the bottom or at the side. Through intensive cooling, the outside of the metal product solidifies while it is slowly pulled out of the mould. A burner cuts the product (e.g. bars, tubes and profiles) to the desired product length.
Continuous measurement	Measurement using an automated measuring system permanently installed on site.
Core-making	Core-making consists of producing cores which can be solid or hollow. Cores are inserted into the mould to provide the internal cavities of the casting before the mould halves are joined.
Diffuse emissions	Non-channelled emissions to air.
Direct discharge	Discharge to a receiving water body without further downstream waste water treatment.
Existing plant	A plant that is not a new plant.
Feedstock	Any metal input entering the smitheries production process.
Finishing	In foundries, this includes a number of mechanical operations carried out after the casting process including deburring, abrasive cutting, chiselling, needling, fettling, slide grinding, shot blasting and welding. In smitheries, this includes fettling, deburring, machining, cutting and chipping.
Flue-gas	The exhaust gas exiting a combustion unit.
Forging	Forging is a deformation and metal-shaping process using heating (at temperatures below the recrystallisation temperatures of metals) and hammers (e.g. pneumatic, steam-driven, mechanical, electrical, hydraulic).
Gas-hardening processes	Curing processes for cores where a catalyst or hardener is injected in a gaseous form in the core box.
Gravity die-casting	Molten metal is poured directly from a ladle into a die under gravity. After solidification, the die is opened and the metal workpiece is released.
Green sand	Mixture of sand, clay (e.g. bentonite) and additives (e.g. coal dust, cereal binders) used for mould making.
Hazardous substances	Hazardous substances as defined in point 18 of Article 3 of Directive 2010/75/EU.
Heat treatment	A thermal process (e.g. annealing, tempering, austempering), carried out after hammering, intended to give a workpiece its required metallurgical properties.
Heating/reheating	A thermal process used to raise the temperature of the feedstock before hammering.
High-pressure die-casting	Molten metal is forced under pressure into a sealed mould cavity. It is held in place by a powerful compressive power until the metal solidifies. After solidification, the die is opened and the metal workpiece is released.

Hot-curing processes	Curing processes for cores where the sand binder hardens into a heated core box.
Indirect discharge	A discharge that is not a direct discharge.
Internal scrap	Internal scrap consists of gates, risers, defective castings, and other metal pieces generated within the installation.
Investment casting	A pattern of the part to be cast is fabricated using wax, which is then dipped into a fine ceramic slurry containing silica and alumina. The mould is dried and heated inside an oven to melt out the wax, leaving a ceramic shell for moulding.
Liquid metal output	The amount of liquid metal produced in the melting furnaces. This does not include remelting.
Lost foam casting	Foam patterns of the parts to be cast, made of expanded polymers (e.g. expanded polystyrene), are produced using automated moulding machines and assembled together into clusters. The clusters are subsequently invested in unbonded sand.
Low-pressure die-casting	Molten metal is transferred from an airtight furnace through a rising tube into a metal die. The molten metal is pushed upwards into the die under low gas pressure. After solidification, the gas pressure is released allowing the rising tube to fall back into the furnace, the die is opened and the casting is released.
Major plant upgrade	A major change in the design or technology of a plant with major adjustments or replacements of the process and/or abatement technique(s) and associated equipment.
Mass flow	The mass of a given substance or parameter which is emitted over a defined period of time.
Metal melting	The production of ferrous or non-ferrous molten metal using furnaces. This also includes remelting of molten metal and heat conservation of molten metal in holding furnaces.
Moulding	Moulding consists of making a mould into which the molten metal will be poured.
Natural sand	Mixture composed of silica sand (e.g. 85 %), clay (e.g. 15 %) and water. Generally, no other additives are mixed.
New plant	A plant first permitted at the site of the installation following the publication of these BAT conclusions or a complete replacement of a plant following the publication of these BAT conclusions.
Nodular iron	Cast iron with carbon in nodular/spheroidal shape, commonly referred to as ductile iron.
Nodularisation	Magnesium treatment of cast iron to change the carbon particles into a nodular/spheroidal shape.
Operational material efficiency	The total yearly amount (expressed in t) of final castings without defects divided by the total yearly amount of liquid metal output.
Periodic measurement	Measurement at specified time intervals using manual or automated methods.
Plant	All parts of an installation covered by the scope of these BAT conclusions and any other directly associated activities which have an effect on consumption and/or emissions. Plants may be new plants or existing plants.
Process chemicals	Substances and/or mixtures as defined in Article 3 of Regulation EC/1907/2006 and used in the process(es). Process chemicals may contain hazardous substances and/or substances of very high concern.
Refining of steel	Steel treatment process to remove carbon (decarburisation) from pig iron (primary refining) followed by removal of impurities.
Residue	Substance or object generated by the activities covered by the scope of these BAT conclusions as waste or by-product.
Sand reconditioning	Any mechanical operation associated with the preparation and reconditioning of green and/or natural sand. This includes screening, removing tramp metal, separating and removing fines and oversized agglomerates. The sand is then cooled and sent to storage/reuse.
Sand regeneration	Any mechanical and/or thermal operation associated with the regeneration of chemically bonded sand in order to remove the residual binders. This includes an initial mechanical step (e.g. crushing, screening) followed by mechanical (e.g. grinding wheel, impact drum) and/or thermal (e.g. fluidised bed or rotary furnaces) processes.
Sensitive receptors	Areas which need special protection, such as: - residential areas; - areas where human activities are carried out (e.g. neighbouring workplaces, schools, day-care centres, recreational areas, hospitals or nursing homes).

Substances of very high concern	Substances as defined in Article 57 and included in the Candidate List of Substances of Very High Concern, according to the REACH Regulation ((EC) No. 1907/2006).
Surface run-off water	Water from precipitation that flows over land or impervious surfaces, such as paved streets, storage areas and rooftops, and does not soak into the ground.
Treatment of molten metal	Refining operations in aluminium melting processes which include degassing, modification and grain refining, and fluxing. Degassing (i.e. removal of dissolved hydrogen using nitrogen) is often combined with cleaning (i.e. removal of alkali or alkaline earth metal such as Ca) using Cl_2 gas.
Valid hourly (or half-hourly) average	An hourly (or half-hourly) average is considered valid when there is no maintenance or malfunction of the automated measuring system.

Pollutants and parameters	
Term used	**Definition**
B[a]P	Benzo[a]pyrene
Cd	The sum of cadmium and its compounds, dissolved or bound to particles, expressed as Cd.
Cl_2	Elemental chlorine.
CO	Carbon monoxide.
COD	Chemical oxygen demand. Amount of oxygen needed for the total chemical oxidation of the organic matter to carbon dioxide using dichromate. COD is an indicator for the mass concentration of organic compounds.
Cr	The sum of chromium and its compounds, dissolved or bound to particles, expressed as Cr.
Dust	Total particulate matter (in air).
Fe	The sum of iron and its compounds, dissolved or bound to particles, expressed as Fe.
HCl	Hydrogen chloride.
HF	Hydrogen fluoride.
Hg	The sum of mercury and its compounds, dissolved or bound to particles, expressed as Hg.
HOI	Hydrocarbon oil index. The sum of compounds extractable with a hydrocarbon solvent (including long-chain or branched aliphatic, alicyclic, aromatic or alkyl-substituted aromatic hydrocarbons).
Mg	Magnesium.
MgO	Magnesium oxide.
MgS	Magnesium sulphide.
$MgSO_4$	Magnesium sulphate.
NH_3	Ammonia.
Ni	The sum of nickel and its compounds, dissolved or bound to particles, expressed as Ni.
NO_X	The sum of nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2.
PCDD/F	Polychlorinated dibenzo-p-dioxins/furans.
Pb	The sum of lead and its compounds, dissolved or bound to particles, expressed as Pb.
SO_2	Sulphur dioxide.
TOC	Total organic carbon, expressed as C (in water); includes all organic compounds.
TSS	Total suspended solids. Mass concentration of all suspended solids (in water), measured via filtration through glass fibre filters and gravimetry.
TVOC	Total volatile organic carbon, expressed as C (in air).
Zn	The sum of zinc and its compounds, dissolved or bound to particles, expressed as Zn.

Acronyms

For the purposes of these BAT conclusions, the following **acronyms** apply.

Acronym	Definition
AOX	Adsorbable organically bound halogens
CBC	Cold blast cupola
CMS	Chemicals management system
DMEA	N,N-Dimethylethanamine
DMIPA	N,N-Dimethyl-2-propanamine
DMPA	N,N-Dimethyl-1-propanamine
EAF	Electric arc furnace
EMS	Environmental management system
EPA	Expanded polystyrene
ESP	Electrostatic precipitator
HBC	Hot blast cupola
HPDC	High-pressure die-casting
NFM	Non-ferrous metal
OME	Operational material efficiency
OTNOC	Other than normal operating conditions
PMMA	Polymethyl methacrylate
TEA	Triethylamine
TMA	Trimethylamine
VOC	Volatile organic compound

General considerations

Best Available Techniques

The techniques listed and described in these BAT conclusions are neither prescriptive nor exhaustive. Other techniques may be used that ensure at least an equivalent level of environmental protection.

Unless otherwise stated, the BAT conclusions are generally applicable.

[NOTE: Whilst cross-references are provided to other parts of this document in order to aid the work of the TWG, they will not be included in the final BAT conclusions themselves. Such cross-references are consequently displayed in italics in square brackets.]

[NOTE: In order to avoid repetition, this section contains general considerations that are essential to the understanding of the BAT conclusions taken as a stand-alone document, such as:

- *reference conditions for emissions to air (e.g. dry gas, standard temperature/pressure);*
- *averaging periods;*
- *sampling times;*
- *conversions to reference conditions;*
- *units in which environmental performance levels are expressed.]*

Emission levels associated with the best available techniques (BAT-AELs) and indicative emission levels for emissions to air

The BAT-AELs and indicative emission levels for emissions to air given in these BAT conclusions refer to concentrations (mass of emitted substances per volume of waste gas) under the following standard conditions: dry gas at a temperature of 273.15 K and a pressure of 101.3 kPa, without correction to a reference oxygen level, and expressed in the unit mg/Nm^3 or ng WHO-TEQ/Nm^3.

For averaging periods of BAT-AELs and indicative emission levels for channelled emissions to air, the following definitions apply.

Type of measurement	Averaging period	Definition
Continuous	Daily average	Average over a period of 1 day based on valid hourly or half-hourly averages.
Periodic	Average over the sampling period	Average value of three consecutive samplings/measurements of at least 30 minutes each ([1]).
([1]) For any parameter where, due to sampling or analytical limitations and/or due to operational conditions (e.g. batch processes), a 30-minute sampling/measurement and/or an average of three consecutive samplings/measurements is inappropriate, a more representative sampling/measurement procedure may be employed. For PCDD/F, one sampling period of 6 to 8 hours is used.		

When the waste gases of two or more sources (e.g. furnaces) are discharged through a common stack, the BAT-AELs apply to the combined discharge from the stack.

For the purpose of calculating the mass flows in relation to BAT 12 and BAT 48, where waste gases with similar characteristics, e.g. containing the same (type of) substances/parameters, and discharged through two or more separate stacks could, in the judgement of the competent authority, be discharged through a common stack, these stacks shall be considered as a single stack.

Emission levels associated with the best available techniques (BAT-AELs) for emissions to water

Emission levels associated with the best available techniques (BAT-AELs) for emissions to water given in these BAT conclusions refer to concentrations (mass of emitted substances per volume of water), expressed in mg/l or µg/l.

Averaging periods associated with the BAT-AELs refer to either of the following two cases:

- In the case of continuous discharge, daily average values, i.e. 24-hour flow-proportional composite samples.
- In the case of batch discharge, average values over the release duration taken as flow-proportional composite samples, or, provided that the effluent is appropriately mixed and homogeneous, a spot sample taken before discharge.

Time-proportional composite samples can be used provided that sufficient flow stability is demonstrated. Alternatively, spot samples may be taken, provided that the effluent is appropriately mixed and homogeneous.

The BAT-AELs apply at the point where the emission leaves the installation.

Other environmental performance levels associated with the best available techniques (BAT-AEPLs)

BAT-AEPLs for specific energy consumption (energy efficiency)

The BAT-AEPLs for specific energy consumption refer to yearly averages calculated using the following equation:

$$\text{specific energy consumption} = \frac{\text{energy consumption rate}}{\text{activity rate}}$$

where:

energy consumption rate: total amount of heat (generated from primary energy sources) and electricity consumed by the plant, expressed in kWh/year; and

activity rate: total amount of liquid metal output (foundries) or total amout of feedstock (smitheries), expressed in t/year.

BAT-AEPLs for specific water consumption in foundries

The BAT-AEPLs for specific water consumption refer to yearly averages calculated using the following equation:

$$\text{specific water consumption} = \frac{\text{water consumption rate}}{\text{activity rate}}$$

where:

water consumption rate: total amount of water consumed by the plant excluding:

- recycled and reused water, and
- cooling water used in once-through cooling systems, and
- water for domestic-type usage,

expressed in m^3/year; and,

activity rate: total amount of liquid metal output, expressed in t/year.

BAT-AEPLs for specific amount of waste sent for disposal in foundries

The BAT-AEPLs for specific amount of residue sent for disposal refer to yearly averages calculated using the following equation:

$$\text{specific amount of residue sent for disposal} = \frac{\text{rate of residue sent for disposal}}{\text{activity rate}}$$

where:

rate of residue sent for disposal:	total amount of residue sent for disposal, expressed in kg/year; and
activity rate:	total amount of liquid metal output, expressed in t/year.

BAT-AEPLs for operational material efficiency (OME) in foundries

The BAT-AEPLs for operational material efficiency (OME) refer to yearly averages calculated using the following equation:

$$\text{operational material efficiency (OME)} = \frac{\text{good casting rate}}{\text{activity rate}}$$

where:

good casting rate:	total amount of castings produced without defects, expressed in t/year; and
activity rate:	total amount of liquid metal output, expressed in t/year.

BAT-AEPLs for sand regeneration in foundries

The BAT-AEPLs for sand regeneration refer to yearly averages calculated using the following equation:

$$\text{sand regeneration ratio} = \frac{\text{amount of regenerated sand}}{\text{total amount of sand used}}$$

where:

amount of regenerated sand:	total amount of regenerated sand, expressed in t/year; and
total amount of sand used:	total amount of sand used, expressed in t/year.

4.1 General BAT conclusions

4.1.1 Overall environmental performance

Note to the TWG: the following description of the general EMS features (i. to xx.) is based on standard text agreed at the level of the IED Article 13 Forum and used in recent documents such as the BAT conclusions for FMP, TXT, SA and WGC. The possibilities for changes are therefore limited to the section dealing specifically with SF issues (from xxi. onward).

BAT 1. In order to improve the overall environmental performance, BAT is to elaborate and implement an environmental management system (EMS) that incorporates all of the following features:

xxx. commitment, leadership, and accountability of the management, including senior management, for the implementation of an effective EMS;

xxxi. an analysis that includes the determination of the organisation's context, the identification of the needs and expectations of interested parties, the identification of characteristics of the installation that are associated with possible risks for the environment (or human health) as well as of the applicable legal requirements relating to the environment;

xxxii. development of an environmental policy that includes the continuous improvement of the environmental performance of the installation;

xxxiii. establishing objectives and performance indicators in relation to significant environmental aspects, including safeguarding compliance with applicable legal requirements;

xxxiv. planning and implementing the necessary procedures and actions (including corrective and preventive actions where needed), to achieve the environmental objectives and avoid environmental risks;

xxxv. determination of structures, roles and responsibilities in relation to environmental aspects and objectives and provision of the financial and human resources needed;

xxxvi. ensuring the necessary competence and awareness of staff whose work may affect the environmental performance of the installation (e.g. by providing information and training);

xxxvii. internal and external communication;

xxxviii. fostering employee involvement in good environmental management practices;

xxxix. establishing and maintaining a management manual and written procedures to control activities with significant environmental impact as well as relevant records;

xl. effective operational planning and process control;

xli. implementation of appropriate maintenance programmes;

xlii. emergency preparedness and response protocols, including the prevention and/or mitigation of the adverse (environmental) impacts of emergency situations;

xliii. when (re)designing a (new) installation or a part thereof, consideration of its environmental impacts throughout its life, which includes construction, maintenance, operation and decommissioning;

xliv. implementation of a monitoring and measurement programme; if necessary, information can be found in the Reference Report on Monitoring of Emissions to Air and Water from IED Installations;

xlv. application of sectoral benchmarking on a regular basis;

xlvi. periodic independent (as far as practicable) internal auditing and periodic independent external auditing in order to assess the environmental performance and to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained;

xlvii. evaluation of causes of nonconformities, implementation of corrective actions in response to nonconformities, review of the effectiveness of corrective actions, and determination of whether similar nonconformities exist or could potentially occur;

xlviii. periodic review, by senior management, of the EMS and its continuing suitability, adequacy and effectiveness;
xlix. following and taking into account the development of cleaner techniques.

Specifically for the smitheries and foundries industry, BAT is also to incorporate the following features in the EMS:

l. an inventory of inputs and outputs (see BAT 2);
li. a chemicals management system (see BAT 3);
lii. a plan for the prevention and control of leaks and spillages (see BAT 4 (a));
liii. an OTNOC management plan (see BAT 5);
liv. an energy efficiency plan (see BAT 7);
lv. a water management plan (see BAT 35);
lvi. a noise and/or vibration management plan (see BAT 8);
lvii. a residues management plan (see BAT 10);
lviii. an odour management plan for foundries (see BAT 32).

Note
Regulation (EC) No 1221/2009 establishes the European Union eco-management and audit scheme (EMAS), which is an example of an EMS consistent with this BAT.

Applicability
The level of detail and the degree of formalisation of the EMS will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

[This BAT conclusion is based on information given in BREF Section 3.1.1.1]

BAT 2. In order to improve the overall environmental performance, BAT is to establish, maintain and regularly review (including when a significant change occurs) an inventory of inputs and outputs as part of the EMS (see BAT 1), that incorporates all of the following features:

(i) information about the production processes, including:
  (a) simplified process flow sheets that show the origin of the emissions to air, water and soil;
  (b) descriptions of process-integrated techniques and waste water/waste gas treatment techniques to prevent or reduce emissions, including their performance (e.g. abatement efficiency);
(ii) information about the quantity and characteristics of raw materials (e.g. scrap, feedstock) and fuels (e.g. coke) used;
(ii) information about water consumption and usage (e.g. flow diagrams and water mass balances);
(iii) information about energy consumption and usage;
(iv) information about the characteristics of the waste water streams, such as:
  (a) average values and variability of flow, pH, temperature and conductivity;
  (b) average concentration and mass flow values of relevant substances (e.g. total suspended solids, TOC or COD, hydrocarbon oil index, metals) and their variability;
(v) information about the quantity and characteristics of the process chemicals used:
  (a) the identity and the characteristics of process chemicals, including properties with adverse effects on the environment and/or human health;
  (b) the quantities of process chemicals used and the location of their use;
(vi) information about the characteristics of the waste gas streams, such as:
  (a) average values and variability of flow and temperature;
  (b) average concentration and mass flow values of relevant substances (e.g. dust, NO_X, SO_2, CO, metals) and their variability;

(c) presence of other substances that may affect the waste gas treatment system (e.g. oxygen, nitrogen, water vapour) or installation safety;

(vii) information about the quantity and charactersistics of residues/waste generated.

Applicability

The level of detail and the degree of formalisation of the inventory will generally be related to the nature, scale and complexity of the plant, and the range of environmental impacts it may have.

[This BAT conclusion is based on information given in BREF Section 3.1.1.2]

BAT 3. In order to improve the overall environmental performance, BAT is to elaborate and implement a chemicals management system (CMS), as part of the EMS (see BAT 1), that incorporates all of the following features:

(i) A policy to reduce the consumption of and risks associated with process chemicals, including a procurement policy to select less harmful process chemicals and their suppliers with the aim of minimising the use of and risks associated with hazardous substances and substances of very high concern as well as to avoid the procurement of an excess amount of process chemicals. The selection of process chemicals is based on:

a) a comparative analysis of their bioeliminability/biodegradability, eco-toxicity and potential to be released into the environment in order to reduce emissions to the environment;
b) a characterisation of the risks associated with the process chemicals, based on the chemicals' hazards classification, pathways through the plant, potential release and level of exposure;
c) the potential for recovery and reuse (see BAT 17(f));
d) regular (e.g. annual) analysis of the potential for substitution with the aim to identify potentially new available and safer alternatives to the use of hazardous substances and substances of very high concern; this may be achieved by changing process(es) or using other process chemicals with no or lower environmental impacts, see BAT 11 for foundries);
e) anticipatory monitoring of regulatory changes related to hazardous substances and substances of very high concern, and safeguarding compliance with applicable legal requirements.

The inventory of process chemicals (see BAT 2) may be used to provide and keep the information needed for the selection of process chemicals.

(ii) Goals and action plans to avoid or reduce the use of and risks associated with hazardous substances and substances of very high concern.

(iii) Development and implementation of procedures for the procurement, handling, storage, and use of process chemicals, disposal of waste containing process chemicals and return of unused process chemicals, to prevent or reduce emissions to the environment (e.g. see BAT 4).

Applicability

The level of detail and degree of formalisation of the CMS will generally be related to the nature, scale and complexity of the plant.

[This BAT conclusion is based on information given in BREF Section 3.1.1.3]

BAT 4. In order to prevent or reduce emissions to soil and groundwater as well as to improve the overall performance of the handling and storage of process chemicals, BAT is to use all of the techniques given below.

Technique		Description	Applicability
a	Set-up and implementation of a plan for the prevention and control of leaks and spillages	A plan for the prevention and control of leaks and spillages is part of the EMS (see BAT 1) and includes, but is not limited to: • site incident plans for small and large spillages; • identification of the roles and responsibilities of persons involved; • ensuring staff are environmentally aware and trained to prevent and deal with spillage incidents; • identification of areas at risk of spillage and/or leaks of hazardous materials and substances of very high concern, and ranking them according to the risk; • identification of suitable spillage containment and clean-up equipment and regularly ensuring it is available, in good working order and close to points where these incidents may occur; • waste management guidelines for dealing with waste arising from spillage control; • regular (at least on an annual basis) inspections of storage and handling areas, testing and calibration of leak detection equipment and prompt repair of leaks from valves, glands, flanges, etc.	The level of detail of the plan will generally be related to the nature, scale and complexity of the plant, as well as to the type and quantity of liquids used.
b	Structuring and management of process areas and raw material storage areas	Techniques include: • Impermeable (for example, cemented) floor for process areas and for scrap/feedstock yards; • separate storage for various types of raw materials, close to the production lines. This can be achieved using e.g. compartments or boxes in the storage areas, bunkers.	Generally applicable.
c	Prevention of the contamination of surface run-off water	Production areas and/or areas where process chemicals, residues or waste are stored or handled are protected against surface run-off water. This is achieved by using at least the following techniques: • drainage channels and/or an outer kerb bund around the plant; • roofing with roof guttering of process and/or storage areas.	Generally applicable.
d	Collection of potentially contaminated surface run-off water	Surface run-off water from areas that are potentially contaminated with process chemicals is collected separately. Collected waste water is discharged only after appropriate measures are taken, e.g. monitoring (see BAT 13), treatment (see BAT 36).	Generally applicable.
e	Safe handling and storage of process chemicals	This includes: • storage in roofed and ventilated areas with floors impermeable to the liquids concerned; • use of oil-tight trays or cellars for hydraulic stations and oil- or grease-lubricated equipment; • collection of spilled liquid; • loading/unloading areas for process chemicals, lubricants and coatings, etc. are designed and constructed in such a way that potential leaks and spillages are contained and sent to on-site treatment (see BAT 28) or off-site treatment. • Highly flammable liquids (e.g. methyl formate,	Generally applicable.

		TEA, DMEA, mould coatings containing isopropyl alcohol) are stored separately from incompatible substances (e.g. oxidisers) in enclosed and well-ventilated storage areas.	
f	Good housekeeping	A set of measures aiming at preventing, or reducing, the generation of emissions (e.g. regular maintenance and cleaning of equipment, work surfaces, floors and transport routes, and containment as well as rapid clean-up of any spillages).	Generally applicable.

[This BAT conclusion is based on information given in BREF Section 3.1.1.4]

BAT 5. In order to reduce the frequency of the occurrence of OTNOC and to reduce emissions during OTNOC, BAT is to set up and implement a risk-based OTNOC management plan as part of the EMS (see BAT 1) that includes all of the following elements:

i. identification of potential OTNOC (e.g. failure of equipment critical to the protection of the environment ('critical equipment')), of their root causes and of their potential consequences;
ii. appropriate design of critical equipment (e.g. off-gas treatment, waste water treatment);
iii. set-up and implementation of an inspection and preventive maintenance plan for critical equipment (see BAT 1 xii.);
iv. monitoring (i.e. estimating or, where possible, measuring) and recording of emissions during OTNOC and of associated circumstances;
v. periodic assessment of the emissions occurring during OTNOC (e.g. frequency of events, duration, amount of pollutants emitted) and implementation of corrective actions if necessary;
vi. regular review and update of the list of identified OTNOC under point i. following the periodic assessment of point v.;
vii. regular testing of backup systems.

Applicability
The level of detail and degree of formalisation of the OTNOC management plan will generally be related to the nature, scale and complexity of the plant, and the range of environmental impacts it may have.

[This BAT conclusion is based on information given in BREF Section 3.1.1.5]

4.1.2 Monitoring

BAT 6. BAT is to monitor at least once every year:

- **the yearly consumption of water, energy and materials used, including process chemicals;**
- **the yearly generation of waste water;**
- **the yearly amount of each type of materials recovered and/or reused;**
- **the yearly amount of each type of residues generated and of each type of waste sent for disposal.**

Description
Monitoring preferentially includes direct measurements. Calculations or recording, e.g. using suitable meters or invoices, can also be used. The monitoring is broken down to the most appropriate level (e.g. to process or plant level) and considers any significant changes in the process or plant.

[This BAT conclusion is based on information given in BREF Section 3.1.2]

4.1.3 Energy efficiency

BAT 7. In order to increase the overall energy efficiency of the plant, BAT is to use all of the techniques given below.

Technique		Description	Applicability
Management techniques			
b.	Energy efficiency plan and energy audits	An energy efficiency plan is part of the EMS (see BAT 1) and entails defining and monitoring the specific energy consumption of the activity/processes, setting objectives in terms of energy efficiency (e.g. kWh/t liquid metal) and implementing actions to achieve these objectives. Energy audits are carried out at least once every year to ensure that the objectives of the energy management plan are met.	The level of detail of the energy efficiency plan, of the energy audits and of the energy balance record will generally be related to the nature, scale and complexity of the plant and the types of energy sources used.
c.	Energy balance record	Drawing up an energy balance record once every year which provides a breakdown of the energy consumption and generation (including energy export) by the type of energy source (e.g. electricity, natural gas, renewable energy, imported heat and/or cooling). This includes: • defining the energy boundary of the processes; • information on energy consumption in terms of delivered energy; • information on energy exported from the plant; • energy flow information (e.g. Sankey diagrams or energy balances) showing how the energy is used throughout the processes.	
Process and equipment selection and optimisation			
d.	Use of general energy-saving techniques	This includes techniques such as: • burner maintenance and control; • energy-efficient motors; • energy-efficient lighting; • optimising steam distribution systems; • regular inspection and maintenance of the steam distribution systems to prevent or reduce steam leaks; • process control systems; • variable speed drives; • optimising air conditioning and building heating.	Generally applicable.

[This BAT conclusion is based on information given in BREF Section 3.1.3]

4.1.4 Noise and vibrations

BAT 8. In order to prevent or, where that is not practicable, to reduce emissions of noise and vibrations, BAT is to set up, implement and regularly review a noise and/or vibration management plan, as part of the EMS (see BAT 1), that includes all of the following elements:

- a protocol containing appropriate actions and timelines;
- a protocol for monitoring emissions of noise and/or vibrations;
- a protocol for responding to identified noise and vibration events, e.g. managing complaints and/or taking corrective actions;
- a noise and/or vibration reduction programme designed to identify the source(s), to measure/estimate noise and/or vibration exposure, to characterise the contributions of the sources and to implement prevention and/or reduction measures.

Applicability
The applicability is restricted to cases where a noise and/or vibration nuisance at sensitive receptors is expected and/or has been substantiated.

[This BAT conclusion is based on information given in BREF Sections 3.1.5]

BAT 9. In order to prevent or, where that is not practicable, to reduce noise emissions, BAT is to use one or a combination of the techniques given below.

Technique		Description	Applicability
a	Appropriate location of equipment and buildings	Increasing the distance between the emitter and the receiver, by using buildings as noise screens and by relocating equipment and/or buildings' exits or entrances.	For existing plants, the relocation of equipment and the exits or entrances of the buildings may not be applicable due to a lack of space and/or excessive costs.
b	Operational measures	These include at least the following: • inspection and maintenance of equipment; • closing of doors and windows of enclosed areas, if possible; • equipment operation by experienced staff; • avoidance of noisy activities at night, if possible; • provisions for noise control, during production and maintenance activities, transport and handling of feedstock and materials, e.g. reducing the number of material transfer operations, reducing the height from which pieces fall on to hard surfaces.	Generally applicable.
c	Low-noise equipment	This includes direct drive motors; low-noise compressors, pumps and fans; low-noise transportation equipment.	

Technique		Description	Applicability
d	Noise control equipment	This includes techniques such as: • use of noise reducers; • use of acoustic insulation of equipment; • enclosure of noisy equipment and processes (e.g. unloading of raw materials, hammering, compressors, fans, shake-out, finishing); • use of building materials with high sound insulation properties (e.g. for walls, roofs, windows, doors).	Applicability to existing plants may be limited by a lack of space.
e	Noise abatement	Inserting obstacles between emitters and receivers (e.g. protection walls, embankments).	Only applicable to existing plants, as the design of new plants should make this technique unnecessary. For existing plants, the insertion of obstacles may not be applicable due to a lack of space.

[This BAT conclusion is based on information given in BREF Section 3.1.5]

4.1.5 Residues

BAT 10. In order to increase material efficiency and reduce the amount of waste sent for disposal, BAT is to implement a residues management plan.

Description
A residues management plan is part of the EMS (see BAT 1) and comprises a set of measures aiming to:

I. minimise the generation of residues;
II. optimise the reuse, recycling and/or recovery of residues, and
III. ensure the proper disposal of waste.

Applicability
The level of detail and the degree of formalisation of the residues management plan will generally be related to the nature, scale and complexity of the plant.

[This BAT conclusion is based on information given in BREF Section 3.1.6]

4.2 BAT conclusions for foundries

4.2.1 General BAT conclusions for foundries

The BAT conclusions in this section apply in addition to the general BAT conclusions given in Section 4.1.

4.2.1.1 Hazardous substances and substances of very high concern

BAT 11. In order to prevent or reduce the use of hazardous substances and substances of very high concern in moulding and core-making with chemically bonded sand, BAT is to use alternative substances which are non- or less hazardous.

Description
Hazardous substances and substances of very high concern used in moulding and core-making are substituted by non-hazardous substances or – when this is not feasible – by less hazardous substances, by using for example:

- aliphatic organic (instead of aromatic) binders in moulding, see BAT 25 (j);
- non-aromatic solvents for cold-box core-making, see BAT 25 (h);
- inorganic binders in moulding and core-making, see BAT 25 (k);
- water-based coatings in moulding and core-making, see BAT 25 (l).

[This BAT conclusion is based on information given in BREF Section 3.2.1.1]

4.2.1.2 Monitoring of emissions

4.2.1.2.1 Monitoring of emissions to air

BAT 12. BAT is to monitor channelled emissions to air with at least the frequency given below, and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

Substance/ Parameter	Process(es) /source(s)	Foundry type	Standard(s)	Minimum monitoring frequency ([1])	Monitoring associated with
Amines	Core-making	All	No EN standard available	Once every year ([2])	BAT 26
	Casting, cooling and shake-out using lost moulds	All			BAT 27
Benzene	Core-making and moulding using lost moulds	All	No EN standard available		BAT 26
	Casting, cooling and shake-out using lost moulds				BAT 27
	Sand reconditioning and regeneration				BAT 31
B[a]P	Metal melting and ladle preheating	Cast iron	No EN standard available		BAT 38
Elemental chlorine (Cl_2)	Treatment of molten metal	Aluminium	No EN standard available		BAT 44
Carbon monoxide (CO)	Heat treatment	All	EN 15058)	Once every year	BAT 24
	Metal melting and ladle preheating				BAT 38 BAT 40 BAT 43
Dust	Heat treatment	All	EN 13284-1 ([3]) ([4])	Once every 6 months for any stack with a dust mass flow ≥ 0.1 kg/h ([5]). Once every year for any stack with a dust mass flow < 0.1 kg/h	BAT 24
	Metal melting and ladle preheating				BAT 38 BAT 40 BAT 43
	Nodularisation	Cast iron			BAT 39
	Refining	Steel			BAT 41
	Core-making and moulding using lost moulds	All			BAT 26
	Casting, cooling and shake-out using lost moulds	All			BAT 27
	Finishing	All			BAT 30
	Casting in permanent moulds	NFM			BAT 29
	Sand reconditioning and regeneration	All			BAT 31

Formaldehyde		Core-making and moulding using lost moulds	All	EN standard under development	Once every 6 months	BAT 26
		Casting, cooling and shake-out using lost moulds			Once every month	BAT 27
		Sand reconditioning and regeneration			Once every 6 months	BAT 31
Gaseous chlorides		Metal melting and ladle preheating	Cast iron and NFM	EN 1911	Once every year	BAT 38 BAT 43
Gaseous fluorides		Metal melting and ladle preheating	Cast iron and NFM	EN standard under development		BAT 38 BAT 43
Metals	Cadmium and its compounds	Metal melting and ladle preheating	All	EN 14385	Once every year ([2])	BAT 38 BAT 40 BAT 43
	Chromium and its compounds	Casting, cooling and shake-out using lost moulds	All			BAT 27
		Metal melting and ladle preheating	Cast iron			BAT 38
	Nickel and its compounds	Sand reconditioning and regeneration	All			BAT 31
		Metal melting and ladle preheating	All			BAT 38 BAT 40 BAT 43
	Lead and its compounds	Casting, cooling and shake-out using lost moulds	All			BAT 27
		Metal melting and ladle preheating	Cast iron and NFM			BAT 38 BAT 43
		Casting in permanent moulds	Lead		Once every 6 months	BAT 29
Nitrogen oxides (NO_X)		Heat treatment	All	EN 14792	Once every 6 months	BAT 24
		Sand reconditioning and regeneration				BAT 31
		Metal melting and ladle preheating				BAT 38 BAT 40 BAT 43
PCDD/F		Metal melting and ladle preheating ([6])	All	EN 1948-1, EN 1948-2, EN 1948-3		BAT 38 BAT 40 BAT 43
Phenol		Core-making and moulding using lost moulds	All	No EN standard available	Once every year ([2])	BAT 26
		Casting, cooling and shake-out using lost moulds				BAT 27
Sulphur dioxide (SO_2)		Sand reconditioning and regeneration	All	EN 14791	Once every 6 months	BAT 31
		Metal melting and ladle preheating ([6])	Cast iron and NFM			BAT 38 BAT 43
Total volatile organic carbon (TVOC)		Core-making and moulding using lost moulds	All	EN 12619		BAT 26

	Alternative casting processes (i.e. lost foam, ceramic shell casting)				BAT 28
	Casting, cooling and shake-out using lost moulds				BAT 27
	Sand reconditioning and regeneration				BAT 31
	Metal melting and ladle preheating (6)				BAT 38 BAT 40 BAT 43
	Low-pressure, high-pressure and gravity die-casting	NFM			BAT 29

(1) To the extent possible, the measurements are carried out at the highest expected emission state under normal operating conditions.
(2) The monitoring only applies when the substance concerned is identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.
(3) If measurements are continuous, the following generic EN standards apply instead: EN 15267-1, EN 15267-2, EN 15267-3, and EN 14181.
(4) If measurements are continuous, EN 13284-2 also applies.
(5) For any stack associated with a cupola furnace and with a dust mass flow > 0.5 kg/h, continuous monitoring applies.
(6) The monitoring does not apply when only electricity is used.

[This BAT conclusion is based on information given in BREF Section 3.2.1.2.1]

4.2.1.2.2 Monitoring of emissions to water

BAT 13. BAT is to monitor emissions to water with at least the frequency given below, and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

Substance(s)/parameter		Process(es)/sources	Standard(s)	Minimum monitoring frequency (1)	Monitoring associated with
Adsorbable organically bound halogens (AOX) (2)		Waste water from wet scrubbing of cupola off-gases	EN ISO 9562	Once every month	BAT 36
Biochemical oxygen demand (BOD_5) (3)		All processes	Various EN standards available (e.g. EN 1899-1, EN ISO 5815)		
Chemical oxygen demand (COD) (4)			No EN standard available		
Free cyanide (2)			Various EN standards available (i.e. EN ISO 14403-1 and -2)		
Hydrocarbon oil index (HOI) (4)			EN ISO 9377-2		
Metals/ metalloids	Arsenic (As) (2)		Various EN standards available (e.g. EN ISO 11885, EN ISO 15586, EN ISO 17294-2)		
	Cadmium (Cd) (2)				
	Chromium (Cr) (2)				
	Iron (Fe) (2)				
	Lead (Pb) (2)				
	Nickel (Ni) (2)				
	Zinc (Zn) (2)				
	Mercury (Hg) (2)		Various EN standards available (e.g. EN ISO 12846, EN ISO 17852)		
Phenol index (2)			EN ISO 14402		
Total organic carbon (TOC) (4)			EN 1484		
Total suspended solids (TSS)			EN 872		

(1) In the case of batch discharge less frequent than the minimum monitoring frequency, monitoring is carried out once per batch.
(2) The monitoring only applies when the substance/parameter is identified as relevant in the waste water stream based on the inventory of inputs and outputs mentioned in BAT 2.
(3) The monitoring only applies in the case of a direct discharge to a receiving water body.
(4) Either COD or TOC is monitored. TOC monitoring is the preferred option because it does not rely on the use of very toxic compounds.

[This BAT conclusion is based on information given in BREF Section 3.2.1.2.2]

4.2.1.3 Energy efficiency

BAT 14. In order to increase energy efficiency, BAT is to use all of the techniques (a) to (d), and an appropriate combination of techniques (e) to (m) given below.

Technique		Description	Applicability
Design and operation			
a.	Selection of an energy-efficient type of furnace	See Section 4.4.1.	Only applicable to new plants and/or major plant upgrades.
b.	Techniques for maximising the thermal efficiency of furnaces	See Section 4.4.1.	Generally applicable.
c.	Furnace automation and control	See Section 4.4.1.	Generally applicable.
d.	Use of clean scrap	See Section 4.4.1.	Generally applicable.
e.	Improving casting yield and decreasing scrap generation	See Section 4.4.1.	Generally applicable.
f.	Reducing energy losses/improving ladle preheating practices	This includes all of the following elements: • use of clean preheated ladles; • keep closed lid on ladles to preserve heat; • use of energy-efficient techniques for preheating ladles (e.g. flameless microporous burners or oxy-fuel burners); • use of large (as practically possible) ladles fitted with heat-retaining covers; • minimise the molten metal transfer from one ladle to another; • transfer the molten metal as quickly as possible.	Generally applicable.
g.	Oxy-fuel combustion	See Section 4.4.1.	Applicability to existing plants may be restricted by furnace design and the need for a minimum waste gas flow.
h.	Use of medium-frequency power in induction furnaces	Use of medium-frequency (250 Hz) induction furnaces instead of mains frequency (50 Hz) furnaces.	Generally applicable.
i.	Compressed air system optimisation	This includes all of the following measures: • applying an appropriate system maintainance to reduce leaks; • efficient monitoring of operating parameters such as flow, temperature, and pressure; • minimising the pressure drops; • applying efficient load management; • reducing the inlet air temperature; • using efficient compressor control system.	Generally applicable
j.	Microwave drying of cores for water-based coatings	Use of microwave drying ovens (e.g. with a frequency of 2 450 Hz) for drying cores coated with water-based coatings (see BAT 21 (f)), resulting in rapid and homogeneous drying of the entire core surface.	Generally applicable.
Heat recovery techniques			
k.	Scrap preheating	Scrap is preheated by blowing hot flue-gases directly onto it.	Generally applicable.

l.	Heat recovery from off-gases generated in furnaces	Waste heat from hot off-gases is recovered (e.g. through heat exchangers) and reused on site or off site (e.g. in thermal oil/hot water/heating circuits, for steam generation or for preheating of combustion air (see technique (n)). This may include the following: • Excess heat from cupola hot off-gases is used for example for steam production, thermal oil heating, water heating. • Excess heat from the furnace cooling system is used for example for drying of raw material, space heating, water heating. • In fuel-fired furnaces in aluminium foundries, excess heat is used for example for heating the premises and/or the water for the casting cleaning facility. • Low-grade heat is converted into electricity using high-molecular-weight fluids by using the Organic Rankine Cycle (ORC).	Generally applicable.
m.	Preheating of combustion air	See Section 4.4.1.	Generally applicable.

[This BAT conclusion is based on information given in BREF Section 3.2.1.3]

Further sector-specific techniques to increase energy efficiency are given in Sections 4.2.2.1 and 4.2.4.1 of these BAT conclusions.

Table 4.1: BAT-associated environmental performance levels (BAT-AEPLs) for specific energy consumption

Foundry type	Unit	BAT-AEPL (Yearly average)
Iron foundries for production of single castings	kWh/t of liquid metal	600-2 500
Iron foundries for serial production of castings		
Steel foundries – low alloy		2 300-3 500
Steel foundries – high alloy		1 300-4 000
Aluminium foundries		800-3 000
Lead foundries		200-600
Zinc foundries		1 000-2 600
Magnesium foundries		1 000-2 500
Copper, brass and bronze foundries		1 500-3 500

The associated monitoring is given in BAT 6.

4.2.1.4 Material efficiency

4.2.1.4.1 Storage and handling of residues, packaging and unused process chemicals

BAT 15. In order to prevent or reduce the environmental risk associated with the storage and handling of residues, packaging and unused process chemicals and to facilitate their reuse and/or recycling, BAT is to use all of the techniques given below.

Technique		Description
a.	Appropriate storage of various residue types	• Fabric filter dust is stored on impermeable surfaces, in enclosed areas and in closed containers/bags. • Other residue types (e.g. slag, dross, spent furnace refractory linings) are stored separately from each other on impermeable surfaces in covered areas protected from surface run-off water.
b.	Reuse of internal scrap	Reuse of internal scrap directly or after treatment. The degree of reuse of internal scrap depends on its content of impurities.
c.	Reuse/recycling of packaging	Process chemicals packaging is selected to facilitate its complete emptying (e.g. considering the size of the packaging aperture or the nature of the packaging material). After emptying, the packaging is reused, returned to the supplier or sent for material recycling. Preferably, process chemicals are stored in large containers.
d.	Return of unused process chemicals	Unused process chemicals (i.e. which remain in their original containers) are returned to their suppliers.

[This BAT conclusion is based on information given in BREF Section 3.2.1.4.1]

4.2.1.4.2 Operational material efficiency in the casting process

BAT 16. In order to increase material efficiency in the casting process, BAT is to use technique (a) and one or both of the techniques (b) and (c) given below.

Technique		Description
a.	Improving casting yield and decreasing scrap generation	See Section 4.4.2.
b.	Use of computer-aided simulation for casting, pouring and solidification	A computer simulation system is used to optimise the casting, pouring and solidification process, to minimise the number of defective castings and increase foundry productivity.
c.	Production of light-weight castings using topology optimisation	Use of topology optimisation (i.e. casting simulation by means of algorithms and computer programs) to reduce the product mass while meeting the product performance requirements.

Table 4.2: BAT-associated environmental performance levels (BAT-AEPLs) for operational material efficiency

Foundry type	Unit	BAT-AEPL (Yearly average)
Iron foundries for production of single castings	%	80-94
Iron foundries for serial production of castings		70-97
Steel foundries		60-100
NFM foundries (all types except HPDC) – Pb		94-97.5
NFM foundries (all types except HPDC) –metals other than Pb		60-98
NFM foundries (HPDC) – Mg		95-98
NFM foundries (HPDC) –metals other than Mg		60-97

The associated monitoring is given in BAT 6

[This BAT conclusion is based on information given in BREF Section 3.2.1.4.2]

4.2.1.4.3 Reduction of material consumption

BAT 17. In order to reduce material (e.g. chemicals, binders) consumption, BAT is to use an appropriate combination of the techniques given below.

Technique		Description	Applicability
Techniques for aluminium high-pressure die-casting			
a.	Separate spraying of release agent and water	See Section 4.4.2.	Generally applicable.
b.	Minimisation of release agent and water consumption	Measures to minimise the consumption of release agent and water include: • use of an automated spraying system; • optimisation of the release agent's dilution factor; • application of in-die cooling; • closed-mould application of release agent.	Generally applicable.
Techniques for processes using chemically bonded sand and core-making			
c.	Minimisation of binder and resin consumption	See Section 4.4.2.	Generally applicable.
d.	Minimisation of mould and core sand losses	Production parameters of the various product types are stored in an electronic database that allows easy changeover to new products with minimised losses in time and materials.	Generally applicable.
e.	Use of best practices for cold-setting processes	See Section 4.4.2.	Generally applicable.
f.	Recovery of amines from acid scrubbing water	When acid washing is used (e.g. using sulphuric acid) to treat the cold-box off-gases, amine sulphate is formed. The amines are recovered from the treatment of amine sulphate using sodium. This may take place on site of off site.	Applicability may be limited due to safety considerations (explosion hazard).
g.	Use of best practices for gas-hardening processes	See Section 4.4.2.	Generally applicable.
h.	Applying alternative moulding/core-making processes	Alternative moulding/core-making processes using no or reduced amount of binders include: • lost foam casting process; • ceramic shell moulding.	Applicability of the lost foam casting process to existing plants may be limited due to the required

			infrastructure modifications. Applicability of ceramic shell moulding may be restricted by product specifications (e.g. high surface finish).

[This BAT conclusion is based on information given in BREF Section 3.2.1.4.3],

4.2.1.4.4 Sand reconditioning and regeneration

BAT 18. In order to reduce the consumption of new sand and the generation of spent sand from sand reconditioning and regeneration in the lost mould casting process, BAT is to use one or an appropriate combination of the techniques given below.

	Technique	Description	Applicability
a.	Optimised reconditioning of green sand (breaking, separation, cooling)	Various techniques can be used for breaking the sand into its original grain size and for removing the fines, e.g. vibrator, drum, shot blasting. For cooling of reclaimed sand, techniques such as evaporative cooling or fluidised bed cooling can be used.	Generally applicable.
b.	Low-waste green sand reconditioning	Green sand reconditioning in aluminium foundries is carried out using a scanner for identifying impurities in green sand based on brightness/colour. These impurities are separated from green sand using an air blast pulse.	Generally applicable.
c.	Preparation of clay-bonded sand by vacuum mixing and cooling	See BAT 25 (b).	May not be applicable to existing green sand plants due to technical constraints (sand properties).
d.	Mechanical regeneration of cold-setting sand	Mechanical techniques (e.g. breaking of lumps, segregation of sand fractions) using crushers or mills are used to regenerate cold-setting sand.	May not be applicable to silicate sand.
e.	Cold mechanical regeneration of clay-bonded or chemically bonded sand using a grinding wheel	Use of a rotating grinding wheel to remove clay layers and chemical binders from used sand grains.	Generally applicable.
f.	Cold mechanical regeneration using an impact drum	Use of an impact drum with a spinning internal axis, equipped with small blades, for abrasive cleaning of sand grains.	Generally applicable.

g.	Cold regeneration using a pneumatic system	Removal of binders from the sand grains using abrasion and impact. The kinetic energy is provided by a compressed air stream.	Generally applicable.
h.	Thermal regeneration	Use of heat to burn binders and contaminants contained in chemically bonded and mixed sand. This is combined with an initial mechanical pretreatment to bring the sand to the correct grain size and remove any metallic contaminant. In the case of mixed sand, the share of chemically bonded sand should be high enough.	Generally applicable.
i.	Combined regeneration (mechanical-thermal-mechanical) for mixed organic-bentonite sands	After pretreatment (sieving, magnetic separation) and drying, sand is mechanically or pneumatically cleaned to remove part of the binder. In the thermal step, organic constituents are burnt and inorganic constituents are transferred to the dust or burned onto the grains. In a final mechanical treatment, these grain layers are removed mechanically or pneumatically and discarded as dust.	Generally applicable.
j.	Combined sand regeneration and heat treatment of aluminium castings	After pouring and solidification, moulds/casting units are loaded into the furnace. When the units reach a temperature > 420 °C, the binders are burnt, the cores/moulds disintegrate, and the castings undergo heat treatment. The sand falls at the bottom of the furnace for final cleaning in a heated fluidised bed. After cooling, the sand is reused in the core sand mixer without further treatment.	Generally applicable.
k.	Wet regeneration for green sand, silicate- or CO_2-bonded sands	Sand is mixed with water to produce a sludge. The removal of grain-bound binder residues is performed through intensive inter-particle rubbing of the sand grains. The binders are released into the wash water. The washed sand is dried, screened and finally cooled.	Generally applicable.
l.	Regeneration of sodium silicate sand (water glass) using a pneumatic system	Sand is heated to make the silicate layer brittle before the use of a pneumatic system (see technique (g). The regenerated sand is cooled before reuse.	Generally applicable.
m.	Internal reuse of core sand (polyurethane (cold-box) and furan resin-bonded)	Sand resulting from broken/faulty cores, and excess sand from the core-making machines (after hardening in a specific unit), are fed to a breaking unit. The resulting sand is mixed with new sand for the production of new cores.	Generally applicable.
n.	Reuse of dust from the green sand circuit in mould making	Dust is collected through the exhaust filtration from the shake-out installation and from the dosing and handling stations for dry green sand. The collected dust (containing active binder compounds) can be recycled into the green sand circuit.	Generally applicable.

[This BAT conclusion is based on information given in BREF Section 3.2.1.4.4].

Table 4.3: BAT-associated environmental performance levels (BAT-AEPLs) for sand regeneration

Foundry type	Unit	BAT-AEPL (Yearly average)
Iron foundries for production of single castings	%	> 90
Iron foundries for serial production of castings	%	> 95
Steel foundries	%	> 80
NFM foundries	%	> 90

4.2.1.4.5 Reduction of generated waste and of waste sent for disposal

BAT 19. In order to reduce the amount of waste sent for disposal, BAT is to recycle off site the used sand, the undersize sand and the collected filter dust (e.g. fabric filter dust).

Description

Used sand and undersize sand resulting from the sand circuit or the sand regeneration process can be directly recycled in off-site applications such as:

- road construction;
- building materials (e.g. cement, bricks, tiles);
- filling of mining cavities;
- landfill construction (e.g. roads on landfills, permanent covers).

Filter dust, if not directly recycled in the furnace (see BAT 20), can be externally recycled, e.g. in metallurgy, sand fabrication, the construction sector.

[This BAT conclusion is based on information given in BREF Section 3.2.1.4.5.1].

BAT 20. In order to reduce the amount of waste generated in metal melting and to reduce the amount of waste sent for disposal, BAT is to use all of the techniques given below.

Technique		Description
Techniques for all furnace types		
a.	Minimisation of slag forming	Slag forming can be minimised by in-process measures, such as: • using clean scrap; • using a lower metal temperature; • avoiding high temperature peaks; • preventing long standing times of molten metal in the melting furnace; • making adequate use of fluxes; • making adequate choice of the furnace refractory lining; • applying water cooling of the furnace walls to avoid the wear of the furnace refractory lining; • liquid aluminium skimming; • using compressed air to recover aluminium residues; • separating collected metal chips from oils using drying.
b.	Mechanical pretreatment of slag / dross / filter dust / spent refractory linings to facilitate recycling	See Section 4.4.2.
Techniques for cupola furnaces		

c.	Adjustment of the slag acidity/basicity	See Section 4.4.2.
d.	Collection and recycling of coke breeze	Coke breeze generated during handling, transport and charging of coke is collected (e.g. by using collection systems below conveyor belts and/or charging points) and recycled in the process (injected into the cupola furnace or used for recarburisation).
e.	Recycling of filter dust in the cupola furnace	Cupola filter dust is partially re-injected into the cupola furnace in order to increase the zinc content in the dust, up to a level that allows Zn recovery (> 18 %).
Techniques for electric arc furnaces		
f.	Recycling of filter dust in the EAF	Collected dry filter dust, usually after pretreatment (e.g. by pelletising or briquetting), is recycled in the furnace to enable the recovery of the metallic content of the dust. The inorganic content is transferred to the slag.

[This BAT conclusion is based on information given in BREF Section 3.2.1.4.5].

Table 4.4: BAT-associated environmental performance levels (BAT-AEPLs) for waste sent for disposal

Waste type	Unit	BAT-AEPL (Yearly average)		
		NFM	Cast iron	Steel
Slag	kg/t of liquid metal	0-20	0-30	0-10
Dross		0-10	0-10	0-10
Filter dust		0-5	0-10	0-10
Spent furnace refractory linings		0-5	0-5	0-5

The associated monitoring is given in BAT 6.

4.2.1.5 Diffuse emissions to air

BAT 21. In order to prevent or, where that is not practicable, to reduce diffuse emissions to air, BAT is to use all of the techniques given below.

	Technique	Description	Applicability
a.	Covering the delivery equipment (containers) and the cargo space of transport vehicles	Cargo space of transport vehicles and delivery equipment (containers) are covered (e.g. with tarpaulins).	Generally applicable.
b.	Cleaning roads and transport vehicle wheels	Roads as well as the wheels of transport vehicles are regularly cleaned, e.g. by using mobile vacuum systems, water lagoons.	Generally applicable.
c.	Using closed conveyors	Materials are transferred using conveyor systems, e.g. closed conveyors, pneumatic conveying. Material drops are minimised.	Generally applicable.

d.	Vacuum cleaning of moulding and casting process areas	The moulding and casting process areas in sand moulding foundries are regularly vacuum-cleaned.	May not be applicable in areas where the sand has a technical or safety-related function.
e.	Substitution of alcohol-based coatings with water-based coatings	See Section 4.4.3.	Applicability may be limited in the case of large or complicated casting shapes because of difficulties for the drying air to penetrate. Not applicable to water glass-bonded sands, the magnesium casting process or the production of manganese steel castings with MgO coating.
f.	Emissions control from quenching baths	This includes the following: • Minimising the generation of emissions from quenching baths by using water-based polymer solutions (e.g. containing polyvinylpyrrolidone or polyalkylene glycol). • Collecting emissions from quenching baths (especially from oil quenching baths) as close as possible to the emission source, using roof ventilation, extraction domes or edge extractors. Extracted off-gases may be treated, e.g. by using a fabric filter (see Section 2.1.3).	Generally applicable.

[This BAT conclusion is based on information given in BREF Section 3.2.1.5]

4.2.1.6 Channelled emissions to air

BAT 22. In order to facilitate the reduction of channelled emissions to air and the recovery of energy, BAT is to limit the number of emission points.

Description
The combined treatment of waste gases with similar characteristics ensures more effective and efficient treatment compared to the separate treatment of individual waste gas streams. The extent to which the number of emission points can be limited depends on technical (e.g. compatibility of the individual waste gas streams) and economic factors (e.g. distance between different emission points). Care is taken that limiting the number of emission points does not lead to the dilution of emissions.

[This BAT conclusion is based on information given in BREF Section 3.2.1.6]

4.2.1.7 Emissions to air from thermal processes

BAT 23. In order to prevent or reduce emissions to air from metal melting and ladle preheating, BAT is to use either electricity generated from fossil-free energy sources in combination with techniques (a) to (c), or techniques (a) to (c) and an appropriate combination of techniques (d) to (g) given below.

	Technique	Description	Applicability
General techniques			
a.	Selection of an appropriate furnace type	See Section 4.4.3.	Generally applicable.
b.	Use of clean scrap	See Section 4.4.1.	Generally applicable.
c.	Techniques for maximising the thermal efficiency of furnaces	See Section 4.4.1.	Generally applicable.
Techniques for reducing the generation of emissions			
d.	Use of a fuel or a combination of fuels with low NO_X formation potential	Fuels with a low NO_X formation potential include natural gas and liquefied petroleum gas.	Generally applicable.
e.	Use of a fuel or a combination of fuels with low sulphur content	Fuels with low sulphur content include natural gas and liquefied petroleum gas.	Generally applicable.
f.	Low-NO_X burners	See section 4.4.3.	Generally applicable.
g.	Oxy-fuel combustion	See section 4.4.3.	Applicability to existing plants may be restricted by furnace design and the need for a minimum waste gas flow.

[This BAT conclusion is based on information given in BREF Sections 3.1.4.1 and 3.2.1.7]

The BAT-AELs for the metal melting and ladle preheating processes are given:
- in Table 4.15 for cast iron foundries;
- in Table 4.17 for steel foundries;
- in Table 4.19 for NFM foundries.

BAT 24. In order to prevent or reduce emissions to air from heat treatment, BAT is to use either electricity generated from fossil-free energy sources in combination with techniques (a) and (e), or all of the techniques given below.

	Technique	Description
General techniques		
a.	Selection of an appropriate furnace type	See Section 4.4.3.
b.	Techniques for maximising the thermal efficiency of furnaces	See Section 4.4.1.
Techniques for reducing the generation of emissions		

c.	Use of a fuel or a combination of fuels with low NO_X formation potential	Fuels with a low NO_X formation potential include natural gas and liquefied petroleum gas.
d.	Low-NO_X burners	See Section 4.4.3.
Collection of emissions		
e.	Off-gas extraction as close as possible to the emission source	Off-gases from heat treatment furnaces (e.g. annealing, ageing, normalising, austempering) are extracted using hoods or cover extraction. The collected emissions may be treated using techniques such as fabric filters.

Table 4.5: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust and NO_X and indicative emission level for channelled emissions to air of CO from heat treatment

Sunstance/ Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)	Indicative level (Daily average or average over the sampling period)
Dust	mg/Nm^3	< 1-4	No indicative level
NO_X		< 20-100	No indicative level
CO		No BAT-AEL	< 10-100

The associated monitoring is given in BAT 12.

[This BAT conclusion is based on information given in BREF Section 3.2.1.8]

4.2.1.8 Emissions to air from core-making and moulding using lost moulds

BAT 25. In order to prevent or reduce emissions to air from core-making and moulding using lost moulds, BAT is to use an appropriate combination of the process-integrated techniques given below.

	Technique	Description	Applicability
Techniques for moulding with clay-bonded sand (green sand)			
a.	Use of best practices for green sand moulding	This includes techniques such as: • precise addition of the required quantity of key components (e.g. clay, water, coal dust or other additives) to restore the chemical properties of the returned green sand; • when needed, addition of new silica sand (e.g. up to 10 %) to the returned green sand and disposal of an equivalent amount of spent sand; • regular testing (e.g. daily) of the green sand properties (e.g. moisture, green strength, compactability, permeability, loss on ignition, volatile content).	Generally applicable.
b.	Preparation of clay-bonded sand by vacuum mixing and cooling	Mixing and cooling processes are combined into a single process step by operating the sand mixer under reduced pressure, which results in cooling by the controlled vaporisation of the water.	May not be applicable to existing green sand plants due to technical constraints (sand properties).
c.	Substitution of coal dust	Coal dust is replaced by clays (e.g. bentonite) containing additives such as graphite, coke flour and zeolites, resulting in significantly lower diffuse emissions during the casting process.	Applicability may be restricted by operational constraints (e.g. less efficient shake-out or

			occurrence of casting defects).
d.	Use of cereal binders	Cereal binders (e.g. starch, dextrins) are added to increase the toughness of the sand and prevent fracture of the compacted sand during mould drying.	Generally applicable.
Techniques for moulding and core-making with chemically bonded sand			
e.	Minimisation of binder and resin consumption	See Section 4.4.3.	Generally applicable.
f.	Use of best practices for cold-setting processes	See Section 4.4.3.	Generally applicable.
g.	Use of best practices for gas-hardening processes	See Section 4.4.3.	Generally applicable.
h.	Use of non-aromatic solvents for cold-box core production	Non-aromatic solvents are used that are based either on protein or animal fat (e.g. fatty acid methyl esters of vegetable oil) or on silicate esters in order to reduce emissions of VOCs (e.g. benzene, toluene).	Generally applicable.
i.	Use of best practices for hot-curing processes	Several hot-curing processes may be used and a series of measures are in place to optimise each process including for the following: Hot-box process: • Curing is carried out within the optimum temperature range (e.g. 220 to 300ºC); • Cores are usually pre-coated using water-based coatings to prevent burns at the core surface which may result in brittleness during pouring; • Core blowers and the area around them is well ventilated and exhausted to capture efficiently the formaldehyde liberated during curing. Warm-box process: • Curing is carried out at a lower optimum temperature range than the hot-box process (e.g. 150 to 190ºC) resulting in lower emissions and energy consumption than the hot-box process. Shell (croning): • Pre-coated sands with a phenol-formaldehyde resin are binded using hexamethylenetetramine that decompose at 160 ºC releasing formaldehyde, necessary for cross-linking the resin, and ammonia. The curing and/or core blowers area is well ventilated and exhausted to capture efficiently the ammonia and formaldehyde liberated during curing.	Generally applicable.
Alternative binding systems for the reduction of VOC emissions			
j.	Use of aliphatic organic binders	Use of organic binders based on aliphatic polyalcohols, instead of aromatic binders.	Only applicable to cold-setting processes.
k.	Use of inorganic binders in aluminium die-casting	Inorganic binders such as sodium silicates (water glass) hardened using, CO_2 or organic esters for example are used in aluminium die-casting.	Generally applicable.
Techniques related to the coatings applied to moulds and cores			
l.	Substitution of alcohol-based coatings with water-based	See Section 4.4.3.	Applicability may be limited in the case of large or complicated casting shapes

	coatings		because of difficulties for the drying air to penetrate. Not applicable to water glass-bonded sands, to magnesium casting and to the production of manganese steel with MgO coating.

[This BAT conclusion is based on information given in BREF Section 3.2.1.9]

BAT 26. In order to prevent or reduce emissions to air from core-making and moulding using lost moulds, BAT is to:

- **prevent the generation of emissions by using either technique (a), (b) or (c); and**
- **collect the emissions using technique (d); and**
- **treat the off-gases by using one or a combination of the techniques (e) to (j) given below.**

	Technique	Description	Applicability
Prevention of emissions			
a.	Selection of a low-emission cold-setting binder system	A cold-setting binder system generating low emissions of formaldehyde, phenols, furfuryl alcohol, isocyanates, etc. is selected. This includes the use of: • no-bake furan resins with low furfuryl alcohol content (e.g. less than 25 wt-%); • no-bake phenol/furan systems with a low-sulphur acid catalyst; • inorganic geopolymers based on polysialates; • ester silicate; • alkyd oil; • resol-ester; • cement.	Applicability may be restricted due to product specifications.
b.	Selection of a low-emission gas curing binder system	A gas curing binder system generating low emissions of amines, benzene, formaldehyde, phenols, isocyanates, etc. is selected. This includes the use of: • inorganic binders, e.g. sodium silicate (water glass) or inorganic geopolymers based on polysialates cured with CO_2; • aliphatic organic binders based for example on aliphatic polyalcohols (instead of aromatic organic binders); • phenolic urethane binders with very low free phenol and formaldehyde content; • phenolic urethane binders with reduced amounts of solvents.	Applicability may be restricted due to product specifications.
c.	Selection of a low-emission hot-curing binder system	A hot-curing binder system generating low emissions of formaldehyde, phenols, furfuryl alcohol, benzene, isocyanates, etc. is selected. This includes the use of inorganic binders such as geopolymers based on polysialates.	Applicability may be restricted due to product specifications.
Collection of emissions			
d.	Extraction of off-gases	See Section 4.4.3.	Generally applicable.

	generated from moulding and/or core-making		
Off-gas treatment			
e.	Cyclone	See Section 4.4.3.	Generally applicable.
f.	Fabric filter	See Section 4.4.3.	Generally applicable.
g.	Wet scrubbing	See Section 4.4.3.	Generally applicable.
h.	Adsorption	See Section 4.4.3.	Generally applicable.
i.	Thermal oxidation	See Section 4.4.3.	Straight thermal oxidation is generally applicable. Applicability of recuperative and regenerative thermal oxidation to existing plants may be restricted by design and/or operational constraints.
j.	Catalytic oxidation	See Section 4.4.3.	Applicability may be restricted by the presence of catalyst poisons in the waste gases.

Table 4.6: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust, amines, benzene, formaldehyde, phenol and TVOC from core-making and moulding using lost moulds

Substance/ Parameter	Process(es)	Unit	BAT-AEL (Daily average or average over the sampling period)
Dust	Moulding and core-making	mg/Nm^3	< 1-4
Amines	Core-making		< 0.5 ([1])
Benzene	Moulding and core-making		< 1 ([1])
Formaldehyde			< 1 ([1])
Phenol			< 1 ([1])
TVOC	Moulding	mg C/Nm^3	10-30
	Core-making		5-30 ([2])

([1]) The BAT-AEL only applies when the substance concerned is identified as relevant in the waste gas streams based on the inventory of inputs and outputs mentioned in BAT 2.
([2]) The lower end of the BAT-AEL range can be achieved by using thermal oxidation.

The associated monitoring is given in BAT 12.

[This BAT conclusion is based on information given in BREF Section 3.2.1.9]

4.2.1.9 Emissions to air from casting, cooling and shake-out processes using lost moulds

BAT 27. In order to prevent or reduce emissions to air from casting, cooling and shake-out processes using lost moulds, BAT is to:

- **prevent the generation of emissions from hand moulding and cold-setting processes by using technique (a); and**
- **collect the emissions by using technique (b); and**
- **treat the off-gases by using one or a combination of the techniques (c) to (h) given below.**

Technique		Description	Applicability
Prevention of emissions			
a.	Use of mould coating material with adsorbent properties	A layer of coating material with adsorbent properties is applied on the upper surface of the mould to adsorb emissions of for example volatile organic compounds and SO_2 during the casting process. Typical components of the layer include calcium carbonate, coarse aluminium silicate, activated carbon, lime and water.	Generally applicable.
Collection of emissions			
b.	Extraction of off-gases generated during the casting, cooling and shake-out processes	Off-gases generated during the casting (especially emissions from pouring), cooling and shake-out processes are appropriately extracted. For the casting and cooling processes, this includes: • restricting the pouring process to a fixed area or position to facilitate the capture of emissions using ventilators and enclosure (e.g. in serial pouring); • enclosure of pouring and cooling lines. For the shake-out process, this includes: • use of ventilator panels situated on both sides and at the rear of the shaker; • use of enclosed units equipped with roof openings or removable covers (e.g. doghouse); • installation of an extraction point situated underneath the shaker in the sand collection box.	Applicability to existing plants of enclosed units or removable covers in the case of shake-out operations may be restricted by a lack of space.
Off-gas treatment			
. c.	Cyclone	See Section 4.4.3.	Generally applicable.
. d.	Fabric filter	See Section 4.4.3.	Generally applicable.
. e.	Wet scrubbing	See Section 4.4.3.	Generally applicable.
. f.	Electrostatic precipitator	See Section 4.4.3.	Generally applicable.
. g.	Adsorption	See Section 2.1.3.	Generally applicable.
. h.	Biofilter	The off-gas stream is passed through a bed of organic material (such as peat, heather, compost, root, tree bark, softwood and different combinations) or some inert material (such as clay, activated carbon, and polyurethane), where it is biologically oxidised by naturally occurring microorganisms into carbon dioxide, water, inorganic salts and biomass. The biofilter is sensitive to dust, high temperatures or high variations in the off-gas composition. Supplementary nutrient feeding may be needed.	Only applicable to the treatment of biodegradable compounds.

Table 4.7: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust, amines, benzene, formaldehyde, phenol, chromium, lead and TVOC from casting, cooling and shake-out processes using lost moulds

Substance/Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
Dust	mg/Nm^3	< 1-4
Amines		< 0.5 ([2])
Benzene		< 1 ([2])
Formaldehyde		< 0.5 ([2])
Phenol		< 1
Cr		< 0.01 ([1]) ([2])
Pb		< 0.01 ([2])
TVOC	mg C/Nm^3	5-20

([1]) The BAT-AEL only applies to cast iron foundries.
([2]) The BAT-AEL only applies when the substance concerned is identified as relevant in the waste gas streams based on the inventory of inputs and outputs mentioned in BAT 2.

The associated monitoring is given in BAT 12.

[This BAT conclusion is based on information given in BREF Section 3.2.1.10]

4.2.1.10 Emissions to air from alternative casting processes (i.e. lost foam, ceramic shell casting)

BAT 28. In order to reduce TVOC emissions to air from alternative casting processes (i.e. lost foam, ceramic shell casting), BAT is to collect the emissions using technique (a) and to treat the off-gases by using one or an appropriate combination of the techniques (b) to (e) given below.

Technique		Description	Applicability
Collection of emissions			
a.	Extraction of off-gases generated from lost foam and ceramic shell casting	In the lost foam casting processes, off-gases from the pyrolysis of the expanded polymer during pouring and shake-out are extracted using an enclosure or a hood for example. In the ceramic shell process, off-gases from the burning of the polystyrene model in the sintering furnace are extracted using enclosure.	Generally applicable.
Off-gas treatment			
b.	Fabric filter	See Section 4.4.3.	Generally applicable.
c.	Thermal oxidation	See Section 4.4.3.	Straight thermal oxidation is generally applicable. Applicability of recuperative and regenerative thermal oxidation to existing plants may be restricted by design and/or operational constraints.
d.	Catalytic oxidation	See Section 4.4.3.	Applicability may be restricted by the presence of catalyst poisons in the waste gases.
e.	Adsorption	See Section 4.4.3.	Generally applicable.

Table 4.8: BAT-associated emission level (BAT-AEL) for channelled emissions to air of TVOC from alternative casting processes (i.e. lost foam, ceramic shell casting)

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
TVOC	mg C /Nm^3	5-20 ([1])
([1]) The lower end of the BAT-AEL range can be achieved by using thermal oxidation.		

The associated monitoring is given in BAT 12.

[This BAT conclusion is based on information given in BREF Section 3.2.1.11]

4.2.1.11 Emissions to air from the casting process in permanent moulds

BAT 29. In order to prevent or reduce emissions to air from the casting process in permanent moulds, BAT is to:

- **prevent the generation of emissions by using one or a combination of techniques (a) to (e); and**
- **collect the emissions by using technique (f); and**
- **treat the off-gases by using one or a combination of techniques (g) to (i) given below.**

Technique		Description	Applicability
Prevention of emissions			
a.	General techniques for gravity and low-pressure die-casting	Techniques include: • appropriate selection of the lubricating material to prevent castings surface defects; • optimised lubricant preparation and application to avoid excessive use.	Generally applicable.
b.	General techniques for high-pressure die-casting	Techniques include: • proper lubrication of the die and plungers using water-based emulsions of silicone oils, ester oils, synthetic waxes for example; • minimisation of the release agent and water consumption by use of for example micro-spraying for application of release agents (see also BAT 17(b)).	
c.	Optimisation of process parameters for centrifugal and continuous casting	In centrifugal casting, important process parameters such as mould rotation, pouring temperature and mould preheating temperature are optimised (e.g. using flow simulation) to reduce the number of defects and minimise emissions. In continuous casting, the casting rate, casting temperature and cooling rate are optimised to minimise emissions and reduce the amount of water consumed for cooling while reaching the required product specification.	
d.	Separate spraying of release agent and water in high-pressure die-casting	See Section 4.4.2.	
e.	Use of water-free release agents in high-pressure die-casting	Water-free release agents (e.g. in a powdered form) are applied to the die using electrostatic deposition.	

Collection of emissions			
f.	Extraction of off-gases generated from the casting process in permanent moulds	Off-gases generated from the casting process in permanent moulds including high-pressure/low-pressure/gravity die-casting, centrifugal and continuous casting are extracted using enclosures or extraction hoods and are sent to an abatement system.	Generally applicable.
Off-gas treatment			
g.	Fabric filter	See Section 4.4.3.	Generally applicable.
h.	Electrostatic precipitator	See Section 4.4.3.	
i.	Thermal oxidation	See Section 4.4.3.	Straight thermal oxidation is generally applicable. Applicability of recuperative and regenerative thermal oxidation to existing plants may be restricted by design and/or operational constraints.

Table 4.9: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust, TVOC and lead from the casting process in permanent moulds

Parameter	Unit	BAT-AELs (Daily average or average over the sampling period)
Dust	mg/Nm^3	<1–4
Pb		0.05–0.1 ([2])
TVOC	$mg\ C/Nm^3$	2–8 ([1])
([1]) The BAT-AEL range only applies to low-pressure, high-pressure and gravity die-casting foundries. ([2]) The BAT-AEL only applies to die-casting lead foundries.		

The associated monitoring is given in BAT 12.

[This BAT conclusion is based on information given in BREF Section 3.2.1.12]

4.2.1.12 Emissions to air from finishing

BAT 30. In order to reduce dust emissions to air from finishing, BAT is to collect the emissions using technique (a) and to treat the off-gases by using one or a combination of the techniques (b) to (d) given below.

Technique		Description
Collection of emissions		
a.	Extraction of off-gases generated from finishing	Off-gases generated from finishing operations, such as deburring, abrasive cutting, fettling, slide grinding, shot blasting, welding, chiselling, needling, are appropriately extracted using, e.g.: • enclosure of the finishing process area; • roof ventilation or dome-shaped roofs; • rigid or adjustable extraction hoods; • extraction arms.
Off-gas treatment		
. b.	Cyclone	See Section 4.4.3.
. c.	Fabric filter	See Section 4.4.3.
. d.	Wet scrubbing	See Section 4.4.3.

Table 4.10: BAT-associated emission level (BAT-AEL) for channelled emissions to air of dust from finishing

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
Dust	mg/Nm^3	< 1-3

The associated monitoring is given in BAT 4.

[This BAT conclusion is based on information given in BREF Section 3.2.1.13]

4.2.1.13 Emissions to air from sand reconditioning and regeneration

BAT 31. In order to reduce emissions to air from sand reconditioning and regeneration, BAT is to:

- **reduce the generation of NO_X and SO_2 emissions by using techniques (a) and (b) in the case of thermal sand regeneration;**
- **collect the emissions using technique (c); and**
- **treat the off-gases by using one or an appropriate combination of the techniques (d) to (g) given below.**

Technique		Description	Applicability
Techniques for reducing the generation of emissions			
a.	Use of a fuel or a combination of fuels with low NO_X formation potential	Fuels with a low NO_X formation potential include natural gas and liquefied petroleum gas.	Generally applicable.
b	Use of a fuel or a combination of fuels with low sulphur content	Fuels with low sulphur content include natural gas and liquefied petroleum gas.	Generally applicable.
Collection of emissions			
c	Extraction of off-gases generated from sand reconditioning and regeneration	Off-gases generated from sand reconditioning and regeneration (e.g. secondary regeneration) are extracted using an enclosure or a hood for example. This includes extraction of the flue-gases generated from fluidised bed furnaces, rotary kilns or multiple-hearth furnaces, etc. used in thermal sand regeneration.	Generally applicable.
Off-gas treatment			
d.	Cyclone	See Section 4.4.3.	Generally applicable.
e.	Fabric filter	See Section 4.4.3.	Generally applicable.
f.	Wet scrubbing	See Section 4.4.3.	Generally applicable.
g.	Thermal oxidation	See Section 4.4.3.	Straight thermal oxidation is generally applicable. Applicability of recuperative and regenerative thermal oxidation to existing plants may be restricted by design and/or operational constraints.

[This BAT conclusion is based on information given in BREF Section3.2.1.14]

Table 4.11: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust, benzene, formaldehyde, nickel, NO_X, SO_2 and TVOC from sand reconditioning and regeneration

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
Dust	mg/Nm^3	< 1-4
Benzene		< 1 ([1])
Formaldehyde		< 0.5 ([1])
NO_X		< 20 ([1])
SO_2		< 10 ([1])
TVOC	mg C/Nm^3	5-20
([1]) The BAT-AEL only applies when the substance concerned is identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.		

The associated monitoring is given in BAT 4.

4.2.1.14 Odour

BAT 32. In order to prevent or, where that is not practicable, to reduce odour emissions, BAT is to set up, implement and regularly review an odour management plan, as part of the environmental management system (see BAT 1), that includes all of the following elements:

- A protocol containing actions and timelines.
- A protocol for conducting odour monitoring as set out in BAT 33. The protocol may be complemented by measurement/estimation of odour exposure or estimation of odour impact.
- A protocol for response to identified odour incidents, e.g. managing complaints and/or taking corrective actions.
- An odour prevention and reduction programme designed to identify the source(s); to measure/estimate odour exposure; to characterise the contributions of the sources; and to implement prevention and/or reduction measures.

Applicability
The applicability is restricted to cases where an odour nuisance at sensitive receptors is expected and/or has been substantiated.

[This BAT conclusion is based on information given in BREF Section 3.2.1.15.1]

BAT 33. BAT is to periodically monitor odour emissions.

Description
Odour emissions can be monitored using:
- EN standards (e.g. dynamic olfactometry according to EN 13725 in order to determine the odour concentration or EN 16841-1 or -2 in order to determine the odour exposure);
- alternative methods (e.g. estimation of odour impact) for which no EN standards are available, ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

The monitoring frequency is determined in the odour management plan (see BAT 32).

Applicability
The applicability is restricted to cases where an odour nuisance at sensitive receptors is expected and/or has been substantiated.
[This BAT conclusion is based on information given in BREF Section 3.2.1.15.2]

BAT 34. In order to prevent or, where that is not practicable, to reduce odour emissions, BAT is to use all of the techniques given below.

Technique		Description	Applicability
a.	Substitution of chemicals containing alcohol-based or aromatic solvents	This includes techniques such as: • the use of water-based coatings (see BAT 25 (l)); • the use of alternative solvents in cold-box core-making (see BAT 25 (h)).	Applicability of water-based coatings may be restricted due to the type of raw material or product specifications (e.g. big moulds/cores, water glass bonded sands, Mg castings, production of manganese steel with MgO coating).
b.	Good ventilation of areas where binders are used	Where process air extraction and treatment is not applied, good ventilation and a minimum rate of air change are ensured so that odour emissions are quickly and efficiently dispersed to the atmosphere.	Generally applicable.
c.	Collection and treatment of amine emissions from the cold-box core-making process	Off-gases containing amines, generated from the gassing of cold-box cores are extracted and treated using for example wet scrubbing, thermal or catalytic oxidation (see BAT 26).	
d.	Collection and treatment of VOC emissions from chemically bonded sand preparation, pouring, cooling and shake-out	Off-gases containing VOCs, generated from the preparation of chemically bonded sand, pouring, cooling and shake-out are extracted and treated using for example wet scrubbing, thermal or catalytic oxidation (see BAT 26).	

[This BAT conclusion is based on information given in BREF Sections 3.2.1.15.3 – 3.2.1.15.6]

4.2.1.15 Water consumption and waste water generation

BAT 35. In order to optimise water consumption and to reduce the volume of waste water generated as well as to improve water recyclability, BAT is to use both techniques (a) and (b), and an appropriate combination of the techniques (c) to (g) given below.

Technique		Description	Applicability
a.	Water management plan and water audits	A water management plan and water audits are part of the EMS (see BAT 1) and include: – flow diagrams and water mass balances of the plant as part of the inventory of inputs and outputs mentioned in BAT 2; – establishment of water efficiency objectives; – implementation of water optimisation techniques (e.g. control of water usage, reuse/recycling, detection and repair of leaks). Water audits are carried out at least once every year to ensure that the objectives of the water management plan are met.	The level of detail of the water management plan and water audits will generally be related to the nature, scale and complexity of the plant.
b.	Segregation of water streams	See Section 4.4.4.	Applicability to existing plants may be limited by the layout of the water collection system.
c.	Reuse and/or recycling of water	Water streams (e.g. process water, effluents from wet scrubbing or cooling water) are reused and/or recycled in closed or semi-closed circuits, if necessary after treatment (see BAT 36).	The degree of water reuse and/or recycling is limited by the water balance of the plant, the content of impurities and/or the characteristics of the water streams.
d.	Prevention of waste water generation from process and storage areas	See BAT 4 (b).	Generally applicable.
e.	Use of dry dedusting systems	This includes techniques such as fabric filters and dry ESP (see Section 4.4.3).	Generally applicable.
f.	Separate spraying of release agent and water in high-pressure die-casting	See Section 4.4.2.	Generally applicable.
g.	Use of waste heat for the evaporation of waste water	When waste heat is available on a continuous basis, it can be used to evaporate waste water.	Generally applicable.

[This BAT conclusion is based on information given in BREF Section 3.2.1.16]

Table 4.12: BAT-associated environmental performance levels (BAT-AEPLs) for specific water consumption

Foundry type	Unit	BAT-AEPL (Yearly average)
Iron foundries	m^3/t of liquid metal	0.5-4
Steel foundries		
Non-ferrous metal foundries (all types except HPDC)		
Non-ferrous metal HPDC foundries		0.5-5

The associated monitoring is given in BAT 6.

4.2.1.16 Emissions to water

BAT 36. In order to reduce emissions to water, BAT is to treat waste water using an appropriate combination of the techniques given below.

	Technique ([1])	Typical pollutants targeted
Preliminary, primary and general treatment, e.g.		
a.	Equalisation	All pollutants
b.	Neutralisation	Acids, alkalis
c.	Physical separation through for example screens, sieves, grit separators, grease separators, hydrocyclones, oil-water separators or primary settlement tanks	Gross solids, suspended solids, oil/grease
Physico-chemical treatment, e.g.		
d.	Adsorption	Adsorbable dissolved non-biodegradable or inhibitory pollutants, e.g. hydrocarbons, mercury, AOX
e.	Chemical precipitation	Precipitable dissolved non-biodegradable or inhibitory pollutants, e.g. metals, fluoride
f.	Evaporation	Soluble contaminants, e.g. salts
Biological treatment, e.g.		
g.	Activated sludge process	Biodegradable organic compounds
h.	Membrane bioreactor	
Solids removal, e.g.		
i.	Coagulation and flocculation	Suspended solids and particulate-bound metals
j.	Sedimentation	Suspended solids and particulate-bound metals or non-biodegradable or inhibitory pollutants
k.	Filtration, e.g. sand filtration, microfiltration, ultrafiltration	Suspended solids and particulate-bound metals
l.	Flotation	
([1]) The descriptions of the techniques are given in Section 4.4.4.		

[This BAT conclusion is based on information given in BREF Section 3.2.1.17]

Table 4.13: BAT-associated emission levels (BAT-AELs) for direct discharges to a receiving water body

Substance/Parameter		Unit	BAT-AEL (1)	Process(es) to which the BAT-AEL applies
Adsorbable organically bound halogens (AOX) (2)		mg/l	< 0.01-0.2	Waste water from wet scrubbing of cupola off-gases
Chemical oxygen demand (COD) (3)			15-45 (4)	All processes
Total organic carbon (TOC) (3)			5-15	
Total suspended solids (TSS)			5-20	
Free cyanide (CN^-) (2)			0.005-0.03	
Hydrocarbon oil index (HOI)			0.1-2	
Metals	Arsenic (As) (2)		< 0.005-0.02	
	Cadmium (Cd) (2)		< 0.001-0.005	
	Chromium (Cr) (2)		< 0.01-0.025	
	Iron (Fe) (2)		0.05-3	
	Lead (Pb) (2)		0.005-0.02	
	Mercury (Hg) (2)	µg/l	0.1-0.5	
	Nickel (Ni) (2)	mg/l	0.01-0.05	
	Zinc (Zn) (2)		0.1-0.5	
Phenol index (2)			0. 05-0.2	
Total nitrogen (TN) (2)			1-20	

(1) The averaging periods are defined in the General considerations.
(2) The BAT-AELs only apply when the substance/parameter concerned is identified as relevant in the waste water stream based on the inventory of inputs and outputs mentioned in BAT 2.
(3) Either the BAT-AEL for COD or the BAT-AEL for TOC applies. The BAT-AEL for TOC is the preferred option because TOC monitoring does not rely on the use of very toxic compounds.
(4) No BAT-AEL applies for biochemical oxygen demand (BOD). As an indication, the yearly average BOD_5 level in the effluent from a biological waste water treatment plant will generally be ≤ 10 mg/l.

Table 4.14: BAT-associated emission levels (BAT-AELs) for indirect discharges to a receiving water body

Substance/Parameter		Unit	BAT-AEL (1) (2)	Process(es) to which the BAT-AEL applies
Adsorbable organically bound halogens (AOX) (3)		mg/l	< 0.01-0.2	Waste water from wet scrubbing of cupola off-gases
Free cyanide (CN^-) (3)			0.005-0.03	All processes
Hydrocarbon oil index (HOI)			0.1-2	
Metals	Arsenic (As) (3)		< 0.005-0.02	
	Cadmium (Cd) (3)		< 0.001-0.005	
	Chromium (Cr) (3)		< 0.01-0.025	
	Iron (Fe) (3)		0.05-3	
	Lead (Pb) (3)		0.005-0.02	
	Mercury (Hg) (3)	µg/l	0.1-0.5	
	Nickel (Ni) (3)	mg/l	0.01-0.05	
	Zinc (Zn) (3)		0.1-0.5	
Phenol index (3)			0. 05-0.2	

(1) The averaging periods are defined in the General considerations.
(2) The BAT-AELs may not apply if the downstream waste water treatment plant is designed and equipped appropriately to abate the pollutants concerned, provided this does not lead to a higher level of pollution in the environment.
(3) The BAT-AELs only apply when the substance/parameter concerned is identified as relevant in the waste water stream based on the inventory of inputs and outputs mentioned in BAT 2.

The associated monitoring is given in BAT 5.

4.2.2 BAT conclusions for iron foundries

The BAT conclusions in this section apply in addition to the general BAT conclusions given in Sections 4.1 and 4.2.1.

4.2.2.1 Energy efficiency

BAT 37. In order to increase energy efficiency in metal melting, BAT is to use an appropriate combination of the techniques given below.

Technique		Description	Applicability
a.	Increase of shaft height in CBC furnaces	Increasing the shaft height in cold blast cupola furnaces enables combustion gases to remain in contact with the charge for longer, resulting in a higher heat transfer.	Generally applicable.
b.	Oxygen enrichment of the combustion air	See Section 4.4.1.	Generally applicable.
c.	Superheating of HBC blast air	Increase of the flame temperature by superheating the blast air to 800-900 °C either by injection of air plasma or by using resistance heaters.	Generally applicable.
d.	Minimal blast shut-off periods for HBC furnaces	Minimisation of blast shut-off periods by programming the schedules of the moulding and casting processes to ensure a reasonably constant demand for metal.	Generally applicable.
e.	Long-campaign cupola	The cupola furnace is set up for long campaign operation to minimise maintenance and process changes. This may be achieved by using more resistant furnace refractory linings in the shaft, bottom and hearth, by using water cooling of the furnace wall and with water-cooled blasting pipes penetrating deeper in the furnace shaft.	May not be applicable in cases where the molten metal production rate is less than 10 t/h.
f.	Post-combustion of off-gases	See Section 4.4.1.	Generally applicable.
g.	Foamy slag practice	See Section 4.4.1.	Generally applicable.

[This BAT conclusion is based on information given in BREF Section 3.2.2.1]

The associated BAT-AEPLs for specific energy consumption are given in Table 4.1

4.2.2.2 Emissions to air from thermal processes

4.2.2.2.1 Emissions to air from metal melting and ladle preheating

BAT 38. In order to prevent or reduce emissions to air from metal melting and ladle preheating, BAT is to:

- use an appropriate combination of process-related techniques (a) to (g); and
- collect the emissions using technique (h); and
- apply primary control measures for the reduction of PCDD/F emissions using all of the techniques (i) to (k); and
- treat the extracted off-gases using one or an appropriate combination of techniques (l) to (q).

Technique		Description	Applicability
Process-related techniques for cupola furnaces			
a.	Control of coke quality	Important characteristics of the coke used (e.g. fixed carbon, ash, volatile matter, sulphur and moisture content, mean size diameter) are systematically controlled.	Generally applicable.
b.	Adjustment of the slag acidity/basicity	See Section 4.4.3.	
c.	Increase of shaft height in CBC furnaces	The shaft height is increased to maximise contact time and heat transfer between combustion gases and charge.	
d.	Oxygen enrichment of the combustion air	See Section 4.4.3.	
e.	Superheating of HBC blast air	The flame temperature is increased by superheating the blast air to 800-900 °C either by injection of air plasma or by using resistance heaters.	
f.	Minimal blast shut-off periods for HBC furnaces	Blast shut-off periods are minimised by programming the schedule of the moulding and casting processes to ensure a reasonably constant demand for metal.	
g.	Long-campaign cupola	The cupola furnace is set up for long campaign operation to minimise maintenance and process changes. This may be achieved by using more resistant furnace refractory linings in the shaft, bottom and hearth, by using water cooling of the furnace wall and with water-cooled blasting pipes penetrating deeper in the furnace shaft.	May not be applicable in cases where the molten metal production rate is less than 10 t/h.
Collection of emissions			
h.	Off-gas extraction	In cupola furnaces, the off-gases are extracted either: • above the charge-hole offtake at the end of the cupola stack using ductwork and a downstream fan; or • below the charge-hole offtake using an annular ring. After extraction, the off-gases are cooled using: • long ducts to decrease the temperature by natural convection; • air/gas or oil/gas heat exchangers; • water quenching. For induction furnaces, off-gases are extracted, for example using: • hood extraction (e.g. canopy or side-draught hoods); • lip extraction; • cover extraction. For rotary furnaces, off-gases are extracted, for example using hood extraction. For EAFs, off-gases are extracted, for example using: • roof-mounted hood extraction; • canopy or side-draught hoods; • partial furnace enclosures (mobile or fixed) mounted around the furnace and tapping area; • total furnace enclosure using a complete room enclosure around the furnace and tapping area equipped with a moveable roof for charging/tapping operations.	Generally applicable.
Primary control measures to minimise PCDD/F emissions			
i.	Maximisation of the off-gases residence time	The temperature of the post-combustion chamber (T > 850 °C) is continuously monitored and the off-gases residence time is maximised (> 2 s).	Generally applicable.

	and optimisation of the temperature in the post-combustion chamber		
j.	Rapid off-gas cooling	The off-gas is cooled rapidly from temperatures above 400 °C to below 250 °C before dust abatement to prevent the *de novo* synthesis of PCDD/F. This is achieved by appropriate design of the furnace and/or the use of a quench system.	
k.	Minimising dust build-up in heat exchangers	The build-up of dust along the cooling trajectory of the off-gas is minimised, especially in the heat exchangers, e.g. by using vertical exchanger tubes, efficient internal cleaning of the exchanger tubes, high-temperature de-dusting.	
Off-gas treatment			
l.	Post-combustion of off-gases	See Section 4.4.3.	Generally applicable.
m.	Cyclone	See Section 4.4.3.	Generally applicable.
n.	Adsorption	See Section 4.4.3.	Generally applicable.
o.	Dry lime injection	Dry lime is injected and dispersed in the off-gas stream. The material reacts with the acidic gaseous species (e.g. SO_2) to form a solid which is removed by filtration (e.g. fabric filter).	Generally applicable.
p.	Fabric filter	See Section 4.4.3.	Generally applicable.
q.	Wet scrubbing	See Section 4.4.3.	Generally applicable.

[This BAT conclusion is based on information given in BREF Section 3.2.2.2.1]

Table 4.15: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust, B[a]P, CO, HCl, HF, NO_X, PCDD/F, SO_2, TVOC, cadmium, chromium, nickel, lead, and indicative emission level for channelled emissions to air of CO from metal melting and ladle preheating

Substance/ Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)	Indicative level (Daily average or average over the sampling period)
Dust	mg/Nm^3	< 1-4	No indicative level
B[a]P		0.001-0.005 ([1])	
HCl		1-5	
HF		< 1	
CO		< 10-75 for CBC and HBC furnaces	< 20 for all other furnace types
NO_X		< 10 for induction furnaces	No indicative level
		< 10-60 for all other furnace types	
PCDD/F	ng WHO-TEQ/Nm^3	< 0.005-0.02	
SO_2	mg/Nm^3	< 10-60 ([1])	
TVOC	mg C/Nm^3	2-10	
Cd	mg/Nm^3	< 0.01 ([1])	
Cr		< 0.01 ([1])	
Ni		< 0.01 ([1])	
Pb		< 0.03 ([1])	

([1]) The BAT-AEL only applies when the substance concerned is identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.

The associated monitoring is given in BAT 12.

[This BAT conclusion is based on information given in BREF Section 3.2.2.2.1]

4.2.2.2.2 Emissions to air from the nodularisation of cast iron

BAT 39. In order to prevent or reduce dust emissions to air from the nodularisation of cast iron, BAT is to use technique (a) or both of the techniques (b) and (c) given below.

Technique		Description
a.	Nodularisation with no magnesium oxide emissions	Use of the in-mould process whereby the magnesium alloy is added as a tablet, directly into the mould cavity, and the nodularisation reaction takes place during moulding.
b.	Off-gas extraction as close as possible to the emission source	When magnesium oxide emissions are generated from the nodularisation technique used (e.g. sandwich, ductilator), off-gases are extracted as close as possible to the emission source using a fixed or movable extraction hood.
c.	Fabric filter	See Section 4.4.3. The magnesium oxide collected may be reused for the production of pigments or refractory materials.

Table 4.16: BAT-associated emission levels (BAT-AELs) for channelled dust emissions to air from the nodularisation of cast iron

Parameter	Unit	BAT-AEL ([1]) (Daily average or average over the sampling period)
Dust	mg/Nm^3	< 1-4
([1]) The BAT-AEL only applies when techniques (b) and (c) are used.		

The associated monitoring is given in BAT 12.

[This BAT conclusion is based on information given in BREF Section 3.2.2.3]

4.2.3 BAT conclusions for steel foundries

The BAT conclusions in this section apply in addition to the general BAT conclusions given in Sections 4.1 and 4.2.1.

4.2.3.1 Emissions to air from thermal processes

4.2.3.1.1 Emissions to air from metal melting and ladle preheating

BAT 40. In order to prevent or reduce emissions to air from metal melting and ladle preheating, BAT is to apply primary control measures for the reduction of PCDD/F emissions using both techniques (a) and (b), to collect the emissions using technique (c) and to treat the off-gases using technique (d) alone or in combination with technique (e).

Technique		Description
Primary control measures to minimise PCDD/F emissions		
a.	Rapid off-gas cooling	The off-gas is cooled rapidly from temperatures above 400 °C to below 250 °C before dust abatement to prevent the *de novo* synthesis of PCDD/F. This is achieved by appropriate design of the furnace and/or the use of a quench system.
b.	Minimising dust build-up in heat exchangers	The build-up of dust along the cooling trajectory of the off-gas is minimised, especially in the heat exchangers, e.g. by using vertical exchanger tubes, efficient internal cleaning of the exchanger tubes, high-temperature de-dusting.
Collection of emissions		
c.	Off-gas extraction	The off-gases from induction furnaces are extracted, for example using: • hood extraction (e.g. canopy or side-draught hoods); • lip extraction; • cover extraction. The off-gases from EAFs, are extracted, for example using: • partial furnace enclosures (mobile or fixed) mounted around the furnace and tapping area; • total furnace enclosure using a complete room enclosure around the furnace and tapping area equipped with a moveable roof for charging/tapping operations; • hood extraction (e.g. roof-mounted, canopy or side-draught hoods); • direct extraction through the fourth hole in the furnace roof.
Off-gas treatment		
d.	Fabric filter	See Section 4.4.3.
e.	Cyclone	See Section 4.4.3.

Table 4.17: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust, NO_X, PCDD/F, TVOC, cadmium, chromium, nickel, lead, and indicative emission level for channelled emissions to air of CO, from metal melting and ladle preheating

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)	Indicative level (Daily average or average over the sampling period)
Dust	mg/Nm³	< 1-4	No indicative level
CO		No BAT-AEL	10-100
NO_X		10-30	No indicative level
PCDD/F	ng WHO-TEQ / Nm³	< 0.001-0.02	
TVOC	mg C/Nm³	2-10	
Cd	mg/Nm³	< 0.005 (1)	
Cr		< 0.01 (1)	
Ni		< 0.02 (1)	
Pb		< 0.01 (1)	
(1) The BAT-AEL only applies when the substance concerned is identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.			

The associated monitoring is given in BAT 12.

[This BAT conclusion is based on information given in BREF Section 3.2.3.1]

4.2.3.1.2 Emissions to air from steel refining

BAT 41. In order to reduce emissions to air from steel refining, BAT is to collect emissions using technique (a) and treat the extracted off-gases using technique (b) given below.

Technique		Description
Collection of emissions		
a.	Off-gas extraction as close as possible to the emission source	Off-gases from steel refining (e.g. from Argon Oxygen Decarburisation (AOD) or Vacuum Oxygen Decarburisation (VOD) converters) are extracted using for example a direct extraction hood or a roof canopy combined with an accelerator stack. Extracted off-gases are treated using technique (b).
Off-gas treatment		
b.	Fabric filter	See Section 4.4.3.

Table 4.18: BAT-associated emission level (BAT-AEL) for channelled emissions to air of dust from steel refining

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
Dust	mg/Nm^3	< 1-4

The associated monitoring is given in BAT 12.

[This BAT conclusion is based on information given in BREF Section 3.2.3.2]

4.2.4 BAT conclusions for non-ferrous metal foundries

The BAT conclusions in this section apply in addition to the general BAT conclusions given in Section 4.1 and 4.2.1.

4.2.4.1 Energy efficiency

BAT 42. In order to increase energy efficiency in metal melting, BAT is to use one ~~or a combination~~ of the techniques given below.

Technique		Description
a.	Molten metal circulation in reverberatory furnaces	A pump is installed on reverberatory furnaces to force the circulation of molten metal and minimise the temperature gradient throughout the molten bath (from top to bottom).
b.	Minimisation of energy losses by radiation in crucible furnaces	Crucible furnaces are covered using a lid and/or equipped with radiant panel linings to minimise energy losses by radiation.

[This BAT conclusion is based on information given in BREF Section 3.2.4.1]

The associated BAT-AEPLs for specific energy consumption are given in Table 4.1

4.2.4.2 Emissions to air from thermal processes

4.2.4.2.1 Emissions to air from metal melting and ladle preheating

BAT 43. In order to reduce emissions to air from metal melting and ladle preheating, BAT is to apply primary control measures for the reduction of PCDD/F emissions using both of the techniques (a) and (b), to collect the emissions using technique (c) and to treat the off-gases using one or a combination of techniques (d) to (g) given below.

Technique		Description
Primary control measures to minimise PCDD/F emissions		
a.	Rapid off-gas cooling	The off-gas is cooled rapidly from temperatures above 400 °C to below 250 °C before dust abatement to prevent the *de novo* synthesis of PCDD/F. This is achieved by appropriate design of the furnace and/or the use of a quench system.
b.	Minimising dust build-up in heat exchangers	The build-up of dust along the cooling trajectory of the off-gas is minimised, especially in the heat exchangers, e.g. by using vertical exchanger tubes, efficient internal cleaning of the exchanger tubes, high-temperature de-dusting.
Collection of emissions		
c.	Off-gas extraction	Off-gases from shaft, crucible, resistance, reverberatory (hearth-type) and radiant roof furnaces are extracted using hood extraction (e.g. canopy hoods). The extraction is fitted in such a way that it enables the capture of emissions during pouring. Off-gases from induction furnaces are extracted, for example using: • hood extraction (e.g. canopy or side-draught hoods); • lip extraction; • cover extraction. Off-gases from rotary furnaces are extracted, for example using hood extraction.
Off-gas treatment		
d.	Cyclone	See Section 4.4.3.
e.	Dry lime injection	See Section 4.4.3.
f.	Fabric filter	See Section 4.4.3.
g.	Wet scrubbing	See Section 4.4.3.

Table 4.19: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust, HCl, HF, NO_X, PCDD/Fs, SO_2, TVOC, Cd, Ni, Pb, and indicative emission level for channelled emissions to air of CO, from metal melting and ladle preheating

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)	Indicative level (Daily average or average over the sampling period)
Dust	mg/Nm^3	< 1-4	No indicative level
HCl		1-3 ([1])	
HF		< 1 ([1])	
CO		No BAT-AEL	5–30 ([2]) ([3])
NO_X		10-50	No indicative level
PCDD/F	ng WHO-TEQ/Nm^3	< 0.001-0.02	
TVOC	mg C/Nm^3	2-10	
SO_2	mg/Nm^3	< 10 ([4])	
Cd		< 0.03 ([5])	
Cr		< 0.04 ([5])	
Ni		< 0.04 ([5])	
Pb		< 0.03 ([5])	

(1) Only applicable to aluminium foundries.
(2) The upper end of the indicative range may be higher and up to 70 mg/Nm^3 in the case of shaft furnaces.
(3) The indicative level does not apply in the case of furnaces using only electric energy (e.g. induction, resistance).
(4) The BAT-AEL does not apply in the case of furnaces using only electric energy (e.g. induction, resistance).
(5) The BAT-AEL only applies when the substance concerned is identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.

The associated monitoring is given in BAT 12.

[This BAT conclusion is based on information given in BREF Section 3.2.4.2.1]

4.2.4.3 Emissions to air from the treatment and protection of molten metal

BAT 44. In order to prevent or reduce emissions of chlorine to air from the treatment of molten aluminium (degassing/cleaning) and to prevent emissions of covering gases with high global warming potential from the treatment and protection of molten metal, BAT is to use one or both of the techniques given below.

Technique		Description
Molten aluminium treatment (degassing/cleaning)		
a.	Optimised degassing/cleaning of molten aluminium	A mobile or fixed rotary impeller degassing station is used to remove hydrogen gas from the melt. In most cases, this is achieved through a simple degassing treatment using argon or nitrogen gas without chlorine gas. In a combined degassing and cleaning process, gas mixtures of argon and chlorine or nitrogen and chlorine are introduced into the melt. In this case, the chlorine concentration in the carrier gas is optimised to ensure good cleaning and low chlorine emissions.
Molten metal protection in magnesium melting		
b.	Selection of oxidation control agents with a low global warming potential in magnesium melting	Oxidation control agents (covering gases) used in magnesium melting are selected by considering their global warming potential. Gas mixtures with a low environmental impact include: • SO_2; • gas mixtures of N_2, CO_2 and/or SO_2; • gas mixtures of argon and SO_2. The use of SO_2 results in the formation of a protective layer composed of $MgSO_4$, MgS and MgO.

Table 4.20: BAT-associated emission level (BAT-AEL) for channelled emissions to air of chlorine from the treatment of molten aluminium (degassing/cleaning)

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
Elemental chlorine (Cl_2)	mg/Nm^3	< 1

The associated monitoring is given in BAT 12.

[This BAT conclusion is based on information given in BREF Section 3.2.4.3]

4.3 BAT conclusions for smitheries

The BAT conclusions in this section apply in addition to the general BAT conclusions given in Section 4.1.

4.3.1 Energy efficiency

BAT 45. In order to increase energy efficiency in heating/reheating, BAT is to use all the techniques given below.

Technique		Description	Applicability
a.	Optimisation of furnace design	This includes techniques such as: • optimisation of key furnace characteristics (e.g. number and type of burners, airtightness, furnace insulation using suitable refractory materials); • minimisation of heat losses from furnace door openings, e.g. by using several liftable segments instead of one in continuous reheating furnaces; • minimisation of the number of feedstock-supporting structures inside the furnace (e.g. beams, skids) and use of suitable insulation to reduce the heat losses from water cooling of the supporting structures in continuous reheating furnaces.	Only applicable to new plants and major plant upgrades.
b.	Furnace automation and control	See Section 4.4.1.	Generally applicable.
c.	Optimisation of feedstock heating /reheating	This includes measures such as: • techniques related to the entire process, e.g. ensure that feedstock heating/reheating target temperatures are consistently met, switch off equipment during idle periods; • furnace operation optimisation, e.g. furnace capacity utilisation, correction of the air/fuel ratio, improvement of insulation, use of covers to avoid heat losses, use of recuperators/regenerators, preheated feedstock loading.	Generally applicable.
d.	Preheating of combustion air	See Section 4.4.1.	Generally applicable.

[This BAT conclusion is based on information given in BREF Section 3.3.1]

Table 4.21: BAT-associated environmental performance level (BAT-AEPL) for specific energy consumption

Sector	Unit	BAT-AEPL (Yearly average)
Smitheries	kWh/t of feedstock	2 500-4 000

4.3.2 Material efficiency

BAT 46. In order to increase the material efficiency, BAT is to use both of the techniques given below.

Technique		Description
a.	Process optimisation	This includes techniques such as: • computerised management of processes, e.g. heating/reheating cycles, hammering sequences, hammer's impact loads; • adjustment of raw material size, either in the forging line (fully automated) or in the organisational area of the material shredding (manual), in order to minimise the amount of residues and the number of process operations.
b.	Optimisation of raw material consumption	This includes techniques such as: • use of computer-aided design of products to optimise the amount of raw material used and reduce the generation of burrs; • use of high-strength raw materials; • reuse/recycling of process residues; • selection of an appropriate type of lubrication material in hot/warm forging, e.g. synthetic lubricant, water-based dispersions of graphite; • centralised distribution system for coolants/lubricants that reduces intermediate storage and consumption, and facilitates leak detection; • systems for collecting and recirculating coolants/lubricants (see BAT 51).

[This BAT conclusion is based on information given in BREF Section 3.3.2]

4.3.3 Vibrations

BAT 47. In order to reduce vibrations occurring from the hammering process, BAT is to use vibration-reducing and insulating techniques.

Description
Vibration-reducing and insulating techniques for hammering equipment include:
- installation of vibration-damping components, e.g. layered elastomeric isolators or viscous spring isolators below the anvil or spring casings below the hammer foundation;
- optimisation of the hammer's impact loads (see BAT 46 a).

[This BAT conclusion is based on information given in the BREF Section 3.3.3]

4.3.4 Monitoring of emissions to air

BAT 48. BAT is to monitor channelled emissions to air with at least the frequency given below, and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

Parameter	Specific process	Standard(s)	Minimum monitoring frequency ([1])	Monitoring associated with
Nitrogen oxides (NO_X)	Heating/reheating, heat treatment	EN 14792 ([2])	Continuous for any stack with NO_X mass flows > 15 kg/h Once every 6 months for any stack with NO_X mass flows between 1 kg/h and 15 kg/h Once every year for any stack with NO_X mass flows < 1 kg/h	BAT 50
Carbon monoxide (CO)	Heating/reheating, heat treatment	EN 15058 ([2])	Once every year	

([1]) To the extent possible, the measurements are carried out at the highest expected emission state under normal operating conditions.
([2]) If measurements are continuous, the following generic EN standards apply instead: EN 15267-1, EN 15267-2, EN 15267-3 and EN 14181.

[This BAT conclusion is based on information given in the BREF Section 3.3.4]

4.3.5 Emissions to air

4.3.5.1 Diffuse emissions to air

BAT 49. In order to prevent or reduce diffuse emissions to air from all process steps (e.g. material handling and preparation, heating/reheating, heat treatment, hammering, finishing), BAT is to use both of the techniques given below.

Technique		Description
a.	Operational measures	This includes techniques such as: • use of closed bags or drums to handle materials with dispersible or water-soluble components; • minimise transport distances; • efficient material handling; • enclosure of storage areas; • enclosure of cooling lines.
b.	Extraction of off-gases from heating/reheating, heat treatment, hammering and finishing processes	Off-gases from heating/reheating, heat treatment, hammering and finishing processes are extracted using enclosures or hoods. Extracted off-gases from finishing processes may be treated using techniques such as fabric filters.

[This BAT conclusion is based on information given in the BREF Sections 3.3.5.1]

4.3.5.2 Emissions to air from heating and reheating

BAT 50. In order to prevent or reduce NO_X emissions to air from heating/reheating and heat treatment while limiting CO emissions, BAT is to use either electricity generated from fossil-free energy sources or an appropriate combination of the techniques given below.

Technique		Description	Applicability
a.	Use of a fuel or a combination of fuels with low NO_X formation potential	Fuels with a low NO_X formation potential include natural gas and liquefied petroleum gas.	Generally applicable.
b.	Combustion optimisation	Measures taken to maximise the efficiency of energy conversion in the furnace while minimising emissions (in particular of CO). This is achieved by a combination of techniques including good design of the furnace, optimisation of the temperature (e.g. efficient mixing of the fuel and combustion air) and residence time in the combustion zone, and use of furnace automation and control.	
c.	Furnace automation and control	See Section 4.4.1.	
d.	Flue-gas recirculation	Recirculation (external) of part of the flue-gas to the combustion chamber to replace part of the fresh combustion air, with the dual effect of lowering the temperature and limiting the O_2 content for nitrogen oxidation, thus limiting the NO_X generation.	Applicability to existing plants may be restricted by a lack of space.
e.	Low-NO_X burners	The technique (including ultra-low-NO_X burners) is based on the principle of reducing peak flame temperatures. The air/fuel mixing reduces the availability of oxygen and reduces the peak flame temperature, thus retarding the conversion of fuel-bound nitrogen to NO_X and the formation of thermal NO_X, while maintaining high combustion efficiency.	Applicability to existing plants may be restricted by design and/or operational constraints.
f.	Limiting the air preheating temperature	Limiting the air preheating temperature leads to a decrease of the concentration of NO_X emissions. A balance has to be achieved between maximising heat recovery from the flue-gas and minimising NO_X emissions.	Generally applicable.
g.	Oxy-fuel combustion	See Section 4.4.3.	Applicability to existing plants may be restricted by furnace design and the need for a minimum waste gas flow.

h.	Flameless combustion	See Section 4.4.3	Applicability to existing plants may be limited by furnace design (i.e. furnace volume, space for burners, distance between burners) and the need for a change of the furnace refractory lining. Not applicable to furnaces operating at a temperature lower than the auto-ignition temperature required for flameless combustion.

[This BAT conclusion is based on information given in the BREF Sections 3.1.4.1 and 3.3.6.2]

Table 4.22: BAT-associated emission level (BAT-AEL) for channelled emissions to air of NO_X and indicative emission level for channelled emissions to air of CO

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)	Indicative emission level (Daily average or average over the sampling period)
NO_X	mg/Nm^3	10-80	No indicative level
CO	mg/Nm^3	No BAT-AEL	< 10

The associated monitoring is given in BAT 48.

4.3.6 Water use and waste water generation

BAT 51. In order to optimise water consumption and to reduce the volume of waste water generated, BAT is to use both of the techniques given below:

- use of closed cooling circuits;
- segregation of water streams (see Section 2.1.4).

[This BAT conclusion is based on information given in the BREF Section 3.3.7.]

4.4 Descriptions of techniques

4.4.1 Techniques to increase energy efficiency

Technique	Description
Foamy slag practice	Simultaneous injection of oxygen and carbon (in the form of coal dust) into the slag at the end of the melting cycle in electric arc furnaces. This injection generates CO bubbles, forming a layer of foamy slag which insulates the molten metal and protects the furnace refractory lining.
Furnace automation and control	The heating process is optimised by using a computer system controlling in real time key parameters such as furnace and feedstock temperature, the air to fuel ratio and the furnace pressure.
Improving casting yield and decreasing scrap generation	Measures are taken to maximise the efficiency of the casting process and to decrease the generation of scrap, e.g.: • optimising melting and pouring operations to reduce for example melting losses, excessive pigging, scrap generation rates; • optimising moulding and core-making to reduce scrap generation resulting from deficiencies in moulds and cores; • optimising gating and rising systems; • using insulated exothermic feeders; • introducing more efficient casting technology (e.g. by using computer-aided simulation) to reduce the number of faulty castings generated.
Oxy-fuel combustion	Combustion air is replaced fully or partially with pure oxygen. Oxy-fuel combustion can be used in combination with flameless combustion.
Oxygen enrichment of the combustion air	Oxygen enrichment of the combustion air is realised either directly at the blast supply or through injection of oxygen into the coke bed, or via the tuyères.
Post-combustion of off-gases	See Section 4.4.3.
Preheating of combustion air	Reuse of part of the heat recovered from the combustion flue-gas to preheat the air used in combustion. This may be achieved for example by using regenerative or recuperative burners (see below). A balance has to be achieved between maximising heat recovery from the flue-gas and minimising NO_X emissions.
Recuperative burner	Recuperative burners employ different types of recuperators (e.g. heat exchangers with radiation, convection, compact or radiant tube designs) to directly recover heat from the flue-gases, which are then used to preheat the combustion air.
Regenerative burner	Regenerative burners consist of two burners which are operated alternately and which contain beds of refractory or ceramic materials. While one burner is in operation, the heat of the flue-gas is absorbed by the refractory or ceramic materials of the other burner and then used to preheat the combustion air.
Selection of an energy-efficient type of furnace	Furnace energy efficiency is taken into consideration for the furnace selection, e.g. furnaces that allow the preheating and drying of incoming charge prior to the melting zone.
Techniques for maximising the thermal efficiency of furnaces	Measures taken to maximise the efficiency of energy conversion in the furnace while minimising emissions (in particular of dust and CO). This is achieved by using furnace automation and control (see above) and by applying a series of process optimisation measures according to the furnace type. Measures include the following: For cupola furnaces: • optimisation of operational regime; • avoidance of excess temperature; • uniform charging; • minimisation of air losses; • good lining practice. For induction furnaces: • feedstock conditions (e.g. optimum size and density for input materials and scrap); • closure of furnace lid; • minimum holding time;

	• keeping a liquid heel in the furnace to reduce the duration of the melting cycle; • addition of carburisers at the beginning of the melting cycle; • operation at maximum power input level; • temperature control to prevent overheating; • prevention of excessive slag build-up by optimising melting temperatures; • minimisation and control of the wear of furnace refractory lining. For rotary furnaces: • use of anthracite and silicon for melt protection; • adjustment of the continuous or discontinuous speed rotation of the furnace to achieve maximum heat transfer; • adjustment of the power and angle of the burner to achieve maximum heat transfer. For electric arc furnaces: • shorter metal melting and/or treatment times using advanced control methods for example for the composition and the weight of the charged materials, the temperature of the melt, as well as by efficient sampling and deslagging methods. For shaft furnaces: • independent control of the fuel/air ratio for each gas-fired burner; • continuous CO or hydrogen monitoring for each row of burners; • addition of oxygen above the melting zone to provide afterburning in the upper level of the shaft; • preheating of the charge using waste heat recovered from the flue-gases. For reverbatory furnaces: • preheating of the charge in the case of dry hearth or side-well reverberatory furnaces; • use of burners with automatic temperature control. For crucible furnaces: • preheating of the crucible prior to charging; • use of crucibles with high thermal conductivity and thermal shock resistance (e.g. graphite); • cleaning of crucible walls immediately after emptying to remove slag or dross.
Use of clean scrap	Melting clean scrap prevents the risk of non-metal compounds being taken up by the slag and/or degrading the furnace or ladle refractory linings.

4.4.2 Techniques to increase material efficiency

Technique	Description
Adjustment of the slag acidity/basicity	Use of an appropriate flux (e.g. limestone for acidic and calcium fluoride for basic cupola operations) to render the slag fluid enough to separate from the iron.
Improving casting yield and decreasing scrap generation	See Section 4.4.1.
Mechanical pretreatment of slag / dross / filter dust / spent refractory linings to facilitate recycling	Generated slag / dross / filter dust / spent refractory linings are pretreated on site, by using techniques such as crushing, segregation, granulation, magnetic separation.
Minimisation of binder and resin consumption	Measures to minimise binder and resin consumption include: • use of a sand quality which is consistent with the binder system; • good management of sand storage and sand testing (purity, grain size, shape, moisture);

	• temperature control; • mixer maintenance and cleaning; • checking mould quality (to prevent and if necessary repair moulding defects); • optimising binder addition; • optimising mixer operation.
Separate spraying of release agent and water in high-pressure die-casting	Water and release agents are applied separately to the mould using an additional row of nozzles mounted on the spray head. Water is sprayed first, leading to a significant cooling of the mould before the application of the release agent, which results in reduced emissions and consumption of release agents and water.

Use of best practices for cold-setting processes	Practices include the following (according to the binding system used):
	• Temperature control: the temperature of the sand is kept as constant as possible and low enough to prevent emissions caused by evaporation. For phenolic- and furan-acid-catalysed, polyurethane and ester silicate systems, the optimum temperature range is between 15 ºC and 25 ºC. For resol-ester systems, the optimum temperature range is between 15 ºC and 35 ºC;
	• for furan-acid-catalysed systems:
	  o the content of free (monomer) furfuryl alcohol in the resin is minimised (e.g. less than 25 wt-%); and
	  o the sulphur content of the acid catalyst is reduced by substituting a portion of the sulphonic acid with a strong sulphur-free organic acid.

Use of best practices for gas-hardening processes	Practices include the following (according to the hardening process used): For phenolic urethane resins (cold-box process): • the consumption of amines is minimised by optimising the diffusion process within the core, typically through computer simulation for optimisation of the gas flow; • the sand temperature is maintained as constant as possible, between 20 ºC and 25 ºC, to minimise gassing time and amine consumption; • the moisture of the sand is maintained below 0.1 % and the gassing and purging air is dried; • core boxes are well sealed to allow the amine catalyst gas to be extracted and the cores are thoroughly purged to prevent amine releases during the storage of cores. For resol-ester resins: • the sand temperature is maintained as constant as possible, between 15 ºC and 30ºC; • curing of the alkaline phenolic resin is achieved using methyl formate that is gasified by air typically heated up to 80 ºC; • core boxes and gassing heads are sealed correctly and the venting of the core box designed to give a slight backpressure so that the curing vapour is held long enough for the reaction to take place. For CO_2-hardened resins (e.g. alkaline phenolic, silicate): • the exact volume of CO_2 gas necessary for curing the resins is used by employing a flow controller and a timer to achieve the best strength and storage time; • for silicate resins, liquid breakdown agents are employed (e.g. soluble carbohydrates) to increase gassing speed. For SO_2-hardened resins (e.g. phenolic, epoxy/acrylic): • the gassing period is followed by purging with the same inert gas (e.g. nitrogen) used for curing to remove the unreacted excess sulphuric dioxide from the sand; • core boxes are well sealed and the cores are thoroughly purged to prevent gas releases during the storage of cores.
Use of clean scrap	See Section 4.4.1.

4.4.3 Techniques to reduce emissions to air

Technique	Description
Adjustment of the slag acidity/basicity	See Section 4.4.2.
Adsorption	The removal of pollutants from a process off-gas or waste gas stream by retention on a solid surface (activated carbon is typically used as the adsorbent). Adsorption may be regenerative or non-regenerative.
Catalytic oxidation	Abatement technique which oxidises combustible compounds in a waste gas stream with air or oxygen in a catalyst bed. The catalyst enables oxidation at lower temperatures and in smaller equipment compared to thermal oxidation. The typical oxidation temperature is between 200 °C and 600 °C.
Cyclone	Equipment for the removal of dust from an off-gas stream based on imparting centrifugal forces, usually within a conical chamber. Cyclones are used as a pretreatment before further dust abatement or abatement of organic compounds. Cyclones can be applied alone or as multicyclones.
Dry lime injection	Dry lime is introduced and dispersed in the off-gas stream. It reacts with the acidic gaseous species (e.g. SO_2) to form a solid which is removed by filtration (e.g. fabric filter).
Electrostatic precipitator	Electrostatic precipitators (ESPs) operate such that particles are charged and separated under the influence of an electrical field. Electrostatic precipitators are capable of operating under a wide range of conditions. Abatement efficiency may depend on the number of fields, residence time (size), and upstream particle removal devices. They generally include between two and five fields, but may contain up to seven fields for the most advanced ESPs. Electrostatic precipitators can be of the dry or of the wet type depending on the technique used to collect the dust from the electrodes. Wet ESPs are typically used at the polishing stage to remove residual dust and droplets after wet scrubbing.
Extraction of off-gases generated from moulding and/or core-making	Off-gases generated from moulding and/or core-making are extracted. The extraction system selected depends on the type of moulding/core-making process. • Natural/green sand moulding: Off-gases generated in the natural or green sand preparation areas (e.g. transport, sieving, mixing and cooling) and in the moulding areas, especially during pouring, are extracted. In the case of automatic moulding machines, appropriate extraction systems are used to collect emissions (e.g. roof extraction). In the case of hand moulding, extraction as close as possible to the emission source is achieved using mobile extraction hoods. • Cold-setting, gas curing, hot-curing processes: In the case of automatic moulding machines, extraction systems are used to collect emissions (e.g. fixed extraction hoods, canopy extraction). In the case of hand moulding, extraction as close as possible to the emission source is realised using mobile extraction hoods. Core shooting machines are enclosed and off-gases are extracted. Extraction is also applied during checking, handling and storage of freshly made cores (e.g. by using hoods at the checking table, above the handling and temporary storage areas).
Fabric filter	Fabric filters, often referred to as bag filters, are constructed from porous woven or felted fabric through which gases are passed to remove particles. The use of a fabric filter requires the selection of a fabric suitable for the characteristics of the waste gas and the maximum operating temperature.
Flameless combustion	Flameless combustion is achieved by injecting fuel and combustion air separately into the combustion chamber of the furnace at high velocity to suppress flame formation and reduce the formation of thermal NO_X while creating a more uniform heat distribution throughout the chamber. Flameless combustion can be used in combination with oxy-fuel combustion (see Section 4.4.1).
Flue-gas recirculation	Recirculation (external) of part of the flue-gas to the combustion chamber to replace part of the fresh combustion air, with the dual effect of lowering the temperature and limiting the O_2 content for nitrogen oxidation, thus limiting the

	NO_X generation. It implies the supply of flue-gas from the furnace into the flame to reduce the oxygen content and therefore the temperature of the flame.
Foamy slag practice	See Section 4.4.1.
Furnace automation and control	See Section 4.4.1.
Limiting the temperature of air preheating	Limiting the air preheating temperature leads to a decrease of NO_X emissions. A choice has to be made between maximising heat recovery from the flue-gas and minimising NO_X emissions.
Low-NO_X burner	The technique (including ultra-low-NO_X burners) is based on the principles of reducing peak flame temperatures. The air/fuel mixing reduces the availability of oxygen and reduces the peak flame temperature, thus retarding the conversion of fuel-bound nitrogen to NO_X and the formation of thermal NO_X, while maintaining high combustion efficiency.
Minimisation of binder and resin consumption	See Section 4.4.2.
Oxygen enrichment of the combustion air	See Section 4.4.1.
Oxy-fuel combustion	See Section 4.4.1.
Post-combustion of off-gases	Post-combustion of CO and other organic compounds contained in furnace off-gases is used to reduce emissions and for heat recovery. The generated heat is recovered with a heat exchanger and used for blast air preheating or other internal purposes. In HBC furnaces, post-combustion takes place in a separate post-combustion chamber preheated with a natural gas burner. In CBC furnaces, post-combustion takes place directly in the cupola shaft. In rotary furnaces, post-combustion is carried out using an afterburner installed between the furnace and before the heat exchanger.
Selection of an appropriate furnace type	Selection of the appropriate furnace type(s) based on the level of emissions and technical criteria, e.g. type of process such as continuous or batch production, furnace capacity, type of castings, availability of raw materials, flexibility depending on raw materials cleanliness and alloy change. The energy efficiency of the furnace is also considered (see technique 'Selection of an energy-efficient type of furnace' in Section 4.4.1).
Substitution of alcohol-based coatings with water-based coatings	Substitution of alcohol-based coatings of moulds and cores with aqueous coatings. Aqueous coatings are dried in ambient air or using drying ovens.
Thermal oxidation	Abatement technique which oxidises combustible compounds in a waste gas stream by heating it with air or oxygen to above its auto-ignition point in a combustion chamber and maintaining it at a high temperature long enough to complete its combustion to carbon dioxide and water. The typical combustion temperature is between 800 °C and 1 000 °C. Several types of thermal oxidation are operated: • Straight thermal oxidation: thermal oxidation without energy recovery from the combustion. • Recuperative thermal oxidation: thermal oxidation using the heat of the waste gases by indirect heat transfer. • Regenerative thermal oxidation: thermal oxidation where the incoming waste gas stream is heated when passing through a ceramic-packed bed before entering the combustion chamber. The purified hot gases exit this chamber by passing through one (or more) ceramic-packed bed(s) (cooled by an incoming waste gas stream in an earlier combustion cycle). This reheated packed bed then begins a new combustion cycle by preheating a new incoming waste gas stream.

Use of best practices for cold-setting processes	See Section 4.4.2.
Use of best practices for gas-hardening processes	See Section 4.4.2.
Wet scrubbing	The removal of gaseous or particulate pollutants from a gas stream via mass transfer to a liquid solvent, often water or an aqueous solution. It may involve a chemical reaction (e.g. in an acid or alkaline scrubber). In some cases, the compounds may be recovered from the solvent. This includes venturi scrubbers.

4.4.4 Techniques to reduce emissions to water

Technique	Description
Activated sludge process	In the activated sludge process, the microorganisms are maintained as a suspension in the waste water and the whole mixture is mechanically aerated. The activated sludge mixture is sent to a separation facility from which the sludge is recycled to the aeration tank.
Adsorption	The removal of soluble substances (solutes) from the waste water by transferring them to the surface of solid, highly porous particles (typically activated carbon).
Aerobic treatment	The biological oxidation of dissolved organic pollutants with oxygen using the metabolism of microorganisms. In the presence of dissolved oxygen, injected as air or pure oxygen, the organic components are mineralised into carbon dioxide and water or are transformed into other metabolites and biomass.
Chemical precipitation	The conversion of dissolved pollutants into an insoluble compound by adding chemical precipitants. The solid precipitates formed are subsequently separated by sedimentation, air flotation or filtration. If necessary, this may be followed by microfiltration or ultrafiltration. Multivalent metal ions (e.g. calcium, aluminium, iron) are used for phosphorus precipitation.
Chemical reduction	The conversion of pollutants by chemical reducing agents into similar but less harmful or hazardous compounds.
Coagulation and flocculation	Coagulation and flocculation are used to separate suspended solids from waste water and are often carried out in successive steps. Coagulation is carried out by adding coagulants with charges opposite to those of the suspended solids. Flocculation is carried out by adding polymers, so that collisions of microfloc particles cause them to bond to produce larger flocs.
Equalisation	Balancing of flows and pollutant loads at the inlet of the final waste water treatment by using central tanks. Equalisation may be decentralised or carried out using other management techniques.
Evaporation	Evaporation of waste water is a distillation process where water is the volatile substance, leaving the concentrate as bottom residue to be handled (e.g. recycled or disposed of). The aim of this operation is to reduce the volume of waste water or to concentrate mother liquors. The volatile steam is collected in a condenser and the condensed water is, if necessary after subsequent treatment, recycled. There are many types of evaporators: natural circulation evaporators; short-tube vertical evaporators; basket-type evaporators; falling film evaporators; agitated thin film evaporators. Typical pollutants targeted are soluble contaminants (e.g. salts).
Filtration	The separation of solids from waste water by passing them through a porous medium, e.g. sand filtration, microfiltration and ultrafiltration.
Flotation	The separation of solid or liquid particles from waste water by attaching them to fine gas bubbles, usually air. The buoyant particles accumulate at the water surface and are collected with skimmers.
Membrane bioreactor (MBR)	MBR consists of the combination of a membrane process (e.g. microfiltration or ultrafiltration) with a suspended growth bioreactor. In an MBR system for biological waste water treatment, the secondary clarifier and the tertiary filtration step of a traditional aerated sludge system is replaced by membrane filtration (the separation of sludge and suspended solids).

Nanofiltration	A filtration process in which membranes with pore sizes of approximately 1 nm are used.
Neutralisation	The adjustment of the pH of waste water to a neutral level (approximately 7) by the addition of chemicals. Sodium hydroxide (NaOH) or calcium hydroxide ($Ca(OH)_2$) is generally used to increase the pH, whereas sulphuric acid (H_2SO_4), hydrochloric acid (HCl) or carbon dioxide (CO_2) is generally used to decrease the pH. The precipitation of some substances may occur during neutralisation.
Physical separation	The separation of gross solids, suspended solids, metal particles from the waste water using for example screens, sieves, grit separators, grease separators, hydrocyclones, oil-water separation or primary settlement tanks.
Reverse osmosis	A membrane process in which a pressure difference applied between the compartments separated by the membrane causes water to flow from the more concentrated solution to the less concentrated one.
Sedimentation	The separation of suspended particles and suspended material by gravitational settling.
Segregation of water streams	Water streams (e.g. surface run-off water, process water) are collected separately, based on the pollutant content and on the required treatment techniques. Waste water streams that can be recycled without treatment are segregated from waste water streams that require treatment.

5 EMERGING TECHNIQUES

5.1 Emerging techniques for smitheries

No information has been submitted on emerging techniques. TWG please provide additional information if available.

5.2 Emerging techniques for foundries

TWG please provide additional information, if available.

5.2.1 Use of low-cost combustible materials in cupola melting

No further information has been submitted for this technique. TWG please provide additional information, if available. If there is no confirmation that this technique is used, it may be deleted.

Description
In order to reduce the consumption of (high quality) coke, techniques have been developed to allow the use of high calorific value solid waste and lower grade coke as a fuel.

A particular type of cupola, named the FAR furnace, has been developed in Brazil, that allows the melting of a conventional charge using tyres and plastic pieces (automotive shredder residue - ASR, fluff, etc.), mixed with second rate coke. The cupola structure is totally different from the conventional one. Only the metallic charge enters from the top. The solid fuel is fed in from the side, so that it reaches the hot zone very quickly. Here hydrocarbons are cracked and combusted.

Alternative injection systems allow the addition of fluff or dust directly through the tuyères or by using specific injectors.

Achieved environmental benefits
A reduction in the consumption of cokes, as they are replaced by solid waste (ASR, fluff), which is difficult to treat in conventional combustion systems.

Operational data
For the FAR furnace, the best results have been obtained using 35 % fluff and 65 % coke. This technique has been developed up to pilot scale.

Cross-media effects
The application of alternative fuels will cause a change in the flue-gas composition; leading to higher amounts of dust for disposal, possibly with a higher content of pollutants and an increased risk of dioxins, PAHs and heavy metals. The thermal efficiency will be reduced.

Applicability
The application of this specific cupola type is only possible for new installations, since it has a specific furnace layout. Injection systems for solid or fluffy fuels may be applied on existing cupola furnaces.

Economics
Since the process has only been developed up to pilot scale, there are no economic data available for industrial scale application.

Driving force for implementation
To reduce the costs for fuels and to integrate the foundry into a waste management policy.

Example plants
TWG please provide information

Reference literature
~~[47, EU Thematic Network Foundry Wastes 2001][47, EU Thematic Network Foundry Wastes 2001]~~

5.2.2 Recycling of metal-bearing filter dust (ferrous metals)

No further information has been submitted for this technique. TWG please provide additional information if available. If there is no confirmation that this technique is used, it may be deleted.

Description
Recovery of metal content from the filter dust in ferrous metal induction furnace.

Technical description
Metal-bearing dust can be agglomerated either using a binder (most preferably cement) or by mixing it with chips from machining, when the foundry has a machining shop. In the latter case the agglomerates may also include metal-bearing sludge. These agglomerates will be mixed in the induction furnace charge and melted. The metal yield can be over 90 %. The rest of the dust goes into the slag. Suitable agglomeration machines exist on the market.

Achieved environmental benefits
The amount of waste to be disposed of in landfills will be reduced, as will the need to buy metallic material outside the foundry. The mineral part of the metallic dust will not melt and is taken up by the slag. Thus it is converted into a less hazardous form of waste.

Environmental performance and operational data
Operational data are currently not available.

Cross-media effects
It may be possible that the slag formed will increase lining wear. Also the energy used in melting may increase slightly. In steel foundries, there is a risk of carbon pick-up.

Technical considerations relevant to applicability
The technique applies to new and existing iron and steel foundries using induction melting furnaces.

Economics
In its current stage of development, no ecomic data are yet available. However, in initial estimates for one iron foundry with a machining shop, the payback time was calculated to be between two and four years.

Driving force for implementation
The main driving force for implementation may be that melting dust could, at least in some cases, be classified as hazardous waste. This would incur very high disposal costs for foundries.

Example plants
No example plants are available.

Reference literature
The technique is under development in the EU in an FP5 Growth project BRICETS "Metal By-Product Recovery in Induction Furnaces - Commercial, Environmental and Technical Solutions", contract number G1RD-CT-2001-00482. The project is due to finish in spring 2004. [47, EU Thematic Network Foundry Wastes 2001][47, EU Thematic Network Foundry Wastes 2001], [100, TWG, 2002]

5.2.3 Amine recovery from the core-making waste gas by gas permeation

No further information has been submitted for this technique. TWG please provide additional information if available. If there is no confirmation that this technique is used, it may be deleted.
For the amine recovery technique, see Section 3.2.1.4.3.6.

Technical description
In a pilot plant, amine (DMIPA) was recycled from the exhaust air of a core shop by means of gas permeation. Its composition was as follows:

- 80 – 90 % amine (DMIPA)
- 10 – 20 % solvent
- 0 % water.

After several test series, the recycled amine was used to gas brake-disk cores. It was found that there was no difference between these cores and the cores which were gased with standard commercial DMIPA. The test cores were poured under normal production conditions and the finished brake disks underwent the usual technical tests.

All the results turned out to be within permissible tolerance. This showed that recycled DMIPA can be used under normal production conditions. Economic efficiency may be achieved after further optimisation of the plant.
[217, Paul, et al., 1994]

Reference literature
[217, Paul, et al., 1994]

~~5.2.4 Inorganic binder material for core-making~~

This technique is now proposed as candidate BAT, see Section 3.2.1.9.11

~~**Description**~~
~~In order to reduce the consumption of organic binding material, which is responsible for emissions and odour in foundries (which can lead to complaints from neighbours), different compositions of inorganic binding materials have been developed for use in core-making in aluminium die-casting and have already been used in the series production of intake pipes for car engines.~~

~~The cores are produced using a binder that contains magnesium sulphate and/or polyphosphate. The inorganic binders consist essentially of salt-water mixtures, as well as small amounts of additives (e.g. ceramic) to prevent sand adhering or sticking to the casting. The proportion of binder relative to the quantity of sand by weight is 3 to 8%. About half of this amount is solvent and crystal water.~~

~~In order to achieve short drying times of 10 to 20 seconds, preheated sand (60 – 80 ºC) is blown into heated core-shooting tools (120 – 140 ºC), in which the solvent water and the crystal water evaporate and are flushed out by air. The inorganic ceramic core will then have a temperature stability of more than 1000 ºC, and will maintain high strength. When coming directly into contact with water, the core disintegrates within a few seconds. The mixing and shooting of warm sand is a patented core-shooting method.~~

~~After casting, core removal can be performed either wet or dry. In dry core removal, the lumps of sand are ground to grain size, which leaves the binder layer on the quartz sand largely intact. Therefore, once core sand is in the core sand cycle, binder must be added to it at only 5 % of the~~

~~binder quantity originally used. In wet core removal, the castings are cooled rapidly by quenching. This can cause a desired improvement of the microstructure and causes the binder to dissolve completely.~~
~~The different sand flowing properties will require revision of the core models and venting upon implementation of this technique in an existing plant. In the drying step, all the moisture needs to leave the core, a requirement which may limit the core dimensions.~~

~~Achieved environmental benefits~~
~~Unlike the cold-box process, which gives rise to emissions of organic compounds such as amines, pyrolysis products and smoke, this technique involves no emissions from the binder, neither during core-shooting nor during casting. No waste is generated through the disposal of sand residues, and there is no need for costly sand regeneration. The quantity of sand to be replaced is very small.~~

~~The ceramic additives contained in the binder eliminate the need to coat the cores.~~

~~When a dry technique is used for core removal, all the binder remaining in the sand can be re-used.~~

~~Operational data~~
~~The fluidity of the binder-sand mixture is sufficient to produce complex shapes such as water jacket cores (cylinder head). The stability of test cores is 250 - 300 N/cm^3. The stability can be adapted to core requirements by adding more binder.~~

~~As no gases form during casting, no problems with gas permeability arise. The binder therefore allows the use of very fine sands, which significantly improve surface quality (e.g. depth of roughness). As the regeneration rate is high, it is economically viable to use even expensive alternative synthetic ceramic sands or e.g. zircon sand.~~

~~Cross-media effects~~
~~As there are no emissions from the binder, there is no need for waste gas collection and treatment. The heating of the binder-sand mixture and the preheating of the core-shooting tools give rise to higher energy costs compared to other core-making techniques.~~

~~Applicability~~
~~This technique is applicable for core-making in aluminium die-casting in new plants and in existing plants after adaptation of the core-shooting automates. Further developments are aimed at adapting the binder for use in iron casting and as a moulding material.~~

~~Economics~~
~~Despite the need to heat core-shooting tools, this technique leads to overall cost savings for core-making, due among other things to the lower consumption of new sand and the fact that costly thermal regeneration or the disposal of sand is no longer necessary. Costs savings can also be generated by recirculating the binder. Considerable cost reductions are achieved by the fact that there is no need for waste gas treatment systems to remove organic compounds, such as amines and pyrolysis products, which can arise during core-shooting and casting when organic binders are used.~~

~~According to rough estimates, the use of this technique reduces the costs for core-making by 30 to 50 % compared to the cold-box process.~~

~~Driving force for implementation~~
~~Considerable cost reduction.~~
~~Reduction of odour problems and organic emissions.~~

~~Example plants~~
~~Foundry of VW AG, Hanover, Germany~~

~~**Reference literature**~~
~~[235, Bischoff, 2003]~~

5.2.5 Fossil-free recycling of residues

TWG, it is unclear whether this emerging technique shall be included in the Smithereis and Foundries BREF or in the next revision of the IS BREF. Based on the information provided, the latter seems more appropriate. TWG, please provide your views on this issue.

Description
Hydrogen-based process to reduce metal oxides, mainly iron, to pure metal without GHG emissions.

Technical description
This flexible technique can be used to recycle oxidised scale filter dust, grinding swarf, mine tailings and produce sponge iron from iron ore.

- the process and system solution is a hydrogen-based process to reduce metal oxides, mainly iron, to pure metal without GHG emissions.
- the process and system solution is also suitable for the reduction of other metal oxides in accordance with the Ellingham diagram, such as copper, cobalt and molybdenum.

The technique consists of a closed-circuit bell furnace with electrical heating units.

The main drivers of the process are the laws regarding temperature, pressure differences and mass:

- hydrogen's affinity to pair with oxygen at 550°C.
- the relatively cold steam formed in the reduction process (endothermic process) will be forced downwards by the surrounding hot hydrogen
- water steam is heavier than hydrogen and therefore forced downwards (9 times heavier than H_2).
- the condensation of water steam creates a pressure difference between the top and bottom area of the furnace (volume reduction 1:1244 from steam to water)

The furnace is loaded with a charge of pellets created from iron ore or residues as oxidised scale, filter dust, grinding swarf etc. The furnace is evacuated and flushed with nitrogen in order to guarantee the absence of oxygen. The hydrogen is then added under pressure, and the hydrogen reacts with the oxygen in the material and water steam is formed. The oxides in the residual products are reduced and the pure metal that is retained in the pellets in the charge can be reintroduced as raw material in the production process.

Achieved environmental benefits
The main environmental benefits are

- no CO_2 emissions.
- increases the proportion of recycling, which will decrease the requirement of virgin material and its processing through CO_2 intensive blast furnaces.
- reduces the need of transport.

The only output from the process is pure metal and water.

The furnace is small and has a low capital expenditure. Therefore, it can be placed at sites, where the residues and waste are created or collected, with the benefit of reducing transportation. Transporting non-oxidised material reduces transported weight by up to 30%.

Environmental performance and operational data
The process energy requirement is 1650-2100 kWh per tonne of iron-containing material depending on the oxidation level of the input material.

Cross-media effects
The water formed in the process may contain some impurities which need to be removed prior to release. The amounts of impurities depend on the input being processed. Prior to processing the material is analysed and a water treatment facility ensures that no water containing harmful substances is released.

From the furnace there are zero gaseous emissions since all gases are converted to water or reused.

The hydrogen used in the process can be produced through electrolysis which would require green electricity to have a lower environmental impact. Alternatively, it can be produced through gasification of biomass to hydrogen. These are hydrogen production methods offered in the market.

Technical considerations relevant to applicability
A furnace with 5 tons charge capability is small, but modular and thus fully scalable. One furnace can process approximately 40 000 tonnes of matter per annum. Two or more furnaces can be operated in parallel. A multi furnace solution operated in asynchronous mode will enable further energy savings by heating the charge to be processed with the hot gases from the cooling process of the previous charge, thus not releasing and losing any energy.

The furnace can be installed at foundries, steel plants, metal manufacturers, recycling centers and at mines with suitable mine tailings.

The technique is applicable for new and existing foundries.

Economics
The cost for a single furnace, the gas handling and its components is approximately EURO 2 million (2021 values), excluding the investment in peripheral equipment such as storage containers, cranes, pelletizer and electrolysis.

Approximately 85 % of the production costs stem from the energy consumed in the production of hydrogen through electrolysis. With the cost of electrolysis steadily falling, while the cost for emission rights is expected to increase, the cost competitive position of this technique compared to existing fossil-based solutions is expected to improve even more over time.

[Sweden will submit updated information regarding costs]

Driving force for implementation
The main drivers for implementation are to contribute to the reduction of CO_2 emissions as well as increased recycling.

Date of implementation
The production furnace is in the final design phase with Seco/Warwick. Linde Gas is providing the hydrogen and the testing is performed in a pilot plant located at a Linde Gas facility in Stockholm.
A realisation of a full-scale commercial size plant is in progress.
[Sweden will submit updated information.]

Example plants
At the Linde Testing Facility in Stockholm, Magnetite and Hematite have been reduced to pure iron with 100% reduction and 100% metallisation.

5.2.6 Online analysis of temperature and chemical composition

TWG, it is unclear where this emerging technique could be useful in foundries. It seems that it could be applied in AOD converters and moulding pot. However, there is need to clarify if these are the only two possible applications and to clarify what exactly the moulding pot is. This technique seems to be entirely aimed at process control and on-line analysis of slag and iron. The environmental benefits are unclear. Please re-submit the technique with the necessary clarifications.

Description

Online analysis of temperature and chemical composition of slag and molten metal by using broadband spectral thermometry (BST) and laser-induced breakdown spectroscopy (LIBS).

Technical description

Within the context of the EU CONSENSO project, equipment for online analysis of temperature and chemical composition was developed. This equipment is based on broadband spectral thermometry (BST) and laser-induced breakdown spectroscopy (LIBS). Installations are planned at various production steps in the iron and steel-making process; typically at the AOD converter and moulding pot.

The main components of the LIBS technique are: laser, optics, spectrometer. The working-principle is as follows: Laser-pulses are focused on the sample to create a plasma. The atoms and ions in the plasma then emit light characteristic to each element. The light is then analysed with a spectrometer. By analysing the spectral data the chemical composition of the sample can then be derived. No chemicals or gases are needed for the equipment, only electricity. In the CONSENSO project LIBS is developed for analysis of chemical composition of slag and iron in the form where it is still hot and thus will be useful for process control. Primarily the technique is developed for quick and easy inline sampling, but could also be applied for online measurement directly in the production process without sampling.

BST is composed of optics and spectrometer only. The principle is tha same as conventional pyrometry. The object mitts radiation which is analysed based on Planck's law for black body radiation. In contrast to normal pyrometry BST uses information in a wide spectral range and can therefore better cope with interferences such as smoke or other unwanted material that is obscuring the sight of the material of interest.

Achieved environmental benefits

The main advantage of the techniques is enhanced process control, which ensures that the material has the right quality when it is being produced and thus less products are rejected and turned to waste. With the chemical analysis it can be ensured that not more than needed material is used, and hence enables a more efficient use of resources. Due to a quicker analysis the time spent heating the metal can be reduced and thus considerable energy savings are possible. With better control of the chemistry it is also possible that the slag composition can be adjusted so that it can be used as a secondary resource and hence cut down on the waste.

Environmental performance and operational data

The CONSENSO project is still in the phase of constructing the prototypes. Next year the techniques will be evaluated at industrial sites, and therefore there are no available actual plant-specific performance data obtained applying the technique.

The techniques developed in CONSENSO will not directly reduce emissions or energy consumption. They instead enable a more efficient process control, which in turn will lead to reduced emission and use of raw material.

Cross-media effects

No negative environmental effects.

Technical considerations relevant to applicability
BST can be used in most sectors where there is a need for temperature control. The greatest need is seen in the metals production since the harsh environment makes other available techniques less suitable.

Economics
Equipment is under development and costs are therefore not known.

Driving force for implementation
BST and LIBS are the only known techniques that work under these requirements. LIBS uses a high power laser that may cause eye-damage. But in the format that the techniques are used in CONSENSO, no safety measures are needed.

Example plants
It has not been installed anywhere yet

Reference literature
EIT RawMaterials: https://eitrawmaterials.eu/

5.2.7 Spark Plasma Sintering

TWG, it is unclear at which stage / for which process this emerging technique could be useful in foundries, please re-submit the technique with the necessary clarifications.

Description
Fast production of high-performance parts using pressure and heat.

Technical description
The special feature of Spark Plasma Sintering (SPS) is based on the heat generation thanks to the passage of a high-intensity current as close as possible to the workpiece via the graphite mould. This leads to a situation in which temperature rises extremely fast (up to 100°C/min) and sintering cycles only take a few minutes. In comparison to natural or conventional sintering, Spark Plasma Sintering, has the advantage of reducing the sintering duration and temperatures. Grain growth in the material is therefore very limited and the materials obtained have much better performances. Better control of microstructures is therefore possible within the parts obtained while also achieving densification rates close to the theoretical density.

The advantages of parts obtained by SPS could be resumed in:
- increase of mechanical performance ;
- reduction of material loss (less than 5%) ;
- reduction of production time (less than 1h).

The target materials could be metal, ceramic or composite. One specificity of SPS is also to work on metal/ceramic assembly. The control of thermal gradient and holding time allows the operator to manage stress in the material during the cooling.

Achieved environmental benefits
SPS technology is based on powder metallurgy. The preparation of specific tools allows the operator to make directly near net shape parts in one step (<1 h of thermal treatment). The material losses are drastically reduced compare to all the traditional process and can be less than 5 %.

This advantage is very useful for high value material used for aerospace, automotive, defence and energy application.

The SPS process is also an opportunity to renew design and composition of critical material with strategic dependence for sourcing. For example, developments are running to reduce or avoid the cobalt amount in tungsten carbide cutting tools. These results will lead to a reduction of strategic needs from non-European countries.

Environmental performance and operational data
No information provided.

Cross-media effects
Buy to fly ratio is one of the more important parameters check in aerospace. The material lost during process could be more than 80% of the material bought initially which is considered high.

SPS is one of the leading technologies which could provide such solution thanks to its two advantages:

- low material loss ;
- possibility to develop smarter material design and composition.

Technical considerations relevant to applicability
SPS technology is not limited to one sector, the problematic of material loss and increasing the material properties are common to all the industries.

Economics
No information provided.

Driving force for implementation
No information provided.

Example plants
Spark Plasma Sintering is now being commercialised. A European SPS machine provider is one of the top two leaders in the world (FCT Systeme GmbH).
Producers are now available in France (Toulouse or at Sintermat). Other stakeolder have invested in the technology as Sandvik Coromant or Mecachrome for their development.

Reference literature
EIT RawMaterials: https://eitrawmaterials.eu/

6 CONCLUDING REMARKS AND RECOMMENDATIONS FOR FUTURE WORK

This Chapter will be completed after the final TWG meeting.

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8 GLOSSARY

8.1 Abbreviations

This section will be updated at a later stage

AEL	associated emission level
ADI	austempered ductile iron
AFS	American Foundrymen Society
AFS number	measure of particle size distribution of foundry sand
AOD converter	argon oxygen decarburisation converter
AOX	absorbable organic halides
BAT	best available techniques
BREF	BAT reference document
BTEX	benzene, toluene, ethylbenzene,xylene
BTX	benzene, toluene,xylene
CAD	(before number): Canadian Dollar - ISO currency unit
CAD	(general): Computer aided design
CAEF	Committee of Associations of European Foundries
CAM	computer-aided manufacturing
CBC	cold blast cupola
CNC	computer numerical controlled
DEM	Deutsche Mark (German Mark - ISO currency unit)
DMEA	dimethyl ethyl amine
DMIPA	dimethyl isopropyl amine
DMPA	dimethylpropylamine
DS	dry solid
EAF	electric arc furnace
EEA	European Environment Agency
EFR	Emission Factor Rating
EIPPCB	European IPPC Bureau
EMS	environmental management system
EP	electrostatic precipitator
EPER	European Pollutant Emission Register
EPS	expanded polystyrene
EUR	euro
FA	furfuryl alcohol
GWP	global warming potential
GBP	Great Britain Pound – ISO currency unit
HBC	hot blast cupola
HCE	hexachloroethane
HFC	hydrofluoro carbon
HIP	hot isostatic pressing
HP	high purity (for Magnesium alloys)
HPDC	high pressure die-casting
ID-fan	induced draught fan
IF	induction furnace
IMA	International Magnesium Association
IPA	isopropyl alcohol
IPPC	integrated pollution prevention and control
IPTS	Institute for Prospective Technological Studies
JRC	Joint Research Centre
l.	left
LCA	life cycle assessment
LOI	loss on ignition
m.	middle

MDI	methyl di-isocyanate
n.a	not applicable
n.d	no data
NM-VOC	non-methane volatile organic carbons
OU	odour units
PAH	polycyclic aromatic hydrocarbon
PCDD/F	polychlorinated dibenzodioxins and -furans
PCB	polychlorinated biphenyl
PE	polyethylene
PEVA	polyethylene vinyl acetate
PF	phenol - formaldehyde
PFC	perfluorinated carbon
PM	particulate matter
PMMA	polymethylmethacrylate
ppm	parts per million
r.	right
RF	rotary furnace
RP	rapid prototyping
RPM	respirable particulate matter
SG	spheroidal graphite
SME	small and medium enterprise(s)
TEA	triethyl amine
TEQ	toxicity equivalent factor
TWA	time-weighted average
TWG	technical working group
VOC	volatile organic compound
VODC	vacuum oxygen decarburisation converter
UF	urea-formaldehyde
USD	United States Dollar – ISO currency unit

8.2 Terms

This section will be updated at a later stage

Annealing	a heat treating process that softens the alloy by slow cooling the metal through its critical temperature range
Austenitising	a heat treating process that holds the alloy above the critical temperature for a sufficient period of time to ensure that the matrix is fully transformed to austenite
Air factor	λ, the ratio of the air added to a combustion process over the stoechiometric quantitiy of air needed for complete oxidation
Cast iron	a ferrous alloy which solidifies with an eutectic solidification reaction, whatever the chemical composition, but normally with a carbon content above 2 %
Casting *(noun)*	general term used for products at or near their finished shape, formed by solidification of a metal or alloy in a mould (ISO 3134-4: 1985)
Diffuse emission	emissions arising from direct contact of volatile or light dusty substances with the environment (atmosphere, under normal operating circumstances). These can result from: - inherent design of the equipment (e.g. filters, dryers…) - operating conditions (e.g. during transfer of material between containers) - type of operation (e.g. maintenance activities) - or from a gradual release to other media (e.g. to cooling water or waste water). Fugitive emissions are a subset of diffuse emissions
Emission	the direct or indirect release of substances, vibrations, heat or noise from individual or diffuse sources in the installation into the air, water or land
"End-of-pipe" technique	a technique that reduces final emissions or consumptions by some additional process but does not change the fundamental operation of the core process. Synonyms: "secondary technique", "abatement technique". Antonyms: "process-integrated technique", "primary technique" (a technique that in some way changes the way in which the core process operates thereby reducing raw emissions or consumptions)
Existing installation	an installation in operation or, in accordance with legislation existing before the date on which this Directive is brought into effect, an installation authorised or in the view of the competent authority the subject of a full request for authorisation, provided that that installation is put into operation no later than one year after the date on which this Directive is brought into effect
Ferrous materials	those materials of which iron is the major constituent, i.e. the content of Fe (%w/w) is higher than that of any other element (following EN10020:2000; §2.1)
Full mould process	moulding technique using a foam model in chemically bonded sand, in which the model is lost upon pouring, generally used only for large castings
Grain refinement	a liquid metal treatment made late in the melting operation to produce a finer and equiaxed grain during solidification.
Green sand	mix of sand, clay and additives as used for mould making
Grey iron	cast iron with grey-coloured fracture; may be found with lamellar, nodular and compact graphite but the term is most often used for lamellar iron
Hearth type furnace	static furnace with direct heating, also called reverberatory furnace and bale-out furnace
Inclusion	(specific term for this sector) impurity in the metal structure, producing structural defects; mostly used for non-ferrous metals (e.g. oxides in magnesium, hydrogen in aluminium)

Jungbüth or net diagram	diagram representing the influence of the blast rate and the coke charge on the tapping temperature of the metal and the melting rate; used for cupola furnaces
Lamellar iron	cast iron with carbon in the form of flakes
Lost Foam process	moulding technique using foam models in unbonded sand, in which the model is lost upon pouring of the metal, used for series production
Lost mould	or single use moulds, a mould that is specially made for each casting and is destroyed after pouring. The moulds are generally made of sand, chemically bonded or clay-bonded, or even unbonded. Investment casting can also be included in this family
Lost mould casting	all processes of the moulding and casting shop in a foundry using lost moulds, such as sand preparation, moulding, core-making, pouring, cooling and shake-out
Malleable iron	iron that is capable of extension or of being shaped under the hammer; produced by decarburising (whiteheart malleable iron) or not decarburising (blackheart malleable iron) heat treatment of graphite-free iron with white fracture surface (white cast iron)
Melting capacity	the aggregate 'plated' capacity of the furnaces at an installation; where the hourly rate multiplied by 24 should be used if appropriate
Modulus	silica-to-soda ratio SiO_2/Na_2O, used to characterise (sodium) silicates
Nodular iron	cast iron with carbon in nodular/spheroidal shape, commonly refered to as ductile iron
Nodularisation	magnesium treatment of cast iron to change the carbon particles into nodular/spheroidal shape
Non-ferrous materials	all materials that are not ferrous
Normalising	a heat treating process that cools the alloy in air from a temperature above its critical range
Off-site sand re-use	utilisation of sands in various ways
Permanent mould	or multi use a mould, mould that is used for gravity and low-pressure casting, pressure die-casting, or centrifugal casting; typically the moulds are metallic
Permanent mould casting	all processes of the coreshop and casting shop in a foundry using permanent moulds, such as sand preparation, core-making, die-casting, take-out and decoring
Pollutant	individual substance or group of substances which can harm or affect the environment
Post combustion	ignition and burning of exhaust gas through the injection of air or the use of a burner; used in order to reduce the amount of CO and (volatile) organic compounds
Primary regeneration	the processing of used green sand for internal re-use in the sand circuit, using screening, sieving, cooling and mixing with new sand, fresh bentonite and other additives
Production capacity	production of 'good castings' and capacity based on the theoretical capacity of the foundry if it was operated for 24 hours, provided that it is technically able to operate that way
Regeneration ratio	the ratio between the mass of regenerated sand and the total mass of sand used in mould and core-making, expressed as a percentage
Sand circuit	the various parts of the installation for storage, transport, preparation and treatment of sand
Sand recycling	on-site used-sand preparation, for external re-use
Secondary (sand) regeneration	measures (mechanical, pneumatic, thermal and wet) aimed at removing spent binder layers from the sand corn (= reclamation); returning the sand to a quality similar to, or better than, new sand

Steel	a ferrous alloy which solidifies according a preritetic reaction. The (mass) content of iron is bigger than that of any other element, and the carbon content is generally lower than 2%; the alloy also usually contains other elements
Tempering	a heat treatment that after the hardening of the alloy consists of heating to a temperature below Ac_1 and cooling in air; after austenitising and liquid quenching, this provides to the alloy the highest possible hardness and strength

8.3 Lexicon

This section will be deleted from the BREF but its content will be used for the translation of technical terms used in the BAT conclusions

English	Deutsch	Français	Nederlands	Español	Italiano	Magyar
bentonite	Bentonit	bentonite	bentoniet	bentonita	bentonite	bentonit
bridging	Brückenbildung	accrochage	brugvorming	colgadura	formazione di corona	adagfennakadás
burr	Grat	barbe	braam	rebarba	bava	fánc
cast iron	Gusseisen	fonte	gietijzer	hierro	ghisa	öntöttvas
cast steel	Stahlguss	acier moulé	gietstaal	acero moldeado	getti d'acciaio	öntött acél
casting	Giessen	couler	het gieten	fundición	colata	öntés
chamfer	Abschrägung	chanfrein	gietsysteem	chaflán	cianfrinatura	formázási ferdeség
channel induction furnace	Rinnenofen	four à induction à canal	kanaal inductieoven	horno de inducción de canal	forno a canale	csatornás indukciós kemence
coating	Schlichte	enduit, poteyage	coating/deklaag	pintura	vernice, verniciatura	formabevonó anyag
cold-box	kalter Kernkaste, Cold-box	boîte froide	cold-box	caja fría	cassa fredda	cold-box
core	Kern	noyau	kern	macho	anima	mag
core box	Kernkasten	boîte à noyaux	kerndoos	caja de macho	cassa d'anima	magszekrény
core-making	Kernfertigung	noyautage	kernmakerij	macheria	formatura di anime	magkészítés
crucible furnace	Tiegelofen	four à creuset	kroesoven	horno de crisol	forno a crogiolo	tégelykemence
decoring	Entkernen	debourrage	ontkernen	extracción de macho	sterratura delle anime	kimagozás
die	Druckgiessform	moule	vorm	mole metálico	stampo	kokilla, nyomásos öntőforma
die lubricant	Druckgiessschlichte	poteyage	koelsmeermiddel	lubricante	distaccante	kokilla-, nyomásos öntőforma kenőanyag
drying oven	Backofen	étuve	droogstoof	estufa	essiccatore	szárító kemence
fettling	putzen	ébarbage	ontbramen	desmazarotado	sbavatura	tisztítás
grinding	schleifen	meulage	slijpen	esmerilada	molatura	csiszolás, köszörülés
induction furnace	Induktionsofen	four à induction	inductieoven	horno de inducción	forno ad induzione	indukciós kemence
lamellar iron *or* grey cast iron	Grauguss, GGL	fonte lamellaire, fonte grise	lamellair gietijzer	hierro gris	ghisa a grafite lamellare, ghisa grigia	lemezgrafitos *vagy* szürke öntöttvas
lustrous carbon	Glanzkohlenstoff	carbone brillant	glanskoolvormer	carbono brillante	carbonio brillante	fényes karbon
malleable iron	temperguss (GT)	fonte malléable	smeedbaar gietijzer	fundición maleable	ghisa malleabile	tempervas
mixer	Menger	malaxeur	menger	mezclador	mescolatore	keverő
mould	Form	mote	vorm	molde	forme	forma
nodular iron, ductile iron, SG iron	GGG, Gusseisen mit Kugelgraphit	fonte à graphite sphéroidal, fonte ductile	nodulair gietijzer	hierro nodular	ghisa sferoidale	gömbgrafitos öntöttvas

pouring	Giessen	couler	gieten	colada	colata	öntés
English	**Deutsch**	**Français**	**Nederlands**	**Español**	**Italiano**	**Magyar**
sand	Sand	sable	zand	arena	sabbia	homok
shaft furnace	Schachtofen	four à cuve	schachtoven	horno de cuba	forno a tino	aknás kemence
shake-out	Ausleeren	décochage	uitschudden	desmoldeo	distaffatura	ürítés, kirázás
shot blasting	Schleuderstrahlen	grenaillage	gritstralen	granallado	granigliatura	szemcseszórás
sprue	Einguss	canal de coulée	voedingskanaal	canal de colada	canale di colata	álló beömlő
turnings	Späne	copeaux	spanen	viruta	trucioli	forgács
veins	rissen	gerces	vinnen	venas	crestine	repedések

9 ANNEXES

9.1 Annex 1 Overview of data for cast iron melting in various cupola types and in the induction furnace

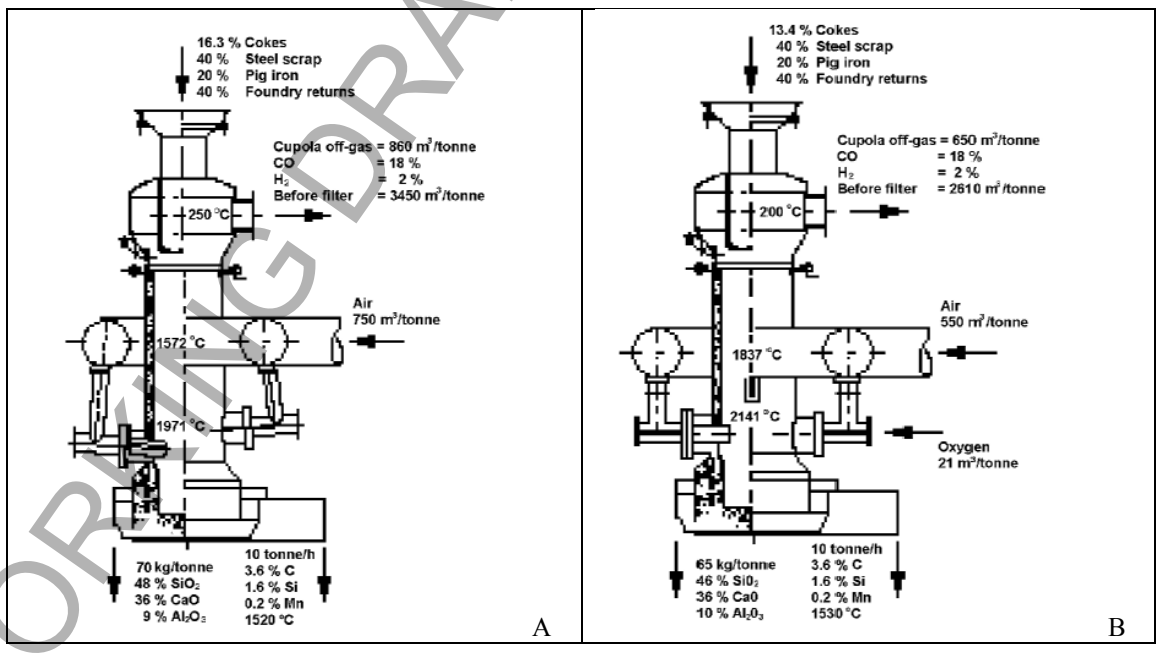
TWG please update the information below

A survey of the consumption and emission levels of the various technical modifications of cupola melting was set up by Neumann in 1994, as given below. All data refer to a system for the production of 10 tonne/h nodular iron with 3.6 % C and 1.6 % Si and at a pouring temperature of 1530 ºC. The balances in Figure 9.1 show inputs, outputs and process temperatures. The latter will be higher compared to operational practice. Comparison of the various balances allows an assessment of the effect of all the modifications.

Additional operational data for cold and hot blast cupolas, with various flue-gas cleaning equipment types, are given and discussed in Section 3.2.2.2. Those data are taken from operating plants.

The pictures show the following techniques:

(A): cold blast, secondary row of tuyères
(B): cold blast, oxygen injection
(C): cold blast with gas burner, oxygen injection
(D): hot blast (500 ºC), long campaign
(E): hot blast with electrical support heating (750 ºC)
(F): hot blast, oxygen injection (6 %)
(G): hot blast, with plasma support heating (1450 ºC)
(H): cokeless cupola in duplex operation (electrical superheating).



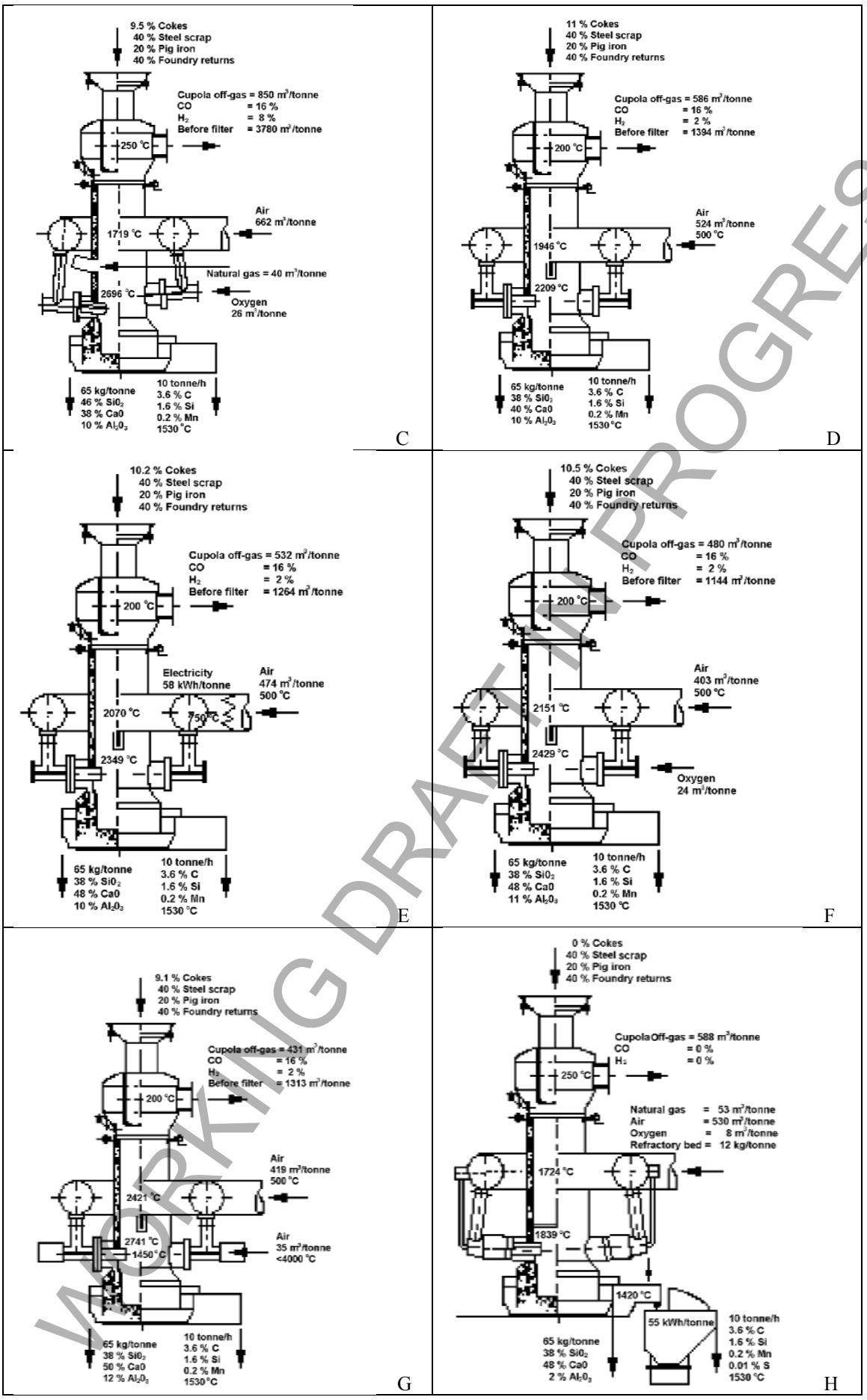


Figure 9.1: Input-output balance for various technical modifications of cupola melting [71, Neumann, F. 1994]

Operational data are given in Table 9.1, Table 9.2 and Table 9.3. These include economic data based on the stated unit costs. Operational data are based on the production of a cast iron with 3.3 % C and 2 % Si. In the cold blast operation 35 % steel scrap is used, while the hot blast operation allows 60 %. This is taken into account when considering the necessary carburisation. For this, C is also supplied through the addition of the SiC briquettes.

Calculation of the heat balance results in the stated heat transfer efficiencies. The cold blast cupola shows an efficiency of <30 %. The application of oxygen or secondary air increases the efficiency to 37 – 40 %. The hot blast cupola shows a further increased efficiency, providing the furnace wall is refractory lined. In liningless operation, the efficiency drops below 40 %, which may be somewhat compensated for by adding oxygen. The cokeless cupola with inductive superheating results in a very high efficiency, close to 60 %.

The calculated operational costs include depreciation of the investment cost, but exclude personnel costs. The cost difference between the various techniques is rather small. The calculation takes account of higher cokes consumption and more expensive scrap/raw material costs for the cold blast cupola. In the case of air preheating using a plasma torch, the increased electricity use leads to increased costs. In practice, this increase may be balanced by an increased usage of swarf as raw material. The cokeless cupola shows the lowest cost. In this evaluation, however, local cost effects and uncertainties, such as the effect of hourly rate, have not been taken into account, but need to be considered. The quoted data are all for installations with a significant hourly rate. This disfavours the performance of cold blast cupolas.

Table 9.1: Operational data of a cold blast cupola (10 tonne/h)

	Units or Cost per unit	Normal	O_2	Second-ary row	Second-ary + O_2
Specific quantity					
Melting cokes	kg/tonne	150	125	120	105
Cokes for carburisation	kg/tonne	10	10	10	10
Natural gas	m^3/tonne				
Electricity	kWh/tonne	20	20	20	20
Oxygen	%	-	3	-	2
Blast air	m^3/tonne	711	562	604	517
Cupola off-gas	m^3/tonne	902	724	731	628
Filtered off-gas	m^3/tonne	3022	2150	1765	1646
Slags	kg/tonne	36	35	46	45
Refractory	kg/tonne	5.2	5.2	4.8	4.8
SiC- briquettes(45 % SiC)	kg/tonne	28.5	28.5	31.3	30.3
Total heat input	MJ/tonne	5003	3643	3588	3416
Heat transfer to iron	%	26.9	37.2	37.8	39.8
Costs					
Investment	EUR million	2.81	2.91	3.06	3.16
Alloy	EUR 332/tonne	9.44	9.44	10.36	10.36
Additives	EUR 10/tonne	0.20	0.20	0.20	0.20
Cokes	EUR 204/tonne	32.65	27.55	26.53	23.47
Steel scrap	EUR 128/tonne	44.64	44.64	44.64	44.64
Scrap iron	EUR 128/tonne	12.76	12.76	12.76	12.76
Pig iron	EUR 194/tonne	38.78	38.78	38.78	38.78
Natural gas	EUR 153/1000 m^3	0.31	0.31	0.31	0.31
Electricity	EUR 89/MWh	1.79	1.79	1.79	1.79
Oxygen	EUR 179/1000 m^3	-	3.01	-	1.84
Graphite	EUR 561/tonne	-	-	-	-
Refractory	EUR 765/tonne	3.98	3.98	3.67	3.67
Capital	10 years/8 %	11.22	11.63	12.24	12.65
Total melting cost	**EUR/tonne**	**155.77**	**154.08**	**151.28**	**150.46**
Iron composition: 3.3 % C; 2.0 % Si; 0.3 % Mn; 0.1 S; 1500 ºC Load composition: 35 % steel scrap; 35 % returns; 20 % pig iron; 10 % scrap iron					

[71, Neumann, F. 1994]

Table 9.2: Operational data of a hot blast long campaign cupola (10 tonne/h)

	Units or Cost per unit	Type A*	Type B	Type C	Type D	Type E
Characteristics						
Daily furnace change		Yes	No	No	No	No
Oxygen enrichment		No	No	Yes	No	Yes
Lining		Yes	Yes	Yes	No	No
Specific quantity						
Melting cokes	kg/tonne	95	100	85	115	100
Cokes for carburisation	kg/tonne	8	7	7	8	8
Oxygen	%	-	-	3	-	3
Air	m^3/tonne	571	566	425	626	473
Cupola off-gas	m^3/tonne	680	667	519	746	586
Filtered gas	m^3/tonne	1798	1471	1134	1819	1473
Slag	kg/tonne	60	60	60	60	60
Refractory	kg/tonne	15	6	6	1.5	1.5
SiC- briquettes(45 % SiC)	kg/tonne	50	53	53	50	50
Total heat input	MJ/tonne	3756	3630	3076	4098	3534
Heat transfer to iron	%	39.8	40.2	44.9	36.5	38.7
Costs						
Investment	EUR million	3.42	3.57	3.65	3.49	3.55
Alloy	EUR 332/tonne	16.58	17.60	17.60	16.58	16.58
Additives	EUR 10/tonne	0.20	0.20	0.20	0.20	0.20
Cokes	EUR 204/tonne	21.02	21.84	18.78	25.10	22.04
Scrap steel	EUR 128/tonne	76.53	76.53	76.53	76.53	76.53
Scrap iron	EUR 128/tonne	12.76	12.76	12.76	12.76	12.76
Oxygen	EUR 179/1000 m^3	-	-	3.06	-	3.42
Refractory	EUR 765/tonne	11.48	4.59	4.59	1.12	1.12
Capital	10 years/8 %	13.67	14.29	14.59	13.98	14.18
Total melting cost	**EUR/tonne**	**152.24**	**147.81**	**148.11**	**146.28**	**146.84**

* Is no longer built as new plant
Iron Composition: 3.3 % C; 2.0 % Si; 0.3 % Mn; 0.1 S; 1530 ºC
Load composition: 60 % steel scrap; 30 % returns; 10 % scrap iron

[71, Neumann, F. 1994]

Table 9.3: Operational data of a cokeless cupola and hot blast cupola with air preheating

	Units or Cost per unit	Cokeless Cupola with O_2 + induct. superh.	Hot blast cupola air preh. using plasma	Hot blast cupola air preh. using electric resistance
Specific quantity				
Melting coke	kg/tonne	-	81	90
Coke for carburisation	kg/tonne	-	10	12
Natural gas	m^3/tonne	55	2	2
Electricity	kWh/t	80	175	82
Oxygen	%	1.5	-	-
Air	m^3/tonne	5.30	419	474
Cupola off-gas	m^3/tonne	692	451	531
Cleaned off-gas	m^3/tonne	815	1313	1264
Slags	kg/tonne	58	59	60
Refractory	kg/tonne	16	9.3	4.3
SiC- briquettes (45 % SiC)	kg/tonne	-	13.7	15.4
FeSi- briquettes (1 kg Si per briquette)	kg/tonne	8	-	-
Total heat input	MJ/tonne	2562	3952	3320
Heat transfer to iron	%	58.4	41.4	41.5
Cost				
Investment	EUR million	2.81	5.10	3.83
Alloy	EUR 332/tonne		4.54	5.10
FeSi-briquettes	EUR 454/tonne Si	3.62		
Additives	EUR 10/tonne	0.56	0.56	0.56
Cokes	EUR 204/tonne		18.57	23.06
Electricity	EUR 89/MWh	7.14	15.61	7.30
Gas	EUR 128/1000 m^3	6.99	0.31	0.31
Scrap steel	EUR 128/tonne	44.64	44.64	44.64
Scrap iron	EUR 128/tonne	44.64	44.64	44.64
Graphite	EUR 561/tonne	6.73		
Oxygen	EUR 179/1000 m^3	1.43		
Refractory	EUR 102/tonne	0.61	0.31	0.20
Refractory	EUR 765/tonne	7.65	4.80	1.79
Capital	10 years/8 %	11.22	20.41	15.31
Total melting cost	**EUR/tonne**	**135.26**	**154.39**	**142.91**
Iron composition: 3.3 % C; 2.0 % Si; 0.3 % Mn; 0.1 S; 1530 ºC Load composition: 35 % steel scrap; 30 % returns; 35 % scrap iron				

[71, Neumann, F. 1994]

CTIF also calculated the costs of liquid cast iron in a comparative study about the different melting ways [121, CTIF 1997]. This study, made in 1997, was updated in 2003 [122, Godinot, P. 2004].

Table 9.4: Comparison of liquid cast iron costs -June 2003. Mass production – 10 t/h

Units	GRADE	Lamellar cost iron (ENGJL 250)				Nodular cost iron (ENGJS 400 – 15)		
	Melting device	Cold blast cupola	Hot blast cupola	Cokeless cupola	Induction furnace	Hot blast cupola	Cokeless cupola	Induction furnace
EUR/t	Metallic charge	95.80	59.52	96.68	72.97	49.75	73.52	59.80
	Ferro alloys + additives	7.62	13.09	27.22	25.72	5.27	24.17	24.85
	Energy and fluids	33.14	35.26	20.29	27.28	40.12	21.07	27.28
	Linings	3.73	4.29	8.79	1.47	4.55	8.79	1.47
	Personnel costs	10.05	10	11	9.10	10.42	11	9.10
	Maintenance	1.55	3.15	0.16	0.93	3.15	0.16	0.93
	Environment	4.50	4.30	3.15	0.55	4.30	3.15	0.55
	Desulphurisation					10.33		
	Depreciation of investment	5.92	14.81	8.89	8.89	14.81	8.89	8.89
	Total per tonne charged	162.31	144.42	176.78	146.91	142.70	150.75	132.97
%	Fire loss	5	5	5	3	5	5	3
EUR/t	Total per tonne liquid	170.85	152.02	185.45	151.45	150.21	158.68	136.98
%	Returns percentage	35	40	35	40	50	50	50
EUR/t	Total per tonne of casting	262.85	253.36	285.31	252.42	300.42	317.37	273.96

Table 9.5: Price of lamellar cast iron: Metallic charge + energy

		Cold blast cupola			Induction			Coreless furnace			Hot blast cupola			Cokeless cupola		
Characteristic	**Unit**	Price EUR/unit	Ratio	Price EUR/t	Price EUR/unit	Ratio	Price EUR/t	Price EUR/unit	Ratio	Price EUR/t	Price EUR/unit	Ratio	Price EUR/t	Price EUR/unit	Ratio	Price EUR/t
Coke	tonne	210	0.145	30.45							210	0.125	26.25			
Electricity	kWh	0.0513	20	1.027	0.0448	609	27.28	0.0448	609	27.28	0.0513	128	6.57	0.0513	165	8.46
Oxygen	Nm^3	0.535	2	1.07							0.535	2	1.07	0.23	11	2.53
Gas	kWh (NCV)	0.0296	20	0.59							0.228	60	1.37	0.0186	500	9.30
Sub total				33.14			27.28			27.28			35.26			20.29
Returns	tonne	0	0.35	0	0	0.40	0	0	0.50	0	0	0.40	0	0	0.35	0
Pig iron	tonne	185	0.20	37	185	0.15	27.75	200	0.10	20				185	0.25	46.25
Scrap iron	tonne	167	0.20	33.4										167	0.15	25.05
Scrap steel (E3)	tonne	101.5	0.25	25.4	101.5	0.225	22.83				101.5	0.30	30.45	101.5	0.25	25.38
Scrap steel (E8)	tonne				99.5	0.225	22.39	99.5	0.40	39.80						
Scrap steel (E1 C)											96.9	0.30	29.07			
Sub total				95.8			72.97			59.80			59.52			96,68
Graphite	kg				0.70	16.7	11.69	0.80	17.92	14.34				0.7	8.12	5.68
FeSi	kg Si	0.68	8	5.44	1.13	10.6	11.98	1.13	9.39	10.61	0.68	15.8	10.74	0.68	11. 71	7.96
FeMn	kg Mn	0.595	2.7	1.60	0.79	2.6	2.05				0.59	3.2	1.89	0.595	1.45	0.86
$CaCO_3$ + div	tonne	12.2	0.048	0.58							12.2	0.0375	0.46			12.72
Balls	tonne															
Sub total				7.62			25.72			24.95			13.09			27.22

Table 9.6: Price of nodular cast iron: Metallic charge + energy

	Units	Hot blast cupola			Cokeless cupola		
		Price EUR/unit	Ratio	Price EUR/t	Price EUR/unit	Ratio	Price EUR/t
Coke	tonne	210	0.14	29.40			
Electricity	kWh	0.0513	140.5	7.21	0.0513	180	9.23
Oxygen	Nm^3	0.535	4	2.14	0.23	11	2.53
Gas	kWh (NCV)	0.0228	60	1.37	0.0186	500	9.30
Sub total				40.12			21.07
Returns	tonne	0	0.40	0	0	0.40	0
Pig iron	tonne				199	0.20	39.8
Scrap iron	tonne				167	0.05	8.35
Scrap steel (E8)	tonne	99.55	0.50	49.75			
Scrap steel (E3)	tonne				101.5	0.25	25.38
Sub total				49.75			73.52
Graphite	kg				0.7	12.37	8.66
FeSi	kg Si	0.68	7	4.76	0.68	4.11	2.79
FeMn	kg Mn						
$CaCO_3$ + div	tonne	12.2	0.042	0.51			12.72
Balls	tonne						
Sub total				5.27			24.17

Table 9.4 summarises the costs of cast iron calculated for the 3 main cupola types compared with coreless induction furnace. Some items greatly depend on the melting device and the grade: energies and fluids, metallic charge and ferro alloys. They are detailed in Table 9.5 and Table 9.6.

The compared melting devices melt at 10 - 12 t/h, in 2 shifts for a mass production typically, e.g. the automotive industry. The investments are paid in 10 years and correspond to the industrial practice in each case, i.e.:

Cold blast cupola
- 2 daily drop cupolas (one per day)
- treatment of fumes: combustion, cooling, dry filtration.

Hot blast cupola
- long campaign cupola
- treatment of fumes: combustion, blast heating, cooling, dry filtration
- holding in a channel induction furnace.

Cokeless cupola
- long campaign cupola
- treatment of fumes: cooling, dry filtration
- heating and recarburisation in a superheater
- holding in a channel induction furnace.

Introduction furnace
- 2 furnaces 12 tonne
- 1 power supply 10MW – 250 Hz.

The cost of cast iron must take into account its downstream recarburisation (cokeless cupola), its holding and also the importance of the fume treatment system.

The price of cast iron was compared for 2 different alloys in the case of mass automotive industry:

- lamellar cast iron (ENGJL 250)
- nodular graphite base cast iron (base for ENGJS 400-15).

The cold blast cupola is increasingly less used for nodular cast iron and was not considered in this case.

Comparing the calculations of CTIF and Neumann:

The position of the melting devices, from the least to the most expensive, is not the same depending on the type of alloy and the authors:

- Lamellar graphite cast iron (LG cast iron)
  CTIF: induction furnace, hot blast, cold blast, cokeless cupola
  Neumann: cokeless, hot blast, cold blast cupola
- Nodular base cast iron
  CTIF: induction furnace, hot blast, cokeless (little different).

The comparison of the different items for Neumann and Godinot leads to the following conclusions:

1. Energies and fluids

- the cokeless cupola is the least expensive in all cases
- it is noticeable that the energy costs strongly depend on the country, particularly with regard to the price and availability of electricity and gas. In the CTIF study, energy costs correspond to the French case (prices published in the review "Energy Plus").

2. Metallic charges and ferro alloys

The classification technique applied of disadvantages the cokeless cupola for CTIF and not for Neumann. The principal differences are the following ones:

- Neumann indicates 0 % pig iron for cokeless cupola, when Godinot indicates a minimum of 25 % according to the industrial practice. Pig iron is the most expensive metallic charge.
- Neumann gives the same cost for steel scrap and cast iron scrap. In the French case, the ratio between these 2 costs has been between 2 and 1.3 for 10 years. This ratio was 1.6 in June 2003, the date considered for the calculation, as indicated in the attached Figure 9.2.

It is noticeable that the cost of raw materials, including scrap, are fixed today at an international level.

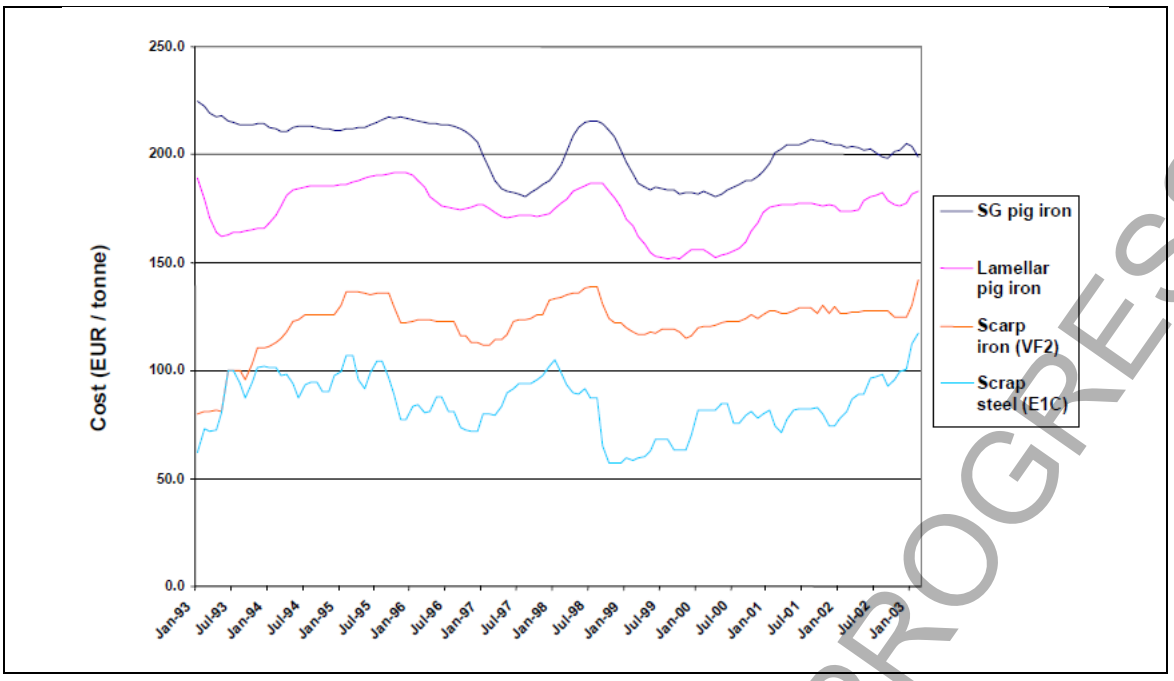


Figure 9.2: Cost of raw materials (France: 1993 to 2003)

3. Other items

The investment is less important than for cold blast, cokeless cupola and coreless induction furnace.

- in the case of the cold blast cupola liquid, cast iron is produced at a good temperature and analysis is possible at the spout of the cupola; moreover the metallurgical results depend little on the hourly production. It is not necessary to hold the cast iron in a channel induction furnace
- in the case of the hot blast cupola, or of the cokeless cupola, it is difficult to modify the hourly production. A reservoir of liquid metal is necessary between the cupola and the moulding shop, i.e. generally a channel induction furnace
- in the case of the cokeless cupola, the specific volume of fumes to be treated is low and it is not necessary to burn CO
- finally, in the case of the coke cupola (hot or cold blast), a desulphurisation is generally practised before holding the base nodular liquid cast iron. The cost of this operation is high, which is favours the cokeless cupola, whose cast iron does not contain any sulphur.

4. Conclusion

Taking industrial practice into account, according to Godinot, the cokeless cupola has the advantage of a low energy consumption but it incurs extra cost for the raw charging materials.

In the case of base nodular cast iron, the cokeless cupola produces a metal without sulphur and with a cost level similar to the hot blast. In the case of lamellar cast iron, in France, this melting device produces a more expensive metal than coke cupolas.

Today, for this type of production in France the limit between cupola and induction is 10 t/h (lamellar cast iron) and probably more in the case of nodular cast iron (the cupola is less expensive for 20 t/h).

These calculations have been made for an automotive type mass production. For other applications, they need to be slightly modified. At least it is possible to say the relative order depends on the local conditions, especially energy costs which depend strongly on the country of application.

9.2 Annex 2 Dust control equipment at a large-scale automotive foundry

TWG please update the information

Dust emission monitoring data were provided by a Swedish large-scale automotive foundry. The foundry uses a continuous particulate emission monitoring system on 17 bag filter exhausts. Data were plotted on a graph for various time ranges and for 4 measurement points as shown in Figure 9.3, Figure 9.4 and Figure 9.5. The figures show a continuous dust level well below 1 mg/Nm³ for sand preparation and shot blasting. A 24h-average of 1.3 – 1.6 mg/Nm³ was obtained for the sand transport.

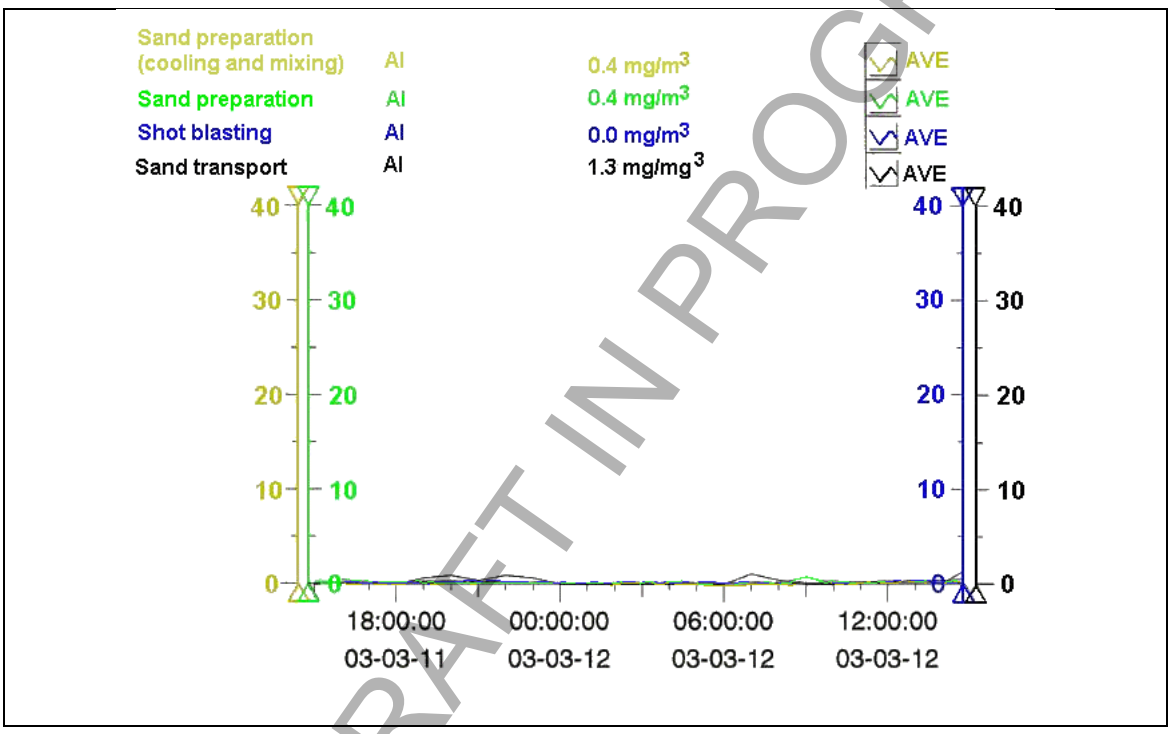


Figure 9.3: Monitoring data for dust emissions from 4 locations in the sand plant (24 hours continuous monitoring)

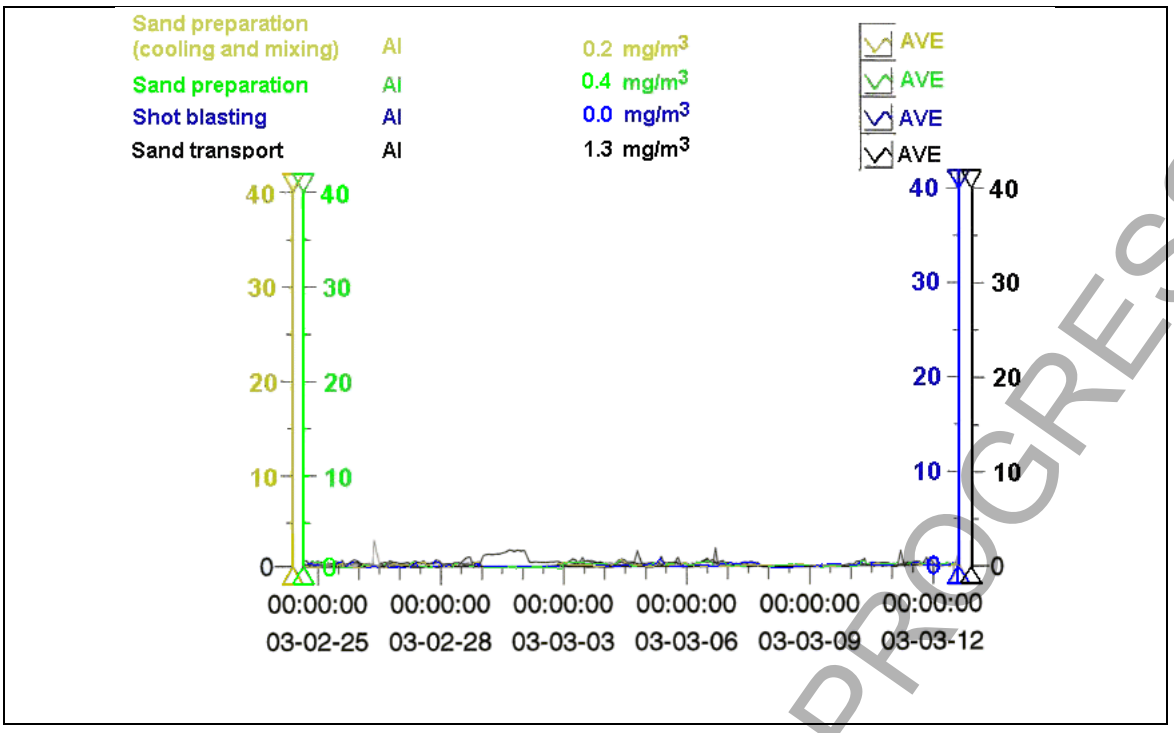


Figure 9.4: Monitoring data for dust emissions from 4 locations in the sand plant (2 weeks continuous monitoring)

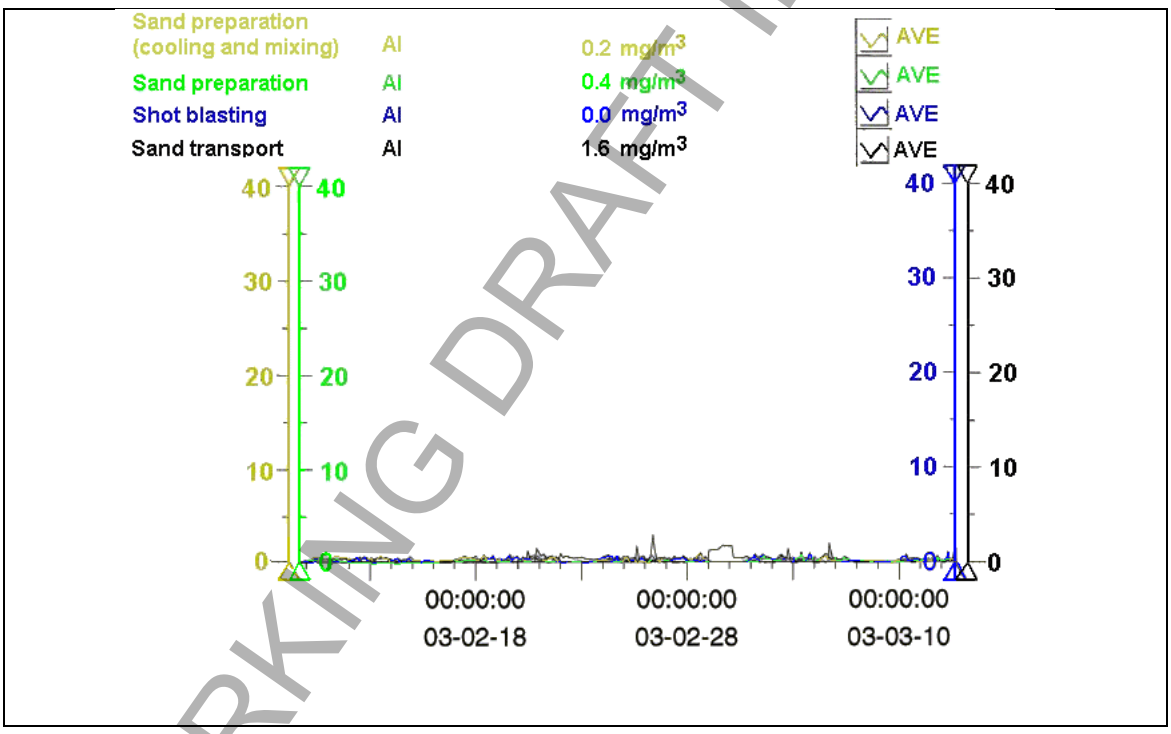


Figure 9.5: Monitoring data for dust emissions from 4 locations in the sand plant (30 days continuous monitoring)

This example plant has a permitted emission limit value for dust of 10 mg/Nm³. The monitoring system has an alarm limit of 5 mg/Nm³. If this limit is passed, the filter is checked and tested with fluorescence material. If the measured value passes 10 mg/Nm³, the production and filter are stopped. Calibration of the monitoring equipment is performed twice a year by an external contractor.

The service and maintenance instructions are as follows:

- daily
  - pressure drop check
  - visual check
  - magnetic valve check
  - condensation water drain
- monthly
  - check tightness
- quarterly (every 3 months)
  - control with fluorescence material.

9.3 Annex 3 List of European Smitheries and Foundries that participated in the data collection

9.3.1 List of European foundries that participated in the data collection

Plant code	Name of the plant	City	Country	2.4 FM	2.5(b) NFM	Metal processed in 2.5 (b) NFM
AT001	Banner GmbH	Linz	Austria		x	Pb
AT002	Borbet Braunau	Braunau	Austria		x	Al
AT003	DYNACAST Österreich GmbH	Weikersdorf	Austria		x	Zn, Al
AT004	EGM Industrieguss GmbH	Möllersdorf	Austria	x		
AT005	Karl Fink GmbH	Leibnitz	Austria		x	Al
AT006	Georg Fischer Fittings GmbH	Traisen	Austria	x		
AT007	GF Casting Solutions Altenmarkt GmbH & Co KG	Altenmarkt	Austria		x	Al, Mg
AT008	STRIKO Schmelzöfen	Herzogenburg	Austria		x	Al
AT009	Gienanth Steyr Guss GmbH	Steyr	Austria	x		
AT010	MAHLE Vöcklabruck GmbH	Vöcklabruck	Austria	x		
AT011	Maschinenfabrik Liezen und Gießerei GesmbH, Foundry	Liezen	Austria	x		
AT012	MRB Guss GmbH	Herzogenburg	Austria	x		
AT013	Nemak Linz GmbH	Linz	Austria		x	Al
AT014	Schindler Fahrtreppen International GmbH	Ternitz	Austria		x	Al
AT015	Tiroler Rohre GmbH / Hall i.T	Hall i.T.	Austria	x		
AT016	voestalpine Giesserei Linz GmbH	Linz	Austria	x		
AT017	voestalpine Gießerei Traisen GmbH	Traisen	Austria	x		
AT018	Wagnerguss	Enns	Austria	x		
BE019	Allard-Europe	Turnhout	Belgium	x		
BE020	Dovre Weelde	Weelde	Belgium	x		
BE021	FONDATEL LECOMTE SA	Andenne	Belgium	x		
BE022	Proferro NV	Ypres	Belgium	x		
BE023	Vandewiele Foundry department	Kortrijk	Belgium	x		
CZ024	ZPS-SLÉVÁRNA, a.s.	Zlín	Czech Republic	x		
CZ025	Slévárny v závodě Mladá Boleslav	Mladá Boleslav	Czech Republic		x	Other
CZ026	Slévárna šedé a tvárné litiny	Hodonín	Czech Republic	x		
CZ027	KOVOLIT a.s.	Modřice	Czech Republic		x	Al
CZ156	Liberty Engineering Products Ostrava s.r.o.	Ostrava	Czech Republic	x		

DE028	ACO- Guss GmbH	Kaiserslautern	Germany	x		
DE029	Michelau, Plant 3	Rudersberg	Germany		x	Zn
DE030	Necklinsberg, Plant 1	Rudersberg	Germany		x	Zn
DE031	ae group nentershausen gmbh	Bebra-Iba	Germany		x	Al
DE032	Alzmetall Werkzeugmaschinenfabrik und Gießerei Friedrich GmbH & Co. KG	Altenmarkt	Germany	x		
DE033	Stihl Magnesium Druckguss / Druckgießerei, Schwerkraftguss	Weinsheim	Germany		x	Mg, Al
DE034	Stihl Magnesium Druckguss / Gießerei	Weinsheim	Germany		x	Mg
DE035	BMW High pressure die-casting foundry	Landshut	Germany		x	Al
DE036	BMW Sand casting foundry sand	Landshut	Germany		x	Al
DE037	BMW foundry Gravity casting and low-pressure die-casting	Landshut	Germany		x	Al
DE038	BMW foundry Lost-Foam	Landshut	Germany		x	Al
DE039	Bosch Rexroth AG	Lohr am Main	Germany	x		
DE040	Buderus Guss Breidenbach	Breidenbach	Germany	x		
DE041	Isselguss GmbH Giessereierzeugnisse	Isselburg	Germany	x		
DE042	Dossmann GmbHEisengießerei und Modellbau	Walldürn-Rippberg	Germany	x		
DE043	DST Defence Service Tracks GmbH - Stahlgießerei	Remscheid	Germany	x		
DE044	Edelstahlwerke Schmees GmbH - Werk Pirna	Pirna	Germany	x		
DE045	Eisengießerei Georg Funk GmbH & Co. KG, Aalen	Aalen	Germany	x		
DE046	Eisenwerk Brühl GmbH	Brühl	Germany	x		
DE047	Eisenwerk Martinlamitz	Schwarzenbach a. d. Saale	Germany	x		
DE048	EMG Casting AG	Waldkraiburg	Germany	x	x	Al
DE049	FONDIUM Singen GmbH	Singen Htwl.	Germany	x		
DE050	FONDIUM Mettmann GmbH	Mettmann	Germany	x		
DE051	Franken Guss GmbH & Co. KG	Kitzingen	Germany	x		
DE052	Werk Hain	Siegen	Germany	x		
DE053	Werk Marienborn	Siegen	Germany	x		
DE054	HegerFerrit GmbH	Sembach	Germany	x		
DE055	HegerGuss GmbH	Enkenbach	Germany	x		
DE056	Harz Guss Zorge	Zorge	Germany	x		
DE057	Kemptener Eisengießerei Adam Hönig AG	Kempten/Allgäu	Germany	x		
DE058	Eisengießerei Weilbach	Weilbach	Germany			
DE060	MAT Foundries Europe GmbH Werk Neunkirchen	Neunkirchen	Germany	x		
DE061	Eisengießerei (Werk Wehrstapel)	Meschede	Germany	x		
DE062	MeierGuss Limburg GmbH	Limburg / Lahn	Germany	x		

	(iron foundry)					
DE063	Foundry Gütersloh	Güterloh	Germany	x		
DE064	Copper casting plant	Andernach	Germany		x	Cu
DE065	Nemak Dillingen GmbH	Dillingen	Germany		x	Al
DE066	Formanlage 1 Buchholz	Olpe	Germany		x	Al
DE067	Gusstechnik	Olsberg	Germany	x		
DE068	Pleissner Guss	Herzberg am Harz	Germany	x		
DE069	Reinhard Tweer GmbH - Stahlgiesserei	Bielefeld	Germany	x		
DE070	Robert Bosch Lollar Guss	Lollar	Germany	x		
DE072	SM Sächsisches Metallwerk Freiberg GmbH	Freiberg	Germany		x	Cu, other
DE073	Stahlwerke Bochum GmbH	Bochum	Germany	x		
DE074	Trompetter Guss Chemnitz GmbH	Chemnitz	Germany	x		
DE075	Aluminum melting furnace	St. Ingbert	Germany	x	x	Al
DE076	WESO-Aurorahütte GmbH	Gladenbach	Germany	x		
DE077	Werk Beuel	Bonn	Germany	x		
DE078	Sandguss	Sigmaringendorf-Laucherthal	Germany		x	Cu, Zn, Al, other
DK079	Vald Birn A/S	Holstebro	Denmark	x		
EL080	SUNLIGHT SYSTEMS SA	Xanthi	Greece		x	Pb
ES081	ALEASTUR	Zeluan	Spain		x	Al, other
ES082	FUCHOSA, S.L.U.	Atxondo	Spain	x		
ES083	ESAL ROD ALLOYS, S.A.	Gozón	Spain		x	Al
ES084	Planta de Fundición de Aluminio Bergara	Arrasate	Spain		x	Al
ES085	Planta de Fundición de Hierro de Markulete	Arrasate	Spain	x		
ES086	Planta de Fundición de Aluminio Uribarri	Arrasate	Spain		x	Al
ES087	Planta de Fundicion de Aluminio de Eskoriatza	Eskoriatza	Spain		x	Al
ES088	Durango	Durango	Spain	x		
ES089	Guivisa, S.L.	Vizcaya	Spain	x		
ES090	INDUSTRIAS HERGOM, S.L.	SOTO DE LA MARINA (SANTA CRUZ DE BEZANA)	Spain	x		
ES091	FUNDERIA CONDALS, S.A.	MANRESA	Spain	x		
ES092	MARTINREA HONSEL SPAIN LPDC	MOSTOLES	Spain		x	Al
ES093	MARTINREA HONSEL SPAIN HPDC	MOSTOLES	Spain		x	Al
ES094	METAL SMELTING S.A. ELORRIO	ELORRIO	Spain	x		
ES095	METAL SMELTING S.A.IURRETA	IURRETA	Spain	x		
ES096	Saint-Gobain PAM, España	Santander	Spain	x		
ES097	SCHMIDT-CLEMENS SPAIN S.A.U.	MURIETA	Spain	x		
ES098	GAMESA ENERGY TRANSMISSION, S.A.U. (GET BURGOS)	BURGOS	Spain	x		
ES099	Teknia Ampuero, S.L.U.	Ampuero	Spain		x	Al

ES100	UCB CAST PROFIL SAU	VILLANUEVA DE GÁLLEGO (ZARAGOZA)	Spain	x		
FI101	Alteams Finland Oy, Laihia	Laihia	Finland		x	Al
FI102	Porin valimo	Pori	Finland	x		
FI103	Tevo Lokomo oy Tampere	Tampere	Finland	x		
FR104	FERRY CAPITAIN	VECQUEVILLE	France	x		
FR105	FMGC	SOUDAN	France	x		
FR106	FOCAST CHATEAUBRIANT	CHATEAUBRIANT	France	x		
FR107	Fonderie BOUHYER Ancenis	Ancenis - Saint Géreon	France	x		
FR108	FONDERIE DE PLOMB	Carquefou	France		x	Pb
FR109	Fonderie Venissieux SAS	Venissieux	France	x		
FR110	KUHN SAS	Saverne	France	x		
FR111	LE CREUSET SAS	FRESNOY LE GRAND	France	x		
FR112	Linamar Montupet	Châteauroux	France		x	Al
FR113	NIDEC LEROY-SOMER Fonderie	ANGOULÊME	France	x		
FR114	PSA Automobiles Fonderie de Charleville	Villers Semeuse	France	x	x	Al
FR115	PMP PSA CHARLEVILLE PLANT	Charleville Mézières	France	x	x	Al
FR116	Aluminium casting / SNC Renault Cleon	CLEON	France		x	Al
FR117	ACI	Le Mans	France	x		
FR118	SG PAM Usine de Bayard sur Marne	Bayard sur Marne	France	x		
FR119	Usine de Foug	Foug	France	x		
FR120	FONDERIE	Merville	France	x		
IT071	Fllispa	Fano	Italy	x		
IT121	FOAM SpA	Rivoli (TO)	Italy		x	Al
IT122	Chivasso Plant	Chivasso	Italy		x	Al
IT123	Grugliasco Plant	Grugliasco	Italy		x	Al
IT124	Fonderia Baraldi S.r.L.	Montagnana	Italy	x		
IT125	FONDERIA_SAN_MARTINO	BARBERINO_TAVARNELLE	Italy	x		
IT126	FONDERIE PALMIERI SPA	CALENZANO	Italy	x		
IT127	Fonderie Valdelsane spa	Monteriggioni (SI)	Italy	x		
IT128	FONDERIA GETTI SPECIALI COLOMBO GIUSEPPE DI CARLO & FIGLI S.P.A.	San Giorgio su legnano (MI)	Italy	x		
IT129	Fondinox Spa	Sergnano	Italy	x		
IT130	MASSIFOND S.P.A.	ORBASSANO (TO)	Italy	x		
IT131	OFFICINE ZEN FONDERIE S.r.l.	ALBIGNASEGO	Italy	x		
IT132	PAROLA E LURAGHI SPA	MAGENTA	Italy	x		
IT133	TECOPRESS SPA	TERRE DEL RENO	Italy		x	Al
IT134	VDC S.r.l.	CAMPOSAMPIERO	Italy	x		

IT154	SOMIPRESS SRL	CASTELFIDARDO (AN)	Italy		x	Al
IT155	LEAD TIME SPA	CALDAROLA (MC)	Italy	x		
IT157	REGULATORY IPPC D.D. 3141 OF 8 AUG 2013 AND REGULATORY IPPC D.D. 2674 OF 17 NOV 2017	FERRERE	Italy	x	x	Mg, other
IT158	ZANARDI FONDERIE SPA	MINERBE	Italy	x		
PL135	Krakodlew S.A.	Cracow	Poland	x		
PL136	Koneckie Zakłady Odlewnicze S.A.	Końskie	Poland	x		
PL137	Foundry_OLE	Olesno	Poland		x	Cu
PL138	Cast iron foundry in Ścinawka Średnia	Ścinawka Średnia	Poland	x		
PT139	Cruz Martins & Wahl, Lda	Vila Nova de Famalicão	Portugal	x		
PT140	Duritcast, S.A.	Águeda	Portugal	x		
PT141	Fucoli-Somepal, Fundição de Ferro, SA - Coimbra	Coimbra	Portugal	x		
PT142	FUNDIVEN - Fundição Venezuela S.A.	Águeda	Portugal		x	Al
PT143	Schmidt Light Metal, Fundição Injectada, Lda	Oliveira de Azeméis	Portugal		x	Al
SE144	Holsbyverken	Vetlanda	Sweden	x		
SE145	Arvika Gjuteri	Arvika	Sweden	x		
SE146	Combi Wear Parts,kv Muttern	Ljungby	Sweden	x		
SE147	Gjuteriteknik AB	Värnamo	Sweden		x	Zn
SE148	Metallfabriken Ljunghäll AB	Södra Vi	Sweden		x	Al
SE149	Sandvik SRP AB	Svedala	Sweden	x		
SE150	Volvo Group Skövde	Skövde	Sweden	x		
SE151	Xylem Water Solutions Manufacturing AB, Emmaboda	Emmaboda	Sweden	x		
SE152	Älmhults gjuteri	Älmhult	Sweden	x		
SE153	Åkers Sweden AB	Åkers Styckebruk	Sweden	x		

9.3.2 List of European smitheries that participated in the data collection

Plant code	Name of the plant	City	Country	2.3 (b)	Other IED activities	Directly Associated Activities
DE001	Georg Group	Willroth	Germany	No	-	-
DE002	Hammerwerk Fridingen GmbH	Fridingen	Germany	No	-	Blasting, Forging shop, Heat treatment, Tool shop
DE003	Hammerwerk Werk 1	Remscheid	Germany	No	-	Heat treatment
DE004	Maschinenfabrik Alfing Kessler GmbH	73433 Aalen	Germany	No	No other IED activity	Forging (counterblow hammer), Heating (batch type furnace), Heating / Forging
DE005	RUD Schöttler Umformtechnik und Systemlieferant GmbH	Hagen	Germany	No	-	Blasting, forge shop, preheating
DE006	Drop forging plant	Warstein-Belecke	Germany	No	No other IED activity	Post-treatment (finishing) thermal treatment
DE007	Schmiede	15745 Wildau	Germany	Yes	No other IED activity	Crank-shaft processing
ES008	CIE AUTOMOTIVE	Ourense	Spain	Yes	-	-
PL009	HSW Kuźnia Stalowa Wola	Stalowa Wola	Poland	Yes	No other IED activity	Mechanical treatment, Thermal treatment

EUROPEAN COMMISSION
DG Joint Research Centre
Directorate B – Growth and Innovation
Circular Economy and Industrial Leadership
European IPPC Bureau

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Seville, 29th October 2019

KICK-OFF MEETING

FOR THE REVIEW OF THE

BEST AVAILABLE TECHNIQUES (BAT) REFERENCE DOCUMENT FOR

THE SMITHERIES AND FOUNDRIES (SF) INDUSTRY

SEVILLE, 17 – 20 September 2019

MEETING REPORT

Edificio Expo, C/Inca Garcilaso 3, E-41092 Seville – Spain
Telephone: +34-95 44 88 218
E-mail: JRC-B5-EIPPCB@ec.europa.eu, Internet: http://eippcb.jrc.ec.europa.eu/

Acronyms used in this Report

General acronyms – Definitions

Acronym	Meaning
AOX	Adsorbable organically bound halogens
BAT	Best Available Techniques (as defined in Article 3(10) of the IED)
BAT-AEL	Emission level associated with the BAT (as defined in Article 3(13) of the IED)
BAT-AEPL	BAT-associated environmental performance level (as described in Section 3.3 of Commission Implementing Decision 2012/119/EU). BAT-AEPLs include BAT-AELs.
BATIS	BAT Information System
B[*a*]P	Benzo[*a*]pyrene
BP	Background Paper
BREF	BAT reference document (as defined in Article 3(11) of the IED)
BREF Guidance	Commission Implementing Decision 2012/119/EU
BTEX	Benzene, toluene, ethylbenzene and xylene
CMR	Carcinogenic, mutagenic or toxic for reproduction
COD	Chemical oxygen demand
DMIPA	*N*,*N*-Dimethylisopropylamine
ECHA	European Chemicals Agency
EFS BREF	BAT reference document on Emissions from Storage
EIPPCB	European IPPC Bureau
ELV	Emission limit value
EN	European Standard adopted by CEN (European Committee for Standardisation, from its French name Comité Européen de Normalisation)
E-PRTR	European Pollutant Release and Transfer Register
ESP	Electrostatic precipitator
EU	European Union
HOI	Hydrocarbon oil index. The sum of compounds extractable with a hydrocarbon solvent (including long-chain or branched aliphatic, alicyclic, aromatic or alkyl-substituted aromatic hydrocarbons).
ICS BREF	BAT reference document on Industrial Cooling Systems
IED	Industrial Emissions Directive (2010/75/EU)
IPs	Initial positions
IPPC	Integrated Pollution Prevention and Control
IS BREF	BAT reference document for Iron and Steel Production
KEI	Key environmental issue
KoM	Kick-off Meeting
MS	Member State
NFM BREF	BAT reference document for the Non-Ferrous Metals Industries
NGO	Non-governmental organisation
NMP	*N*-methyl-2-pyrrolidone
NMVOC	Non-methane volatile organic compound(s)
OTNOC	Other than normal operating conditions
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PCDD/Fs	Polychlorinated dibenzo-*p*-dioxins/furans
POPs	Persistent organic pollutants
REACH	Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals
ROM	JRC Reference Report on Monitoring of Emissions to Air and Water from IED Installations
SF BREF	BAT reference document for the Smitheries and Foundries Industry
STS BREF	BAT reference document on Surface Treatment Using Organic Solvents (including Wood and Wood Products Preservation with Chemicals)
SVHC	Substance of very high concern: a chemical substance (or part of a group of chemical substances) which has to be regulated by REACH if using it within the European Union

Total N	Total nitrogen (TN), expressed as N, includes free ammonia and ammonium nitrogen (NH_4-N), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N) and organically bound nitrogen
TOC	Total organic carbon, expressed as C (in water); includes all organic compounds
TSS	Total suspended solids
TVOC	Total volatile organic carbon, expressed as C (in air)
TWG	Technical Working Group
US EPA	United States Environmental Protection Agency
VOC	Volatile organic compound (as defined in Article 3(45) of the IED)
WFD	EU Water Framework Directive; Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for the Community action in the field of water policy
WHO-TEF	World Health Organisation toxic equivalence factor
WI BREF	BAT reference document for Waste Incineration
WT BREF	BAT reference document for Waste Treatment
WWTP	Waste water treatment plant

Participants in the Kick-off Meeting

Acronym	Meaning	Number of delegates in the Kick-off Meeting
Member States		
AT	Austria	2
BE	Belgium	2
CZ	Czech Republic	1
DE	Germany	2
DK	Denmark	2
EL	Greece	1
ES	Spain	5
FI	Finland	2
FR	France	3
IT	Italy	2
NL	Netherlands	2
PL	Poland	1
SE	Sweden	2
UK	United Kingdom	3
Environmental organisation		
EEB	European Environmental Bureau	2
Industry organisations		
CAEF	The European Foundry Association	16
EUROFER	The European Steel Association	3
EUROFORGE	European forging industry association	1
EUROMETAUX	European Association of Metals	2
ORGALIM	Europe's Technology Industries	2
European Commission		
DG ENV	Directorate-General for Environment	1
DG JRC - EIPPCB	Directorate-General Joint Research Centre - European IPPC Bureau	7
		Total: 64

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1 INTRODUCTION

1.1 Kick-off Meeting for the review of the SF BREF

The Technical Working Group (TWG) for the review of the Reference Document on Best Available Techniques (BAT) for the Smitheries and Foundries Industry (SF BREF) held its first plenary meeting at the JRC premises in Seville, Spain, on 17 – 20 September 2019. This report is a summary of this first meeting (also referred to as the Kick-off Meeting or KoM).

TWGs are set up to facilitate the exchange of information under Article 13(1) of Directive 2010/75/EU (IED) on Industrial Emissions (Integrated Pollution Prevention and Control).

The review of the SF BREF started with the activation of the TWG in July 2018. The SF TWG is made up of about 150 experts representing EU Member States (MS), industry, environmental non-governmental organisations and the European Commission.

The call for the expression of TWG members' initial positions for the review of the SF BREF was sent out by the European IPPC Bureau (EIPPCB) on 22 January 2019, with a deadline for responses of 15 March 2019. Responses were received from 15 Member States, 4 industry organisations and one environmental NGO.

In order to facilitate the discussions at the Kick-off Meeting, a Background Paper (BP) highlighting the items to be discussed was prepared by the EIPPCB and sent to the SF TWG members 12 weeks in advance of the meeting, on 20 June 2019. The term 'EIPPCB proposal' used in the present document refers to the way forward that the EIPPCB proposed to the TWG in the BP after taking into account the TWG members' 'initial positions'. The Kick-off Meeting was attended by 64 TWG members (30 from MS, 24 from industry, 2 from an environmental NGO and 8 from the European Commission).

The meeting started on Tuesday 17 September 2019 in the morning and finished on Friday 20 September 2019 at midday (i.e. the meeting lasted three and a half days). The meeting agenda included presentations and discussions on the exchange of information for the review of the SF BREF (as provided for in Article 13 of Directive 2010/75/EU).

The head of the EIPPCB chaired the meeting and the SF BREF co-authors (i.e. the SF BREF team of the EIPPCB) introduced each topic and led the technical discussions.

During the meeting, discussions were held on the TWG members' initial positions and on the EIPPCB proposals that were based on those initial positions. The key issues on which agreement was sought at the meeting were the scope of the revised SF BREF, the interface with other BREFs, the structure of the revised SF BREF, the key environmental issues (KEIs), the data collection and the next steps for the review of the SF BREF.

The items were discussed following a common pattern at the meeting. The EIPPCB gave a presentation based on the Background Paper for each issue and proposed a way forward. The participants then had the opportunity to discuss each issue and to ultimately reach a conclusion by consensus.

This document presents the main issues discussed for each item and the conclusions reached at the meeting by the TWG.

All presentations given at the meeting are available to TWG members on the BAT Information System (BATIS) workspace together with the conclusion slides of the meeting.

1.2 Introductory presentations at the Kick-off Meeting

The presentation given by a representative of the Directorate-General for Environment of the European Commission (DG ENV) recalled the overall context and legal framework of the SF BREF review as well as the need to focus the information exchange.

The presentation also mentioned three ongoing or recently finalised studies which have been commissioned by DG ENV and which are of interest for the review of the SF BREF: one study about the preliminary identification of key environmental issues (KEIs) for the review of the SF BREF, the second study for the identification and promotion of novel and emerging sustainable techniques (the so-called Innovation Observatory) and the third study on the IED and the Circular Economy.

A member of the EIPPCB gave a general introduction to the *Sevilla process* (i.e. the process to draw up and review BREFs) including the general approach for deriving BAT and BAT-associated emission levels (BAT-AELs). It was made clear in particular that deriving BAT and BAT-AELs is a pragmatic and iterative process involving the whole TWG. In this process, the EIPPCB's responsibility is to make concrete proposals on BAT and BAT-AELs to the whole TWG based on the information collected, especially based on the plant-specific data collected through questionnaires. The TWG is invited to comment on these proposals and to submit any evidence supporting alternative proposals. Decisions on BAT are taken by consensus by the whole TWG at the Final TWG Meeting.

The work of the SF TWG will follow the BREF Guidance for the exchange of information under the IED (i.e. Commission Implementing Decision 2012/119/EU of 10 February 2012).

2 SCOPE

2.1 Inclusion of smitheries activity

In the BP, the EIPPCB had proposed to include in the scope of the SF BREF the activities specified in point 2.3(b) of Annex I to the IED: smitheries with hammers the energy of which exceeds 50 kJ per hammer and where the calorific power used exceeds 20 MW.

During the meeting, 2 MS and 2 industry organisations expressed concerns in relation to the small number of IED smitheries installations in Europe and the potential difficulties to collect information and data for those plants. Three other MS and one environmental organisation expressed the opinion that smitheries should be included and at least to seek information as well as collect data. One MS underlined that the small number of IED-size smitheries in Europe is due to the current IED Annex I thresholds which need revising.

The EIPPCB recalled that the smitheries activity is in the IED and that discussion on the IED-covered activities and related thresholds is not within the remit of this TWG.

Conclusions reached by the TWG:

- To include in the scope of the SF BREF the activities specified in point 2.3(b) of Annex I to the IED: smitheries with hammers the energy of which exceeds 50 kJ per hammer and where the calorific power used exceeds 20 MW.
- The TWG to provide written contributions for drafting the chapters on 'General information', 'Applied processes and techniques', 'Techniques to consider in the determination of BAT' and 'Emerging techniques'.
- Not to cover forging presses in the scope of the SF BREF.

2.2 Ferrous metal foundries

In the BP, the EIPPCB had proposed to cover in the SF BREF the operation of ferrous metal foundries with a production capacity exceeding 20 tonnes per day, as specified in point 2.4 of Annex I to the IED.

During the meeting, some TWG members expressed the opinion that information should be collected from smaller plants (i.e. plants below the IED Annex I point 2.4 threshold) to be included in the descriptive part of the BREF.

Conclusions reached by the TWG:

- To cover in the SF BREF the operation of ferrous metal foundries with a production capacity exceeding 20 tonnes per day, as specified in point 2.4 of Annex I to the IED.

2.3 Interface with other BREFs

2.3.1 Interface with the IS BREF

In the BP, the EIPPCB had proposed the following:

- To exclude from the scope of the SF BREF the continuous casting of iron and/or steel that is covered by the IS BREF (i.e. to produce thin slabs, thin strips, and sheets).

- To include in the scope of the SF BREF ferrous metal foundries employing continuous casting processes for the production of grey or nodular iron castings.

Two TWG members requested to include a clarification in order to specify that castings produced in ferrous metal foundries are at or near their final shape. In addition, one MS expressed the opinion that the phrase 'without further forming' needs to be included. One industry organisation expressed the opinion that casting is the finished product (final shape) even though there may be some further processing (but no further forming) in the foundry installation, and therefore that the inclusion of 'at or near their final shape' would be sufficient. However, one industry organisation indicated that the terminology 'near-net shape' was generally used in foundries and could be an alternative option to consider. This proposal was not supported by the TWG. The EIPPCB explained that the scope of the second bullet point is to include continuous casting for the production of grey and nodular iron castings.

Conclusions reached by the TWG:

- To exclude from the scope of the SF BREF the continuous casting of iron and/or steel which is covered by the IS BREF (i.e. to produce thin slabs, thin strips, and sheets).
- To include in the scope of the SF BREF ferrous metal foundries employing continuous casting processes for the production of grey or nodular iron castings at or near their final shape.

2.3.2 Interface with the NFM BREF

In the BP, the EIPPCB had proposed the following:

- To exclude from the scope of the SF BREF the production of semi-finished non-ferrous castings requiring further forming that is covered by the NFM BREF.
- To include in the scope of the SF BREF non-ferrous metal foundries using alloyed ingots, internal scrap, recovered products (e.g. external scrap) or liquid metal for the production of castings at or near their final shape.

A number of TWG members expressed the need to clarify the term 'external scrap'. One MS pointed out that external scrap was not used in their foundries and therefore it was better not to use this terminology at all in order to avoid any potential confusion between installations covered under the NFM BREF and the SF BREF. One industry organisation indicated that there was a clear distinction between secondary smelters covered under the NFM BREF that use external scrap irrespectively of scrap quality and foundries which can also use significant amounts of external scrap but only of high quality (clean scrap). One MS indicated that limiting the potential type of scrap materials used in foundries to internal scrap only was not a realistic approach because foundries do use external scrap of high quality. One MS proposed, as an alternative, to use the general terminology 'recovered product' in order to stay in line with the terminology employed in point 2.5(b) of Annex I to the IED. Based on the discussion, it was decided not to use the terminology 'external scrap' in the conclusions, but rather to refer to 'scrap' in general and to use the term 'recovered product' in order to stay in line with the IED. It was noted that the quality of the external scrap used in foundries is a key issue that needs to be considered as part of the SF BREF review.

One environmental organisation expressed the opinion that information on candidate BAT may also be collected from plants below the IED Annex I point 2.5(b) capacity threshold (i.e. melting capacity 4 tonnes per day for lead and cadmium and 20 tonnes per day for all other metals). At this point, it could be mentioned that while preference may be given to information collection on techniques that are applied in IED-size installations, information on techniques applied in non-IED-size plants may be considered useful as long as there is evidence that these techniques can also be applied in IED-size plants.

Conclusions reached by the TWG:

- To exclude from the scope of the SF BREF the production of semi-finished non-ferrous metal products requiring further forming.
- To include in the scope of the SF BREF the non-ferrous metal foundries using alloyed ingots, scrap, recovered products or liquid metal for the production of castings at or near their final shape.

In addition and in relation to bell and art casting, the EIPPCB had placed this item in Chapter 3 of the BP (items not proposed for discussion during the KoM). No TWG member requested its discussion prior to the KoM, so the proposal was agreed without further discussion.

Conclusions reached by the TWG:
- To cover in the SF BREF the operation of non-ferrous metal foundries with a melting capacity exceeding 4 tonnes per day for lead or 20 tonnes per day for all other metals, as specified in point 2.5(b) of Annex I to the IED.
- To exclude from the scope of the SF BREF cadmium, titanium and precious metal foundries, as well as bell and art casting.

2.3.3 Interface with the STS BREF

In the BP, the EIPPCB had proposed to include in the scope of the SF BREF the coating of moulds and cores but to exclude the coating of castings.

The EIPPCB had placed this item in Chapter 3 of the BP (items not proposed for discussion during the KoM). No TWG member requested its discussion prior to the KoM, so the proposal was agreed without further discussion.

Conclusions reached by the TWG:
- To include in the scope of the SF BREF the coating of moulds and cores but to exclude the coating of castings.

2.3.4 Interface with the EFS BREF

In the BP, the EIPPCB had proposed the following:
- To include in the scope of the SF BREF foundry-specific aspects of the storage, transfer and handling of materials, including the storage and handling of scrap and sand.
- To refer to the EFS BREF for general issues associated with the storage, transfer and handling of materials.

The EIPPCB had placed this item in Chapter 3 of the BP (items not proposed for discussion during the KoM). No TWG member requested its discussion prior to the KoM, so the proposal was agreed without further discussion.

Conclusions reached by the TWG:
- To include in the scope of the SF BREF foundry-specific aspects of the storage, transfer and handling of materials, including the storage and handling of scrap and sand.
- To refer to the EFS BREF for general issues associated with the storage, transfer and handling of materials.

2.3.5 Interface with the ICS BREF

In the BP, the EIPPCB had proposed to exclude indirect cooling systems from the scope of the SF BREF.

The EIPPCB had placed this item in Chapter 3 of the BP (items not proposed for discussion during the KoM). No TWG member requested its discussion prior to the KoM, so the proposal was agreed without further discussion.

Conclusions reached by the TWG:

- To exclude indirect cooling systems from the scope of the SF BREF.

2.4 Independently operated waste water treatment plants (WWTPs) and combined treatment of waste water

In the BP, the EIPPCB had proposed the following:

- To include in the scope of the SF BREF the activity in point 6.11 of Annex I to the IED only if emissions to water are considered a KEI and where the main pollutant load originates from activities in points 2.4 or 2.5(b) of Annex I to Directive 2010/75/EU.

Two MS and one environmental organisation expressed the opinion that the smitheries activity (IED Annex I point 2.3(b)) should also be referred to. Feedback from one industry organisation indicated that waste water is not an issue for smitheries. One industry organisation asked for clarification on how this scope provision is going to be implemented (potentially different operators of the 6.11 WWTPs compared to the foundry operators). One MS asked for the inclusion of combined treatment of waste water from different origins in the event that the main pollutant load originates from 2.4 or 2.5(b) activities.

The EIPPCB recalled that both topics (IED Annex I point 6.11 (Independently operated WWTPs) and combined treatment) have been discussed during many BREF reviews (e.g. TXT, FDM, SA) with the same conclusion. Moreover, the EIPPCB invited MS and industry to promote the participation of relevant independently operated waste water treatment plants (WWTPs) in the plant-specific data collection.

Conclusions reached by the TWG:

- To include in the scope of the SF BREF the activity listed in point 6.11 of Annex I to the IED where the main pollutant load originates from activities in points 2.4 or 2.5(b) of Annex I to the IED falling under the scope of this BREF.
- To include the combined treatment of waste water from different origins if the main pollutant load originates from the activities covered in points 2.4 or 2.5(b) of Annex I to the IED falling under the scope of this BREF and the WWTP is not covered by Directive 91/271/EEC.

3 STRUCTURE OF THE SF BREF AND OF ITS BAT CONCLUSIONS

In the BP, the EIPPCB had proposed the following:

- To include a new chapter dedicated to smitheries in the SF BREF (subject to the TWG decision on the scope as discussed in Section 2.1.3) containing sections on:
    - applied processes and techniques;
    - current consumption and emission levels;
    - techniques to consider in the determination of BAT;
    - emerging techniques.
- The TWG to provide written contributions for drafting these chapters.
- To derive BAT conclusions for smitheries (subject to the TWG decision on the scope as discussed in Section 2.1.3) to be incorporated in the BAT conclusions chapter of the revised SF BREF.
- To update Chapter 1 on 'General information' with up-to-date information.
- To significantly revise and update the current Chapter 2 on 'Applied processes and techniques' in foundries with the aim to better reflect the current structure of the foundry sector. A new section in Chapter 2 will be created to expand the information contained in Tables 2.5, 2.7 and 4.19 with the aim to clearly specify the relevance of each process per foundry type.
- To generally keep the structure of the current BREF for Chapter 3 and Chapter 4 and to update the sections therein with new information received from the TWG. In particular, the sections on 'Techniques to consider in the determination of BAT' will be revised and similar techniques will be merged. Techniques may also be further grouped according to their environmental benefits, as this has been done in previous published BREFs.
- The TWG to provide written contributions for drafting the chapters on 'Applied processes and techniques' and 'Techniques to consider in the determination of BAT'.

The TWG generally welcomed the EIPPCB proposal and the discussions were related to whether or not the BAT conclusions chapter as well as the Emerging techniques chapter will be common for both smitheries and foundries activities. Another important point of discussion was brought up by one industrial association concerning the need to provide more clarity in the BREF regarding the current structure of the foundry industrial sector. Nowadays, the foundry sector is divided into six main clusters and it would be important to reflect this in the revision of the SF BREF but also to consider this classification when drafting the questionnaires and potentially when drawing up the BAT conclusions at a later stage. The six clusters proposed for the foundry industrial sector are as follows:

1. iron foundry for mass production (serial production with automatic moulding plant – 'machine moulding');
2. iron foundry for large casting (single piece or small batch production – 'hand moulding');
3. steel casting foundry;
4. non-ferrous sand foundry;
5. non-ferrous permanent mould foundry;
6. non-ferrous pressure die-casting foundry.

Conclusions reached by the TWG:
For smitheries:

- To include a new chapter dedicated to smitheries in the SF BREF containing sections on:
    - general information;
    - applied processes and techniques;
    - current consumption and emission levels;

- techniques to consider in the determination of BAT;
- emerging techniques.

- The TWG (and in particular EUROFORGE) to provide written contributions for drafting this chapter.
- To derive BAT conclusions for smitheries to be incorporated in the BAT conclusions chapter of the revised SF BREF.

For foundries:

- To update the current Chapter 1 on 'General information' with up-to-date information.
- To significantly revise and update the current Chapter 2 on 'Applied processes and techniques' in foundries with the aim to better reflect the current structure of the foundry sector. A new section in Chapter 2 will be created to expand the information contained in Tables 2.5, 2.7 and 4.19 with the aim to clearly specify the relevance of each process per foundry type.
- Information on the six foundry clusters to be provided by CAEF at an early stage and before the development of the questionnaire.
- To generally keep the structure of the current BREF for Chapter 3 and Chapter 4 and to update the sections therein with new information received from the TWG. In particular, the sections on 'Techniques to consider in the determination of BAT' will be revised and similar techniques will be merged. Techniques may also be further grouped according to their environmental benefits, as this has been done in previous published BREFs.
- The TWG to provide written contributions for drafting the chapters on 'Applied processes and techniques' and 'Techniques to consider in the determination of BAT'.

4 PROCESS STEPS IN FOUNDRIES

The EIPPCB had placed this item in Chapter 3 of the BP (items not proposed for discussion during the KoM). No TWG member requested its discussion prior to the KoM, so the proposal was agreed without further discussion.

Conclusions reached by the TWG:

- To cover in the SF BREF the same process steps covered by the current SF BREF, namely:
  - pattern-making;
  - raw materials storage and handling;
  - melting and metal treatment;
  - mould and core production, and moulding techniques;
  - casting or pouring and cooling;
  - shake-out;
  - finishing;
  - heat treatment;
  - sand regeneration.

5 EMISSIONS TO AIR AND TO WATER

5.1 Overview

A large part of the meeting was dedicated to the identification of substances/parameters emitted to air and to water by SF installations and for which emission-related data will be collected in a systematic way via questionnaires, with the aim to derive emission levels associated with BAT (i.e. BAT-AELs) or with the aim for the TWG to decide at a later stage, based on the data collected through the plant-specific questionnaires, whether BAT-AELs should be derived. These substances/parameters are called KEIs (key environmental issues). See Section 6 for other KEIs related to energy; chemicals and oils consumption; water consumption and waste water discharge; and residues generation.

For substances/parameters that are not proposed as KEIs, unless specified otherwise, no data will be collected via questionnaires and BAT-AE(P)Ls will not be set, although 'bulk information' on associated techniques can be provided by the TWG (see Section 9).

In the BP, more than 70 substances/parameters (or KEI candidates) emitted to air and to water by SF installations were assessed (as single substances or groups of substances). In the BP to the KoM, all substances/parameters were included, assessed and proposals were made to be concluded on by the TWG. Most of these substances/parameters were discussed during the KoM.

The EIPPCB had assessed those substances/parameters by using an approach based on the following four criteria:

1. What is the environmental relevance of the substance/parameter?
2. What is the significance of the activity?
3. What is the potential for identifying new or additional techniques that would further significantly reduce pollution?
4. What is the potential for BAT-AELs that would significantly improve the level of environmental protection from current emission levels?

This approach was detailed in the BP and in the presentation made at the KoM by the EIPPCB.

This document does not aim to report the detailed discussion that took place for each and every substance/parameter, but focuses only on the most important points. The list of KEIs included in the review of the SF BREF is summarised in Table 1 and Table 3 (Sections 5.2 and 5.3 of this document).

5.2 Emissions to water

5.2.1 Emissions to water from foundries

In the BP, the EIPPCB had proposed the following:

- To consider emissions to water a KEI and to include emissions to water from both direct and indirect discharges in the data collection.
- To collect contextual information on the source of emissions to water, the type of treatment (dedicated or combined) and the contribution of the SF activity to the WWTP both in total flow and total load.

One industry organisation asked for clarification on the meaning of the term 'indirect discharges' and various MS expressed their views and experiences on how the waste water emissions from foundries are regulated in their jurisdictions.

The TWG discussed the process steps which may be considered relevant for emissions to water. The following processes were identified as particularly relevant:

- die-casting,
- wet flue-gas treatment systems,
- heat treatment,
- surface run-off water from storage,
- direct cooling,
- wet sand regeneration and
- cupola furnace slag granulation.

Most parameters for emissions to water were foreseen for discussion and were discussed during the KoM, while the EIPPCB had placed the rest of the parameters in Chapter 3 of the BP (items not proposed for discussion during the KoM). For the items not requested for discussion prior to the KoM, the proposals were agreed without further discussion.

Based on the proposals made by the EIPPCB in the BP and on the discussions that took place during the KoM for each substance/parameter, the TWG concluded to include in the review of the SF BREF the KEIs for emissions to water which are summarised in Table 1. Furthermore, emissions to water which are concluded NOT to be considered as KEIs to water are summarised in Table 2. However, for some parameters of Table 2 (not considered as KEIs), it was agreed to collect contextual information on discharges.

Table 1: KEIs for emissions to water included in the review of the SF BREF

(Groups of) Substance(s)	Remarks – additional conclusions
Amines	Total nitrogen (TN) for direct discharges. To collect information on the specific amine compounds used and their properties
Non-readily biodegradable amines (e.g. DMIPA)	For both direct and indirect discharges
Total nitrogen (TN)	For direct discharges only
Absorbable organically combined halogens (AOX)	For both direct and indirect discharges
Hydrocarbon oil index (HOI)	For both direct and indirect discharges. During the questionnaire development to further define the requested parameter (e.g. HOI vs total hydrocarbons)
Metals (As, Cd, Cr, Cu, Ni, Pb, Zn)	For both direct and indirect discharges
Mercury (Hg)	For both direct and indirect discharges

Cyanide (CN^-)	For both direct and indirect discharges
Phenols (phenol index)	For direct discharges only
Chemical oxygen demand (COD)	For direct discharges only
Total organic carbon (TOC)	For direct discharges only
Total suspended solids (TSS)	For direct discharges, but to collect data for indirect discharges as contextual information

Table 2: Parameters concluded as NOT KEIs for emissions to water in the review of the SF BREF

(Groups of) Substance(s)	Remarks – additional conclusions
Total phosphorus (TP)	NOT a KEI for emissions to water
Other metals (Cr(VI), Al, Co, Mn, Fe, Ba)	NOT KEIs for emissions to water. To collect information for direct and indirect discharges of Co and Mg (i.e. by EEB). To collect information on Ba emissions (i.e. by EEB) One MS expressed its concern on Fe discharges as Fe is considered in the Water Framework Directive (WFD) and national legislation. In addition, to collect contextual information on metal emissions in the case of wet dedusting processes.
Ammonium nitrogen (NH_4^-N)	NOT a KEI for emissions to water, but to collect contextual information for direct discharges
Sulphite (SO_3^{2-})	NOT a KEI for emissions to water
Total phosphorus (TP)	NOT a KEI for emissions to water
Other parameters, i.e. (Cl^- ; SO_4^{2-}; F^-; 1,2,4-trimethylbenzene; sulphide, toxicity to fish eggs, PAHs)	NOT KEIs for emissions to water
pH and conductivity	To collect data as contextual information

Additional conclusions reached for substances or parameters (emissions to water) are as follows:

Conclusions reached by the TWG (generally for emissions to water):

- To include emissions to water from die-casting, wet flue-gas treatment systems, heat treatment, surface run-off water from storage, direct cooling, wet sand regeneration and cupola furnace slag granulation as a KEI and to include emissions to water from both direct and indirect discharges in the data collection.
- To collect contextual information on the source of emissions to water, the type of treatment (dedicated or combined) and the contribution of the SF activity to the WWTP both in total flow and total load.

Conclusions reached by the TWG in relation to amines:

- To collect information on the specific amine compounds used and their properties.
- To include total nitrogen (TN) as a KEI for direct emissions to water and to collect data on TN emissions to water through plant-specific questionnaires with the aim to derive BAT-AELs.
- To include non-readily biodegradable amines (e.g. DMIPA) as a KEI for both direct and indirect emissions to water and to collect data on their emissions through plant-specific questionnaires. The TWG to decide at a later stage, based on the data collected through the questionnaires, whether BAT-AELs should be derived for non-readily biodegradable amines.

Conclusions reached by the TWG in relation to AOX:

- To include AOX as a KEI for both direct and indirect emissions to water and to collect data on AOX emissions to water through plant-specific questionnaires with the aim to derive BAT-AELs.

Conclusions reached by the TWG in relation to hydrocarbon oil index (HOI):

- To include HOI as a KEI for both direct and indirect emissions to water and to collect data on HOI for emissions to water through plant-specific questionnaires with the aim to derive BAT-AELs.

Conclusions reached by the TWG in relation to metals:

- To include As, Cd, Cr, Cu, Ni, Pb and Zn as KEIs for both direct and indirect emissions to water and to collect data on As, Cd, Cr, Cu, Ni, Pb and Zn emissions to water through plant-specific questionnaires with the aim to derive BAT-AELs.
- Information on Mn, Co and Ba emissions from foundries to be provided by EEB.
- To collect information on the emissions of other metals in the case of wet dedusting processes as contextual information.
- Not to include aluminium (Al) as a KEI for emissions to water and not to collect data on Al emissions to water.
- Not to include Cr(VI) as a KEI for emissions to water and not to collect data on Cr(VI) emissions to water.
- Not to include Ba compounds as a KEI for emissions to water (see also Table 2).
- Not to include Fe as KEI for emissions to water and not to collect data on Fe emissions to water (see also Table 2).
- Not to include Co and Mn as KEI for emissions to water (see also Table 2).

Conclusions reached by the TWG in relation to mercury:

- To include mercury (Hg) as a KEI for both direct and indirect emissions to water and to collect data on Hg emissions to water through plant-specific questionnaires with the aim to derive BAT-AELs.
- The TWG to decide at a later stage, based on the data collected through the questionnaires, whether BAT-AELs should be derived for Hg.

Conclusions reached by the TWG in relation to cyanide:

- To include cyanide (CN^-) as a KEI for both direct and indirect emissions to water and to collect data on CN^- emissions to water through plant-specific questionnaires with the aim to derive BAT-AELs.

Conclusions reached by the TWG in relation to phenols (phenol index):

- To include phenols as a KEI for direct emissions to water and to collect data on phenol emissions to water (as phenol index) through plant-specific questionnaires with the aim to derive BAT-AELs.

Conclusions reached by the TWG in relation to chemical oxygen demand (COD) and/or total organic carbon (TOC):

- To include both COD and TOC as KEIs for emissions to water for direct discharges and to collect data on COD and TOC for emissions to water through plant-specific questionnaires with the aim to derive BAT-AELs.

Conclusions reached by the TWG in relation to total suspended solids (TSS):

- To include TSS as a KEI for emissions to water for direct discharges and to collect data on TSS emissions to water through plant-specific questionnaires with the aim to derive BAT-AELs.
- To collect data on TSS emissions to water for indirect discharges as contextual information.

Conclusions reached by the TWG in relation to ammonium nitrogen (NH_4^-N):

- Not to include ammonium nitrogen (NH_4^-N) as a KEI for emissions to water but to collect contextual information in the case of direct emissions with the aim to assess the abatement efficiency of the WWTP.

Conclusions reached by the TWG in relation to sulphite (SO_3^{2-}):
- Not to include sulphite as a KEI for emissions to water and not to collect data on sulphite emissions to water.

Conclusions reached by the TWG in relation to total phosphorus (TP):
- Not to include TP as a KEI for emissions to water and not to collect data on total phosphorus emissions to water.

Conclusions reached by the TWG in relation to other parameters, i.e. Cl^- and SO_4^{2-}, F^-, 1,2,4-trimethylbenzene, sulphide, toxicity to fish eggs, PAHs:
- Not to include Cl^- and SO_4^{2-} as KEIs for emissions to water, but to collect data in order to obtain contextual information about the waste water treatment.
- Not to include F^- as a KEI for emissions to water and not to collect data on F^- emissions to water.
- Not to include 1,2,4-trimethylbenzene as a KEI for emissions to water and not to collect data on 1,2,4-trimethylbenzene emissions to water.
- Not to include sulphide as a KEI for emissions to water and not to collect data on sulphide emissions to water.
- Not to include toxicity to fish eggs as a KEI for emissions to water and not to collect data on toxicity to fish eggs.
- Not to include PAHs as a KEI for emissions to water and not to collect data on PAH emissions to water.

Conclusions reached by the TWG in relation to the collection of data as contextual information for pH and conductivity:
- To collect data on the following parameters as contextual information:
    - pH;
    - conductivity.

5.2.2 Emissions to water from smitheries

Emissions to water from smitheries are not considered a KEI.

5.3 Emissions to air

General consideration
As stated in the BP, for emissions to air, when derivation of BAT-AELs is mentioned, this refers to channelled emissions.

A total of more than 70 parameters (individual substances or groups of substances) were assessed in the BP for emissions to air from foundries, based on the initial positions (IPs) submitted. The presentation of the KoM conclusion is presented in Section 5.3.1.

For emissions to air from smitheries, the KoM conclusions are presented in Section 5.3.2.

Conclusions reached by the TWG:
- For emissions to air, when derivation of BAT-AELs is mentioned, this refers to channelled emissions.

5.3.1 Emissions to air from foundries

Based on the proposals made by the EIPPCB in the BP and on the discussions which took place during the KoM for each substance/parameter, **the TWG concluded to include in the review of the SF BREF the KEIs for channelled emissions to air which are summarised in Table 3 and to collect data through plant-specific questionnaires for these substances with the aim to derive BAT-AELs (unless mentioned otherwise). The parameters agreed to be considered as KEIs for emissions to air are summarised for each process in Annex II.**

Table 3: KEIs for emissions to air from foundries included in the review of the SF BREF

(Groups of) Substance(s)	Type of installation or process	Remarks – additional conclusions
NH_3	Processes using urea-based binders and/or hexamethylenetetramine hardener	The TWG to decide at a later stage, based on the data collected through the questionnaires, whether BAT-AELs should be derived for NH_3. To collect data on the different types of binders and hardeners used.
B[*a*]P and PAHs	Metal melting, moulding and casting	The TWG to decide at a later stage, based on the data collected through the questionnaires, whether BAT-AELs should be derived for PAHs as a sum and/or for individual compounds particularly relevant for the SF sector.
$Cl_{2(g)}$	Treatment of molten non-ferrous metals where substitution of $Cl_{2(g)}$ is not possible	To collect information on techniques to substitute the use of $Cl_{2(g)}$ with alternative degassing/cleaning agents that have a lower environmental impact.
NO_X	All types of furnaces (with the exception of induction furnaces), thermal sand regeneration	For other types of electrically heated furnaces (e.g. electric arc, resistance), to collect data and the TWG to decide at a later stage whether a BAT-AEL should be derived.
SO_2	Metal melting, casting, moulding, thermal sand regeneration	SO_2 emissions may also arise from using of SO_2 as covering gas.
HCl	Metal melting	The TWG to decide at a later stage whether a BAT-AEL should be derived.
Dust	All processes	-

(Groups of) Substance(s)	Type of installation or process	Remarks – additional conclusions
TVOC	Furnaces using solid, liquid and/or gaseous fuels, moulding, casting, sand regeneration	-
CO	Cupola furnaces	For all other types of furnaces to consider CO as a parameter of contextual information on combustion efficiency.
PCDD/Fs and dioxin-like PCBs	Metal melting when using scrap or fuels (e.g. coke, fuel oils) in particular for shaft furnaces, hot and cold blast cupola furnaces and rotary furnaces, or when using scrap in electrical arc furnaces	To derive BAT-AELs for PCDD/Fs. The TWG to decide at a later stage whether BAT-AELs should be derived for the sum of PCDD/Fs and dioxin-like PCBs. To assess the dioxin-like PCBs data in combination with PCDD/Fs using the WHO-TEQ international toxicity scheme.
HF	Metal melting	The TWG to decide at a later stage whether a BAT-AEL should be derived.
Odour	Cupola furnaces, moulding, core making, casting	The TWG to decide at a later stage whether a BAT-AEL should be derived. To collect information on techniques to prevent and/or reduce diffuse odour emissions.
Amines	Processes using amines in the binding systems	The TWG to decide at a later stage whether a BAT-AEL should be derived. To identify the specific amine compounds for which data will be collected. To collect data on the different types of binders used.
Formaldehyde	Moulding, core-making, casting for processes using binders containing formaldehyde	To collect information on the different types of binders used.
Hg	Metal melting when using scrap or coke	The TWG to decide at a later stage whether a BAT-AEL should be derived.
Metals	Al, As, Cd, Co, Cr_{total}, Cr(VI), Cu, Mg, Mn, Ni, Pb, Sb, Se, Sn, Te, Tl, V and Zn	The TWG to decide at a later stage whether BAT-AELs should be derived and for which metals/metalloids or groups of metals. To structure the questionnaire in such a way that will allow - in addition to the individual substance - the reporting of grouped data for metal emissions. Information on Ba and Be emissions from foundries to be provided by EEB.
Phenol	Moulding, core-making, thermal sand regeneration when using binders containing phenols	To collect information on the different types of binders used.
Benzene	Moulding, casting	-
Diffuse emissions	All foundry processes	To collect information on applied techniques and control measures for the minimisation of diffuse emissions from the foundry processes to derive BAT without any associated environmental performance levels.

Most parameters for emissions to air were foreseen for discussion and were discussed during the KoM, while the EIPPCB had placed the rest of the parameters in Chapter 3 of the BP (items not proposed for discussion during the KoM). For the items not requested for discussion prior to the KoM, the proposals were agreed without further discussion.

It is noted that it is a standard process during the questionnaire development to ask for information on the monitoring standard applied. This is especially important for parameters where an EN monitoring standard is not available.

In addition, a number of conclusions were reached for some substances or parameters / groups of parameters, as follows.

Conclusions reached by the TWG in relation to noise:

- To include noise as a KEI and to collect information on techniques applied for noise reduction to derive BAT without any associated environmental performance levels.

Conclusions reached by the TWG in relation to emissions of oil mist:

- Not to include oil mist as a KEI but to collect information on techniques used to prevent or reduce oil mist emissions.

Conclusions reached by the TWG in relation to emissions of furfuryl alcohol:

- Not to include furfuryl alcohol as a KEI and not to collect data on furfuryl alcohol emissions to air.
- To collect information on the furfuryl alcohol content of furan binders that are employed in foundries.
- To collect information on techniques to reduce the furfuryl alcohol content in furan binders.
- The TWG to explore options to substitute the use of binders containing furfuryl alcohol with alternative binders which have a lower environmental impact.

Conclusions reached by the TWG in relation to emissions of toluene, ethylbenzene and xylenes (TEX):

During the KoM discussion, an industry organisation supported the opinion that benzene is the principal compound emitted in moulding and casting in comparison with other compounds including toluene, ethylbenzene and xylenes (TEX). However, some MS and an environmental organisation expressed the view that, in some cases, TEX emissions may be as high as or even higher than those of benzene. Therefore, the following conclusion was reached:

- Not to include toluene, ethylbenzene and xylenes (TEX) as a KEI but to collect data on TEX emissions to air through plant-specific questionnaires as contextual information.

Conclusions reached by the TWG in relation to emissions of other organic compounds:

- Not to include styrene and 1,2,4-trimethylbenzene as KEIs and not to collect data.
- Information on styrene emissions from foundries to be provided by ES and EEB.
- Information on 1,2,4-trimethylbenzene emissions from foundries to be provided by EEB.

Conclusions reached by the TWG in relation to emissions of CMR substances:

- Not to include CMR substances as a group as a KEI and not to collect data on emissions to air of CMR substances as a group[1].
- Not to include as KEIs and not to collect data on emissions to air for the following CMR substances:
    - 1,3-butadiene;
    - N-methyl-2-pyrolidone (NMP);
    - trichloroethylene;
    - 1,2-dichloropropane;
    - 1-bromopropane;

[1] It is noted that some of the substances/parameters concluded to be included as KEIs in the SF BREF review (see **Table 3)** are classified as CMR. This conclusion refers to the consideration of CMR substances expressed as a group as a KEI.

- 4,4'diphenylmethanediisocyanate.

Conclusions reached by the TWG in relation to emissions of SF_6:

- Not to include SF_6 as a KEI but to collect information on the substitution of SF_6 by alternative cover gases in magnesium foundries and by alternative degassing agents in aluminium foundries.

Conclusions reached by the TWG in relation to other proposals:

- Not to include as KEIs the following parameters:
  - acetone;
  - acrolein;
  - aldehydes;
  - aniline;
  - cresols;
  - hydrogen cyanide;
  - hydrogen sulphide;
  - isocyanic acid;
  - methyl isocyanate;
  - respirable crystalline silica;
  - xylenols.

5.3.2 Emissions to air from smitheries

In the BP, the EIPPCB had proposed the following:

- To include as KEIs for smitheries the emissions to air from heating furnaces (i.e. dust, NO_X and SO_2) and to collect data on dust, NO_X and SO_2 emissions to air through plant-specific questionnaires with the aim to derive BAT-AELs.
- Not to include carbon monoxide (CO) as a KEI, but as a parameter in the questionnaires in order to obtain contextual information about combustion efficiency.
- To include noise and vibrations as KEIs for smitheries and to collect information on applied techniques for noise and vibration reduction to derive BAT without any associated environmental performance levels.

One industry organisation expressed the opinion that there are no channelled emissions from smitheries for dust, NO_X and SO_2. Another industry organisation expressed the opinion that only natural gas is used as fuel in smitheries, therefore only NO_X emissions are relevant for smitheries. One MS expressed the view that for channelled emissions dust and metals are relevant parameters. On noise and vibrations, one industry organisation expressed the opinion that both issues are plant-specific and there is no noise or vibration nuisance beyond the plant perimeter. The EIPPCB proposal in the BP was supported by all other TWG members that expressed their views during the discussion on this topic.

After considering all the points made, the TWG concluded as presented below.

Conclusions reached by the TWG:

- To include NO_X as a KEI for smitheries for heating furnaces using exclusively natural gas and to collect data on NO_X emissions to air through plant-specific questionnaires.
- The TWG to decide at a later stage, based on the data collected through the questionnaires, whether BAT-AELs should be derived for NO_X.
- Not to include carbon monoxide (CO) as a KEI, but as a parameter in the questionnaires in order to obtain contextual information about combustion efficiency.

- To include noise and vibrations as KEIs for smitheries and to collect information on applied techniques for noise and vibration reduction to derive BAT without any associated environmental performance levels.

6 CONSUMPTION OF ENERGY, CONSUMPTION OF CHEMICALS AND OILS, WATER CONSUMPTION AND WASTE WATER DISCHARGE, RESIDUES GENERATION

6.1 Consumption of energy

6.1.1 Consumption of energy in smitheries

In the BP, the EIPPCB had proposed the following:

- To include specific energy consumption as a KEI for smitheries and to collect data through plant-specific questionnaires.
- The TWG to identify during the questionnaire development phase the contextual information needed to understand and compare the data collected.
- The TWG to decide at a later stage, based on the availability and comparability of the data collected through the questionnaires, whether BAT-AEPLs on specific energy consumption can be derived.

One industry organisation expressed the opinion that energy consumption in smitheries is influenced by many parameters such as: the operation regime (e.g. number of shifts, batch production), product portfolio and special products that are usually requested by clients, comparability of data, small number of plants in Europe.

Conclusions reached by the TWG:

- To include specific energy consumption as a KEI for smitheries and to collect data through plant-specific questionnaires.
- The TWG to identify during the questionnaire development phase the contextual information (e.g. plant configuration, system boundaries, operational regime, level of aggregation of consumption data, product types, energy management systems, energy recovery/reuse flows) needed to understand and compare the data collected.
- The TWG to decide at a later stage, based on the data collected through the questionnaires, whether BAT-AEPLs on specific energy consumption can be derived.

6.1.2 Consumption of energy in foundries

In the BP, the EIPPCB had proposed the following:

- To include specific energy consumption as a KEI for melting, holding and heat treatment furnaces and to collect data through plant-specific questionnaires.
- To collect information on techniques and best practices to decrease scrap generation (e.g. increase the operational material efficiency of foundries) in order to minimise energy consumption.
- The TWG to identify, during the questionnaire development phase, the contextual information (in terms of plant configuration, type of processes, level of aggregation of consumption data, raw materials, product specifications, etc.) needed to understand and compare the data collected.
- The TWG to decide at a later stage, based on the availability and comparability of the data collected through the questionnaires, whether BAT-AEPLs on specific energy consumption can be derived.

During the KoM discussion, one industry organisation expressed the opinion that:

- energy consumption in foundries is influenced by many parameters such as: the operation regime (e.g. number of shifts, batch production), product portfolio and special products that are usually requested by clients.
- it would be necessary to describe energy efficiency plans in detail.
- any data collection on this topic is meaningless, as the foundry industry is continuously targeting energy consumption reduction.

Another industry organisation expressed the opinion that energy consumption is sufficiently covered under the ETS and it is not necessary to consider this as a stand-alone parameter in the BREF. It was finally proposed to discuss how to combine the IED with other legislation at the IED Article 13 Forum level. One environmental NGO expressed the opinion that emphasis should be given to the decarbonisation of the foundry processes, e.g. type of energy used in melting, alternative fuels, furnace type (as there is a range of more energy-efficient furnace types available to substitute the currently existing ones). One MS underlined the importance of defining the energy system boundaries in order to have reliable and comparable data and of the consideration of possible energy recovery flows. Another MS stressed the importance of considering energy consumption in the BREF. Another MS noted that not all foundries are under the scope of the ETS and that the relation between the ETS and energy efficiency will be useful for the permit writers.

The EIPPCB underlined that the EIPPB proposals are fully in line with European Commission policy and other EU legislation. It was also stressed that energy is considered in both the IED (i.e. 'use of energy', IED Article 13(2)) and the BREF Guidance (BREF Guidance, i.e. Commission Implementing Decision 2012/119/EU, in Sections 2.3.5, 2.3.6, 2.3.7, 3.3.2 and 5.4.2) while energy efficiency is an important issue in the context of the Circular Economy. In addition, the importance of operational material efficiency (OME: the ratio of good casting to the total quantity of metal melted) in the overall energy consumption and efficiency in foundries was underlined.

Conclusions reached by the TWG:

- To include specific energy consumption as a KEI for melting, holding and heat treatment furnaces and to collect data through plant-specific questionnaires.
- To collect information on techniques and best practices to decrease energy consumption (e.g. by energy recovery, reduction of scrap generation).
- The TWG to identify, during the questionnaire development phase, the contextual information (e.g. plant configuration, system boundaries, operational regime, type of furnaces, type of processes and fuels, level of aggregation of consumption data, raw materials, product type, energy management systems, energy recovery/reuse flows) needed to understand and compare the data collected.
- The TWG to decide at a later stage, based on the data collected through the questionnaires, whether BAT-AEPLs on specific energy consumption can be derived.

6.2 Consumption of chemicals and oils

In the BP, the EIPPCB had proposed the following:

For the consumption of chemicals

- To consider the consumption of chemicals a KEI and to collect information on techniques used to minimise the consumption of chemicals in the foundry processes.

For the consumption of oils

- To consider the consumption of oils a KEI and to collect information on techniques used to minimise the consumption of oils in the foundry processes.

For the additionally proposed KEI candidates (control of raw material contamination and soil contamination and decommissioning)

- To update the information of the current BREF on the techniques and control measures describing raw material storage and handling, decommissioning and control of scrap quality.

In relation to the consumption of chemicals:
Two MS expressed their opposition to considering the consumption of chemicals a KEI but they supported the collection of general information. Another two MS underlined the importance of considering chemicals that are characterised as substances of very high concern (SVHC) and to include the consideration of substitution options for hazardous and/or odorous substances. One industry organisation expressed the view that consumption of chemicals strongly depends on a number of parameters and any collected data would be meaningless. They also underlined possible confidentiality issues in collecting such data. An environmental organisation stressed the need to collect information on the types and characteristics of the chemicals used.
In relation to the consumption of oils:
One MS and one industry organisation proposed further clarification regarding the terminology used (mould-release agents, lubricating oils).

Conclusions reached by the TWG:
- In the context of the Circular Economy, the consumption of chemicals, mould-release agents and lubricating oils is considered important.
- To collect information on techniques used to minimise the consumption of chemicals in the foundry processes.
- Not to collect quantitative data on the consumption of chemicals via the plant-specific questionnaires.
- To collect qualitative information on the selection, types and hazard profiles of the chemicals used in foundries (e.g. resins, catalysts, additives) via the plant-specific questionnaires.
- To collect information on potential substitution techniques to reduce the use of hazardous or odorous chemicals in the foundry processes (e.g. alternative binders).
- To include consumption of mould-release agents and lubricating oils as a KEI and to collect information on techniques used to minimise the consumption of mould-release agents and lubricating oils in the foundry processes.

Additionally proposed KEI candidates (control of raw material contamination and soil contamination and decommissioning)
One industry organisation questioned the meaning of the term ‘control measures’ while an environmental organisation proposed the inclusion of monitoring of raw material quality. One MS asked for clarification as to whether chemicals used are included in raw materials and two industry organisations reported that there is an EN standard (EN 13920/1) on scrap quality available as well as a European scrap sort list.

Conclusions reached by the TWG:
- To update the information in the current BREF on the techniques relevant to raw material storage and handling, control of scrap quality and decommissioning.
- Information on scrap quality in the aluminium sector to be provided by EUROMETAUX (e.g. EN standard 13920/1 under revision).
- Information on European scrap sort lists (ferrous / non-ferrous metals) to be provided by CAEF.

6.3 Water consumption and waste water discharge

In the BP, the EIPPCB had proposed the following:

- To include the amount of water consumed and the amounts of waste water discharged as KEIs and to collect data through plant-specific questionnaires. To focus the data collection on gathering quantitative data on water consumption / water discharge at installation level and, additionally, on specific processes for which water consumption is significant and consumption data can be obtained. Based on the assessment above, the following processes could be included in the data collection:
    - cupola furnaces with wet scrubbers;
    - high-pressure die-casting foundries;
    - core production using the SO_2 process, Croning or the cold-box method.
- To collect the contextual information (water reuse, type of processes, level of aggregation of consumption data, raw materials, product specifications, etc.) needed to understand and compare the data.
- The TWG to decide at a later stage, based on the availability and comparability of the data collected through the questionnaires, whether BAT-AEPLs on specific water consumption and waste water discharge can be derived.

The TWG agreed in general with the proposal and the discussion mainly focused on the clarification of its wording.

Conclusions reached by the TWG:

- To include the amount of water consumed and the amounts of waste water discharged as KEIs and to collect data through plant-specific questionnaires. To focus the data collection on gathering quantitative data on water consumption / water discharge at installation level and, additionally, on specific processes for which water consumption is significant and consumption data can be obtained. The following processes could be included in the data collection:
    - abatement processes using wet scrubbers (e.g. cupola furnaces, SO_2 process, cold-box and Croning);
    - moulding with wet sand;
    - high-pressure die-casting foundries.
- To collect the contextual information (water reuse, type of processes, level of aggregation of consumption data, raw materials, product types, etc.) needed to understand and compare the data.
- The TWG to decide at a later stage, based on the data collected through the questionnaires, whether BAT-AEPLs should be derived for specific water consumption and/or waste water discharge.

6.4 Residues generation

In the BP, the EIPPCB had proposed the following:

- To include the following waste streams as KEIs and to collect data through plant-specific questionnaires with the aim to derive BAT-AEPLs:
    - the amount of slags and dross generated and sent for disposal and/or for internal/external recovery;
    - the amount of swarf recovered internally and the amount of other scrap metal sent for external recycling;
    - the amount of filter dust recycled and/or sent for disposal;
    - the amount of refractory linings recycled and/or sent for disposal in ladles and melting furnaces.
- To include as a KEI the regeneration of foundry sand and to collect data through plant-specific questionnaires on regeneration ratios, the amounts of spent foundry sand externally reused and/or sent for disposal with the aim to derive BAT-AEPLs.

- The TWG, during the questionnaire development phase, to identify the contextual information (in terms of processes, raw materials, product specifications, etc.) needed to understand and compare the data collected.
- Not to consider the amounts of spent oils or emulsions and oil-contaminated wastes as a KEI and therefore not to collect quantitative data on these parameters via the plant-specific questionnaires.

During the KoM discussion, one industry organisation expressed the opinion that the quantities of residues generated strongly depend on the type of product and the derivation of any BAT-AEPL will have no real meaning while in some cases it may have a detrimental impact. One MS proposed to take into consideration the system boundaries while another MS proposed to add a reference to the Circular Economy and to amend the proposal to mention that the TWG will decide later on the possible derivation of BAT-AEPLs.

Conclusions reached by the TWG:

- To include the following residue as KEIs in the context of the Circular Economy and to collect data through plant-specific questionnaires on:
    - the amounts of slags and dross generated and sent for disposal and/or for internal/external recovery;
    - the amounts of filter dust recycled and/or sent for disposal;
    - the amounts of refractory linings recycled and/or sent for disposal in ladles and melting furnaces.
- The TWG to decide at a later stage, based on the data collected through the questionnaires, whether BAT-AEPLs should be derived for residues generation.
- To include as a KEI the regeneration of foundry sands and to collect data through plant-specific questionnaires on regeneration ratios, the amounts of spent foundry sands externally used and/or sent for disposal.
- The TWG to decide at a later stage, based on the data collected through the questionnaires, whether BAT-AEPLs should be derived for the regeneration of foundry sands.
- Information on the sand regeneration processes / systems to be provided by CAEF in advance of the questionnaire development.
- The TWG, during the questionnaire development phase, to identify the contextual information (in terms of processes, raw materials, product type, operational conditions etc.) needed to understand and compare the data collected.
- Not to include the amounts of spent oils and oil-contaminated wastes as a KEI and therefore not to collect quantitative data on these parameters via the plant-specific questionnaires.

7 DATA COLLECTION

7.1 General

7.1.1 Expression of BAT-AELs for emissions to air/water

In the BP, the EIPPCB had proposed the following:

- To generally express BAT-AEPLs for emissions to air and to water in concentrations and/or if deemed appropriate as specific loads.
- To include in the data collection the information needed to evaluate emission loads, abatement efficiencies or specific energy consumption.
- During the drafting of the questionnaire(s), to clearly define all parameters influencing emission concentrations, loads or abatement efficiencies (e.g. type of products/raw materials, boundaries of the process, flows of materials, product, pollutants and waste waters, specific operating conditions associated with the manufacture of products).

The TWG broadly agreed with the EIPPCB proposal to generally express BAT-AELs for emissions to air and to water in concentrations and/or if deemed appropriate as specific loads.

It was stressed by one industry organisation that BAT-AELs have to be derived on the basis of mathematics and statistics. Additionally, it was stressed by one MS that information on specific load could be confidential and it might be difficult to collect data on it.

The TWG supported the idea to include in the data collection information specifically on emission loads and profiles, abatement efficiencies, specific energy consumption, monitoring standards and LoD/LoQ of monitoring techniques, where available.

During the drafting of the questionnaire, the TWG agreed to clearly define all parameters influencing emission concentrations, loads or abatement efficiencies (e.g. type of products/raw materials, boundaries of the process, flows of materials, product, pollutants and waste waters, specific operating conditions associated with the manufacture of products). Regarding the LoD/LoQ, it was explained by the EIPPCB that this information is systematically requested in the data collection via questionnaires.

Conclusions reached by the TWG:

- To generally express BAT-AEPLs for emissions to air and to water in concentrations and/or if deemed appropriate as specific loads.
- To include in the data collection information specifically on emission loads and profiles, abatement efficiencies, or specific energy consumption and LOD/LOQ of monitoring techniques, where available.
- During the drafting of the questionnaire(s), to clearly define all parameters influencing emission concentrations, loads or abatement efficiencies (e.g. type of products/raw materials, boundaries of the process, flows of materials, product, pollutants and waste waters, specific operating conditions associated with the manufacture of products).

7.1.2 Averaging periods for BAT-AELs

In the BP, the EIPPCB had proposed the following:

- For channelled emissions to air, to generally express BAT-AELs as short-term averages, i.e. as daily averages (for continuous measurements) or as averages over the sampling period (for periodic measurements).

- For emissions to water, to generally express BAT-AELs as daily averages, obtained via 24-hour flow-proportional composite samples. To complement that:
    - time-proportional composite samples may also be considered provided that sufficient flow stability is achieved;
    - spot sampling may also be considered provided that the effluent is appropriately mixed and homogeneous.

During the meeting, the TWG supported the EIPPCB proposal made in the BP to generally express BAT-AELs for emissions to air as short-term averages and BAT-AELs for emissions to water as daily averages. A MS asked for the inclusion of a specific reference to the case of batch discharge.

Conclusions reached by the TWG:

- For channelled emissions to air, to generally express BAT-AELs as short-term averages, i.e. as daily averages (for continuous measurements) or as averages over the sampling period (for periodic measurements).
- For emissions to water, to generally express BAT-AELs as daily averages, obtained via 24-hour flow-proportional composite samples. To complement that:
    - time-proportional composite samples may also be considered provided that sufficient flow stability is achieved;
    - spot sampling may also be considered provided that the effluent is appropriately mixed and homogeneous;
    - average values over the release duration, taken as flow-proportional composite samples, may be considered in the case of batch discharges.

7.1.3 Collection of data on consumption of energy, water, materials and generation of residues

In the BP, the EIPPCB had proposed the following:

- To collect data on energy consumption expressed as specific energy consumption (ratio of total energy consumption divided by a suitable activity rate figure), on a yearly average basis.
- To collect data on water consumption expressed as specific water consumption (e.g. m^3/tonne of product for the following processes: cupola furnaces with wet scrubbers; high-pressure die-casting foundries; core production using the SO_2 process, Croning or the cold-box method, on a yearly average basis.
- To collect data on waste water discharge expressed as specific waste water discharge (yearly average).
- To collect data on waste generation expressed as specific waste generation on an annual basis for the following streams;
    - the amount of slags and dross generated;
    - the amounts of filter dust recycled and/or sent for disposal;
    - the amounts of refractory linings recycled and/or sent for disposal in ladles and melting furnaces.
- In addition, to collect data on the foundry sand regeneration ratio expressed as a percentage.

An industry organisation expressed concerns on the representability of the data that would be collected, the amount of contextual information needed to be collected and possible confidentiality issues in relation to the requested information. Two MS stressed that the conclusion wording needs to leave flexibility for the questionnaire development phase of the process.

Conclusions reached by the TWG:

- To collect data on energy consumption expressed as specific energy consumption (ratio of total energy consumption divided by a suitable activity rate figure), on a yearly average basis.
- To collect data on water consumption expressed as specific water consumption (e.g. m^3/tonne of product) in particular for the following processes: wet scrubber abatement systems for cupola furnaces, SO_2 process, cold-box and Croning, wet sand moulding and high-pressure die-casting foundries, on a yearly average basis.
- To collect data on waste water discharge expressed as specific waste water discharge (ratio of total waste water discharge divided by a suitable activity rate figure), on a yearly average basis.
- To collect data on residues generation expressed as specific residues generation on an annual basis for the following streams;
  - the amount of slags and dross generated;
  - the amounts of filter dust recycled and/or sent for disposal;
  - the amounts of refractory linings recycled and/or sent for disposal in ladles and melting furnaces;
- In addition, to collect data on the foundry sand regeneration ratio expressed as a percentage.
- Information on the relevant parameters needed to design the questionnaire to be provided by CAEF, EUROFORGE and any other interested TWG member in advance of the questionnaire development.

7.2 Selection of plants

7.2.1 IED Annex I, activities 2.3(b), 2.4 and/or 2.5(b) and proposal of well-performing plants

In the BP, the EIPPCB had proposed the following:

- To collect data from well-performing IED plants carrying out 2.4 and/or 2.5(b) activities and directly associated activities.

The proposal made by the EIPPCB was agreed without further discussion. Editorial amendments have been made to the conclusions presented on the last day of the KoM to better reflect the inclusion of IED activity 2.3(b) (smitheries) (see Section 2.1 of this document) and for text consistency/clarity reasons. In addition, the EIPPCB explained that an Excel template will be posted on BATIS for the TWG to submit their proposals for well-performing plants.

Conclusions reached by the TWG:

- To collect data from well-performing plants carrying out activities covered under points 2.4 and/or 2.5(b) of Annex I to the IED and directly associated activities falling under the scope of this BREF.
- To collect data from well-performing plants carrying out activities covered under point 2.3(b) of Annex I to the IED.
- The TWG to complete their proposals of well-performing (including best-performing) plants/installations to be included in the data collection, if necessary after consultation with the national smitheries and foundry organisations, by the beginning of February 2020.
- EIPPCB to finalise the list and to check its completeness by mid-February 2020. This might imply additional requests for information to individual TWG members.

7.3 Questionnaire for gathering plant-specific information and data

The EIPPCB proposal in the BP was agreed without further discussion.

Conclusions reached by the TWG:

- To follow the established BREF process for the collection of plant/installation-specific data via questionnaire.

7.3.1 Collection of data at process level

The EIPPCB proposal in the BP was agreed without further discussion.

Conclusions reached by the TWG:

- To collect information at the process level, when available, for the parameters agreed as KEIs. The processes for which specific data and contextual information will be requested will be further determined during the questionnaire development phase.

7.3.2 Data collection procedure

The EIPPCB proposal in the BP was agreed without further discussion.

Conclusions reached by the TWG:

- To follow the established BREF review process for the collection of plant/installation-specific data via questionnaires including the following:
  - the preparation of the draft questionnaire by the EIPPCB followed by the commenting of the whole TWG, if necessary in several iterations;
  - if it is deemed necessary, the organisation of a questionnaire development workshop to finalise the questionnaire;
  - the testing of the draft final questionnaire by a selected (small) number of plants/installations;
  - the preparation of the final questionnaire by the EIPPCB;
  - the distribution of the final questionnaire to the participating plants through the Member States' competent authorities;
  - the filling in of the questionnaire by the participating plants/installations;
  - the collection of the filled-in questionnaires by Member States' representatives;
  - the quality check of the filled-in questionnaires by Member States' representatives (possibly with the help of a checklist that the TWG/EIPPCB could have developed);
  - the submission of the quality-checked questionnaires to the TWG via BATIS by Member States' representatives.
- The TWG, in particular the MS, to decide on the possible involvement and contribution of national smitheries and foundries organisations in the data collection.
- To collect data over the years 2019, 2018 and 2017 or for the last three measurement campaigns in the case of a longer measurement frequency.

In relation to the last bullet point of the conclusions above, it is noted that in case of longer monitoring frequencies (e.g. once every 2 years), the last three measurement campaigns will be considered.

7.4 Confidentiality issues

In the BP, the EIPPCB had proposed to design the questionnaire in a way that avoids requesting confidential data, and to decide at a later stage (e.g. during the workshop on the questionnaire finalisation) on the type and format of potentially confidential information (CBI). One industry organisation asked for clarification on the submission and handling of confidential information that may be included in the submitted questionnaires. One environmental organisation expressed the opinion that MS competent authorities would have access to CBI from plants from other MS. The EIPPCB explained the general procedures on submission, assessment, storage and presentation of CBI, reminding the TWG of the general principles of the BREF Guidance (Section 5.3 of the BREF Guidance) and underlining that emission data could not be considered confidential. The TWG appreciated the explanations given by the EIPPCB. This proposal received broad support from the TWG.

Conclusions reached by the TWG:

- To design the questionnaire in a way that avoids requesting confidential data as much as possible so that the data provided by operators can be posted directly onto BATIS and shared with the whole TWG.
- The TWG to decide at a later stage (i.e. during the questionnaire development) about the type and format of potentially confidential information that needs to be collected (e.g. quantity of raw materials treated and plant's actual production).
- The Member States' representatives in the TWG to:

- submit the versions of the questionnaires containing the confidential information directly to the EIPPCB via email; and
- post the versions of the questionnaires containing the non-confidential information to BATIS.

8 TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT AND EMERGING TECHNIQUES

As was explained during the KoM, full lists of techniques for both candidate BAT and emerging techniques have been uploaded on BATIS and the TWG is kindly asked to provide additional feedback. The uploaded tables are structured as follows:

Part 1 – Techniques to consider in the determination of BAT: Techniques in Chapter 4 of the current SF BREF (2005).
Part 2 – Additionally proposed candidate BAT: Candidate BAT proposed in the course of expression of Initial Positions (IPs) by some of the TWG members.
Part 3 – Emerging techniques: Emerging techniques in the current SF BREF (2005).
Part 4 – Additionally proposed Emerging techniques: Candidate Emerging techniques proposed in the course of expression of Initial Positions (IPs) by some TWG members.

For all lists, the EIPPCB already included (in the uploaded template on BATIS) an initial assessment and a proposal for the way forward as well as additional information (including relevant references / sources).

9 NEXT STEPS TO BE TAKEN AFTER THE MEETING

During the final session of the meeting, the TWG agreed on the following actions and timetable for the next steps to be taken.

Step	Targeted time
EIPPCB to issue the first draft questionnaire	End of October 2019
TWG to provide feedback on the first draft questionnaire	End of November 2019
EIPPCB to issue the second draft questionnaire	Middle of December 2019
Workshop on the questionnaire finalisation (if necessary)	End of January 2020
TWG to provide proposals of well-performing plants for the data collection	Beginning of February 2020
EIPPCB to compile the list of well-performing plants and to check its completeness; if necessary, EIPPCB to ask TWG members to amend/complete the list	Middle of February 2020
EIPPCB to issue the third draft questionnaire	Middle of February 2020
Questionnaire testing	End of February 2020
EIPPCB to issue the final questionnaire to the TWG and distribution to the participating plants through the Member States' competent authorities	Middle of March 2020
TWG to provide bulk information in order to update the SF BREF (e.g. information on applied processes and techniques, techniques to consider in the determination of BAT)	End of March 2020
Submission of filled-in questionnaires in BATIS	Middle of June 2020

9.1 Site visits

The EIPPCB also asked the TWG members to make proposals for site visits in the coming months, as provided for in Section 4.4.4 of the BREF Guidance.

Conclusions reached by the TWG:

- EIPPCB to contact the TWG members that have proposed to organise site visits. Ideally, visits to take place during the testing phase of the questionnaire (November 2019 to February 2020).
- Additional proposals for site visits to be submitted by the TWG.

10 ANNEX I: STANDARD STRUCTURE FOR DESCRIBING THE 'TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT'

When providing information on 'Techniques to consider in the determination of BAT', the use of a standard structure is required in order to enable comparisons of techniques so that an objective assessment against the definition of BAT given in the IED can be made. This standard structure is stipulated in the BREF Guidance. It is necessary to use this standard structure for the provision of information for specific techniques.

Standard structure for describing BAT candidate techniques (see BREF Guidance)

In order to determine BAT, all techniques to be considered in the BAT decision-making process will be presented in the BREF according to a standard structure, shown in the first two columns of the following table. The third column gives more details on the specific data which are needed in order to draft 'Techniques to consider in the determination of BAT' and to derive useful BAT conclusions from them.

Name of the type of information	Type of information to be included in the BREF	Important information to collect and to report
Description	A brief description of the technique with a view to being used in the BAT conclusions.	
Technical description	A detailed and concise technical description of the technique (including chemical or other equations, pictures, diagrams and flow charts when appropriate).	The description can include both prevention and control techniques (in-process and end-of-pipe).
Achieved environmental benefits	The main potential environmental benefits (including reduced consumption of energy, reduced emissions to water, air and land, raw material savings as well as production yield increases, reduced waste, etc.) to be gained through implementing the technique.	
Environmental performance and operational data	Actual plant-specific performance data (including consumption and emission levels, consumption levels – of raw materials, water, energy – amounts of residues/wastes generated, including reference conditions – e.g. O_2 level – and monitoring methods used) achievable applying the technique. Any other information on how to design, operate, maintain and control the technique.	Emission data • Both the concentration and (specific) load of pollutant(s) (if available) or the data needed to derive this information. For specific load data, the product referred to should be clearly defined. • The quantity of the pollutant before and after the abatement system in order to determine the abatement efficiency. • Details of relevant operating conditions (percentage of full capacity, fuel composition, bypassing of the abatement technique, inclusion or exclusion of other than normal operating conditions, reference conditions). • Emission monitoring issues (including information on frequency, averaging period, uncertainties, plant operating condition, etc.). Consumption data: • The type and amount of fuel, energy (heat, electricity), water and raw materials/chemicals consumed/used by the technique. Waste: • The type and quantities of waste generated and treatment/disposal methods and/or techniques to prevent waste. Others: • Sensitivity and durability of the technique. • Operation/control/maintenance issues. • Issues regarding accident prevention.
Cross-media effects	Relevant negative environmental effects due to implementing the technique, allowing a comparison amongst techniques in order to assess the impact on the environment as a whole (such as consumption and nature of raw materials and	The Reference Document on Economics and Cross-media Effects (ECM) is a document that should be taken into account with regard to cross-media aspects as far as there are significant cross-media effects. This document is available from the European IPPC Bureau website at

Name of the type of information	Type of information to be included in the BREF	Important information to collect and to report
	water, energy consumption and contribution to climate change, stratospheric ozone depletion potential, photochemical ozone creation potential, acidification resulting from emissions to air, particulate matter in ambient air (including microparticles and metals), eutrophication of land and waters resulting from emissions to air or water, oxygen depletion potential in water, persistent/toxic/bioaccumulable components (including metals), generation of residues/waste, limitation of the ability to reuse or recycle residues/waste, generation of noise and/or odour, increased risk of accidents.	http://eippcb.jrc.ec.europa.eu/reference/BREF/ecm_bref_0706.pdf
Technical considerations relevant to applicability	Indication as to whether the technique can be applied throughout the sector; otherwise, information on the main general technical restrictions on the use of the technique (including an indication of the type of plants or processes within the sector to which the technique cannot be applied, and constraints to implementation).	
Economics	Information on costs (both investment and operational) and possible savings, including details on how these costs have been calculated	• Capital/investment, operating and maintenance costs including details on how these costs/savings have been calculated/estimated. • Possible savings (including payback time), including details on how these costs/savings have been calculated/estimated. • Cost data will preferably be given in euros (EUR). If a conversion is made from another currency, the data in the original currency and the year when the data were collected will be indicated. This is important as conversion rates vary over time. • Price/cost of equipment or service will be accompanied by the year it was purchased. • Information relevant to both new and existing plants enabling, where possible, the determination of the economic viability of the technique for the sector concerned. • Information on the cost-effectiveness of the technique (e.g. in EUR per abated mass of pollutant), where relevant. The Reference Document on Economics and Cross-media Effects (ECM) and the JRC Reference Report on Monitoring of Emissions to Air and Water from IED Installations (ROM) should be taken into account with regard to economic aspects and monitoring costs, respectively. Both documents are available from the European IPPC Bureau website at http://eippcb.jrc.ec.europa.eu/reference/
Driving force for implementation	Local conditions or requirements (e.g. legislation, safety measures) or non-environmental triggers (e.g. increased yield, improved product quality, economic incentives) which drive or may stimulate implementation. Information on reasons other than environmental ones for implementation.	Examples: • information on type/quality of receiving waters (e.g. temperature, salinity); • information on environmental quality standards; • information on the increase of production or productivity.
Example plants	Reference to plants in which the technique is implemented and from which information has been collected and used in writing the section, including an indication of the degree to which the technique is in use in the EU or worldwide.	
Reference literature	Literature or other reference material that was used in writing the section and that contains more detailed information. When the reference material consists of a large number of pages, reference will be made to the relevant page(s) or section(s).	

11 ANNEX II: KEIS FOR EMISSIONS TO AIR BY PROCESS

	NH_3	BaP	PAHs	Cl_2	NOx	SO_2	HCl	Dust	TVOC	CO	PCDD/F	Dioxin-like PCB	HF	Odour	Amines	Formaldehyde	Hg	Metals	Phenols	Benzene	Diffuse emissions	Noise
Pattern-making								x										x			x	x
Raw material storage and handling	x							x							x			x			x	x
Melting and metal treatment		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x			x	x
~~Mould and core production, and moulding techniques~~																						
- moulding	x	x	x			x		x	x					x	x	x			x	x	x	x
- core-making ~~production~~	x	x	x			x		x	x					x	x	x			x	x	x	x
~~Casting or pouring and cooling~~																						
- casting or pouring	x	x	x			x		x	x					x	x	x		x	x	x	x	x
- cooling	x	x	x			x		x	x					x	x	x		x	x	x	x	x
Shake-out	x	x	x					x	x					x	x	x		x	x	x	x	x
Finishing								x										x			x	x
Heat treatment					x	x		x		x								x			x	x
Sand regeneration					x	x		x	x						x			x	x		x	x