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Emission Estimation Protocol for Iron and Steel Foundries

Version 1
Final

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Office of Air Quality Planning and Standards
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List of Acronyms and Abbreviations

µm	micrometers
Acfm	actual cubic feet per minute
AFS	American Foundry Society
Atm	atmosphere
BID	Background Information Document
Btu/mol	British thermal units per mole
Btu/scf	British thermal units per standard cubic feet
CAA	Clean Air Act
CEMS	continuous emission monitoring system
CERP	Casting Emission Reduction Program
CFR	Code of Federal Regulations
CO	carbon monoxide
CS	Core system
Cr^{+6}	hexavalent chromium
dscf/MMBtu	dry standard cubic feet per million British thermal unit
dscfm	dry standard cubic feet per minute
EAF	Electric arc furnace
EIF	Electric induction furnace
EPA	U.S. Environmental Protection Agency
ESP	electrostatic precipitator
FID	flame ionization detector
GHG	greenhouse gases
HAP	hazardous air pollutants
HHV	Higher heating values
Hg	Mercury
hr/yr	hours per year
ICR	information collection request
in.	Inches
kg/kg-mol	kilogram per kilogram mole
kg/yr	kilograms per year
lb/dscf	pounds per dry standard cubic foot
lb/hr	pounds per hour

lb/kg	pounds per kilogram
lb/ton	pounds per ton
LOI	Loss on ignition
MACT	Maximum Achievable Control Technology
MDI	Methylene diphenyl diisocyanate
mg/kg	milligrams per kilogram
min/hr	minutes per hour
Mph	Miles per hour
MMBtu/scf	million British thermal units per standard cubic foot
MS	Mold system
MSDS	Material safety data sheets
MW	molecular weight
Ni	Nickel
NATA	National-scale Air Toxics Assessment
NESHAP	National Emission Standards for Hazardous Air Pollutants
Ni	Nickel
NO	nitric oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
O_2	Oxygen
OCDD	octachloro-dibenzo-p-dioxin
OCDF	octachloro-dibenzo-furan
OCMA	Ohio Cast Metals Association
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenyls
PCS	Pouring, cooling, and shakeout
PM	particulate matter
PM_{10}	PM emissions that are 10 µm in diameter or less
PM_{10}-FIL	filterable (or front-half catch) portion of the PM emissions that are 10 µm in diameter or less
PM_{10}-PRI	“primary” PM emissions that are 10 µm in diameter or less
$PM_{2.5}$	PM emissions that are 2.5 µm in diameter or less
$PM_{2.5}$-FIL	filterable (or front-half catch) portion of the PM emissions that are 2.5 µm in diameter or less

$PM_{2.5}$-PRI	“primary” PM emissions that are 2.5 µm in diameter or less
PM-CON	condensable PM (or back-half catch)
POM	polycyclic organic matter
Ppmv	parts per million by volume
ppmw	parts per million by weight
Psi	pounds per square inch
Psia	pounds per square inch absolute
Psig	pounds per square inch gauge
PUCB	Phenolic urethane cold box
QA	quality assurance
QC	quality control
RMT	Residuals Management Technology
SCC	Standard Classification Code
SIP	State implementation plan
SO_2	sulfur dioxide
TCDD	tetrachlorodibenzo-p-dioxin
TDS	total dissolved solids
TEA	Triethyl amine
TEF	Toxic Equivalent factors
TEQ	toxic equivalents
THC	total hydrocarbons
TOC	total organic compounds
tons/hr	tons per hour
tons/kg	tons per kilogram
tons/yr	tons per year
VMT	Vehicle miles traveled
VOC	volatile organic compounds
vol%	volume percent
wt%	weight percent
WHO	World Health Organization
°C	degrees Celsius
°F	degrees Fahrenheit
°R	degrees Rankine

1. Introduction

This Foundry Emissions Protocol document is intended to provide guidance and instructions to iron and steel foundry owners and operators for the purpose of improving emission inventories, and emission reporting in general, by source owners and operators. This document presents a hierarchy of emission measurement or estimation methods for various foundry emission sources and provides a listing of pollutants that may be emitted by each source type. This document may also be used by other entities, such as federal, state, and local agencies, for consistency in estimating emissions from iron and steel foundries.

This Foundry Emissions Protocol document provides methods for estimating criteria pollutant and hazardous air pollutant (HAP) emissions from foundry operations. Methodologies for estimating emissions of greenhouse gases (GHG) are not included in this Foundry Emissions Protocol document. Methodologies for estimating emissions of GHG are provided in the Mandatory Greenhouse Gas Emissions Reporting Rule (Final Rule, 74 Federal Register [FR] 56260) for selected foundry processes.

1.1 Need for Emission Inventories

Air emission inventories are a fundamental first step in developing air quality and emission control strategies. Section 172, Part C, of the Clean Air Act (CAA) as amended in 1990, which addresses state implementation plan (SIP) requirements, states that ". . .plan provisions shall include a comprehensive, accurate, current inventory of actual emissions from all sources or the relevant pollutants or pollutants in such area . . ." Regulatory agencies and industrial facilities rely on emission inventories on an ongoing basis as indicators of air quality changes and for setting permit requirements.

Section 112 of the CAA establishes a two-stage regulatory process to address emissions of hazardous air pollutants (HAP) from stationary sources. In the first stage, Section 112 of the CAA directs the Environmental Protection Agency (EPA) to develop technology-based "maximum achievable control technology" (MACT) standards to control all major and some area sources emitting HAP. Emission inventories were used to identify source categories with facilities that are major sources of HAP emission (i.e., emit at least 10 tons per year (tons/yr) of a single HAP or 25 tons/yr of any combination of HAP). Iron foundries and steel foundries were two of the listed source categories and MACT standards for major source iron and steel foundries were established on April 22, 2004 (69 FR 21906). Section 112(k)(3)(B) of the CAA calls for the EPA to identify at least 30 air toxics that pose the greatest potential health threat in urban areas, and section 112(c)(3) requires the EPA to regulate the area source categories that represent 90 percent of the emissions of the 30 "listed" air toxics. Again, emission inventories were used to identify these pollutants and source categories and iron and steel foundries were two of the listed source categories. The EPA published national emission standards for area source iron and steel foundries (i.e., facilities that emit less than 10 tons per year (tons/yr) of a single HAP and less than 25 tons/yr of any combination of HAP) on January 2, 2008 (73 FR 226).

The second stage in standard-setting focuses on reducing any remaining "residual" risk according to CAA section 112(f). Section 112(f)(2) requires the EPA to determine for source categories subject to certain section 112(d) standards, such as the foundry rules identified above, whether the emissions limitations protect public health with an ample margin of safety. Once again, the emission inventory will be used as a key input to assess the risk from iron and steel foundries and to determine if the MACT standards for HAP provide an ample margin of safety to protect public health and prevent an adverse environmental effect.

The importance placed on emission inventories requires that they be of the highest quality obtainable considering their end use. Since they are the foundation of many air quality decisions, inventory quality is critical to defining realistic regulations and attainment strategies. Deficiencies and inconsistencies in existing compilation processes accentuate the need for developing and implementing more uniform and systematic approaches to collecting and reporting data. One of the primary goals of this Foundry Emissions Protocol document is to improve the quality of inventory data so that it is a reliable source of information for sound decision making regarding the iron and steel foundry source categories.

1.2 History of Foundry Emission Factors

The EPA has developed air emission factors to support inventory development and publishes these factors in the *Compilation of air pollutant emission factors* (commonly referred to as "AP-42") (U.S. EPA, 1995 and 2003). The emission factors available in AP-42 are primarily limited to criteria pollutants (although lead is both a criteria pollutant and an HAP). In 1998, the EPA conducted a detailed survey of iron and steel foundries to support HAP regulatory development. This data, along with other information collected during this study, are summarized in the Foundry Background Information Document (BID) (U.S. EPA, 2002). The 2002 BID provides additional data regarding particulate matter (PM) emissions and some default HAP emission factors for selected processes. For example, it provides typical chemical binder compositions and usage rates by which HAP emissions were estimated for mold and core making processes.

The methods and factors presented in this Foundry Emissions Protocol document rely heavily on factors and methods established in AP-42 and the 2002 foundry BID. When emission factors were not available for certain pollutants or sources in these documents, available source test data were reviewed to develop default emission factors for these sources/pollutants. These default emission factors are expected to represent emissions during normal operations. As many processes in the foundry operate in a batch or cyclic nature, the default emission factors were developed, to the extent practical, to include the available source test data occurring during typical cyclic operation. The emission factors developed specifically for this Foundry Emissions Protocol document used source test data located in US EPA publications and peer reviewed journals. Additional source test data was identified but not used due to the difficulty to assess the representativeness of the process operations and to quality assure the test procedures. The test data used was evaluated and compiled following the general guidelines presented in the 1997 Procedures for Preparing Emission Factor Documents, EPA-454/R-95-015 (U.S. EPA, 1997). To accommodate future emissions factors development efforts, the individual test data used in this Foundry Emissions Protocol document will be submitted electronically using the alternative procedure described on the Electronic Reporting Tool web page (http://www.epa.gov/ttn/chief/ert/index.html), as resources allow.

1.3 Ranking of Emission Estimation Methods

For each emission source, the various emission measurement or estimation methods specific to that source are ranked in order of preference, with "Methodology Rank 1" being the preferred (most accurate) method, followed by "Methodology Rank 2," and so on. The highest ranked method (with Methodology Rank 1 being the highest) ***for which data are available*** should be used. Methodology Ranks 1 or 2 generally rely on continuous emission measurement data for pollutant concentrations and either continuous measurement data for flow rates (Methodology Rank 1) or engineering calculations for flow rates (Methodology Rank 2). When continuous measurement data are not available, but site-specific emission source test data are available, emission estimates based on site-specific emission factors (Methodology Rank 3) are specified. When site-specific measurement or test data are not available, default emission factors (Methodology Rank 4) are provided.

1.4 Completeness

While this Foundry Emissions Protocol document attempts to identify and provide methodologies for each emission source at a typical foundry, there may be certain sources located at the foundry facility (i.e., that are owned or under the common control of the foundry owners or operators) that are not specifically addressed within the Foundry Emissions Protocol document. Additionally, there are sources included in this Foundry Emissions Protocol document for which no emission data are available to provide default emission factors (Methodology Rank 4) methods. The absence of a default emission factor is not necessarily sufficient grounds to exclude these sources from an emissions inventory. The emission inventory should be as complete as possible. If there are known emission release points within the facility for which no default emission factors are available, the emissions from these sources should be estimated using available process data, product knowledge, and engineering judgment, and these emission estimates should be included in the facility's emissions inventory.

1.4.1 General Foundry Emission Sources and Pollutants

There are five or six primary operations conducted at a typical iron and steel foundry, as illustrated in **Figure 1-1**. Foundry operations start with two parallel paths: one path includes the scrap and material handling and metal melting, and one path includes mold and core making. The two paths merge and continue the production with pouring of the molten metal into the mold, followed by cooling of the casting, and separation of the solid casting from the mold (commonly referred to as "shakeout" or "knockout"). For sand mold foundries, sand is typically recovered from the shakeout operations, reconditioned, and reused in the mold and core making operations. The cast metal recovered from the shakeout operations goes to the cutting, grinding, finishing, and cleaning processes or can also be reused in the melting operations. Additional description of foundry processes and their emission points is provided in the foundry BID (U.S. EPA, 2002).

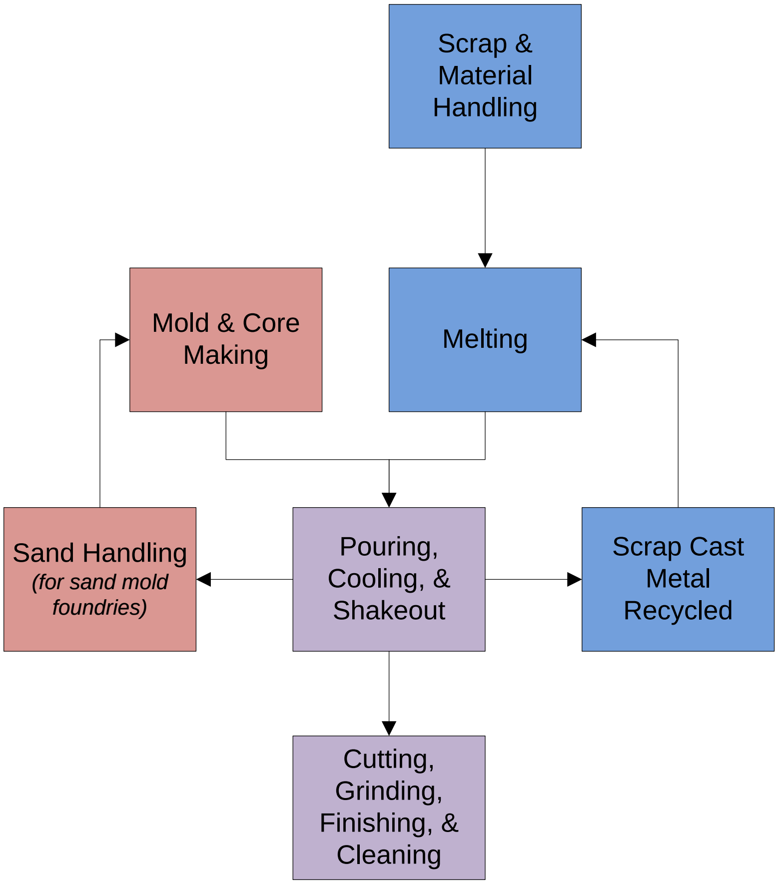


Figure 1-1. Simplified schematic of a typical iron and steel foundry operation.

The types of pollutants emitted vary by the type of foundry operation. **Table 1-1** provides a listing of the pollutants expected to be emitted by various sources at iron and steel foundries described in this protocol document. While Table 1-1 is intended to provide a comprehensive list of pollutants for each foundry emission source, the inventory developer should take into consideration facility-specific operations or conditions. In particular, emissions from mold and core making can vary widely based on the chemical binder system used at the facility. There may be numerous pollutants identified in Table 1-1 as being potentially emitted from mold- and core-making operations that are not released by a given facility based on the binder system employed. Likewise, it is possible that there may be pollutants that are not indicated in Table 1-1, but that are released from a given binder system. Thus, Table 1-1 should be used as a guide to identify pollutants to include in the emissions inventory, but site-specific factors should also be evaluated in developing a final pollutant list for the emissions inventory. To the extent possible, pollutant groupings such as volatile organic compounds (VOCs) and particulate matter (PM) should be speciated for a comprehensive and accurate emission inventory.

Table 1-1. Summary of Pollutants and Emission Sources Inclusion in a Foundry's Emission Inventory

CAS Number or Pollutant Code	Substance	Melting							Pouring/ Cooling						Shakeout/ Knockout	Finishing/ Grinding	Cleaning/ Coating	Mold & Core Making	Sand Handling	Materials Handling	Scrap Management	Slag Piles
		Electric Induction	Electric Arc	Cupola	Reverberatory	Crucible	Scrap Preheating	Inoculation	Green Sand Molds	Chemically-bonded Sand Molds	Centrifugal Casting	Permanent Casting	Investment Casting	Expendable Pattern Casting								
Criteria Pollutants																						
630-08-0	Carbon monoxide		●	●			○		●	●	●	●	●	●	●							
7439-92-1	Lead	●	●	●	●	●	●	●	●							●				●	●	
PM-PRI	Particulate matter (PM) of any particle size	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●
PM-FIL	Filterable PM	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●
PM10-PRI	PM ≤ 10 micrometers (µm)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●
PM10-FIL	Filterable PM ≤ 10 µm	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●
PM25-PRI	PM ≤ 2.5 µm	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●
PM25-FIL	Filterable PM ≤ 2.5 µm	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●
PM-CON	Condensable PM	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●	●	●	●	●
10102-44-0	Nitrogen dioxide		○	●	●		○															
NO_X	Nitrogen oxides		○	●	●		○															
7446-09-5	Sulfur dioxide		○	●	●		○															
VOC	Volatile organic compounds		○	●	●		○		●	●	●	○	●	●	●		●	●				
Specific VOC Constituents (Compounds listed below plus those listed under "Volatile Organic HAPs")																						
74-85-1	Ethylene		○	○	○		○		○	○	○	○	○	○	○		○	○				
74-86-2	Acetylene		○	○	○		○		○	○	○	○	○	○	○		○	○				
74-98-6	Propane		○	○	○		○		○	○	○	○	○	○	○		○	○				

CAS Number or Pollutant Code	Substance	Melting							Pouring/ Cooling													
		Electric Induction	Electric Arc	Cupola	Reverberatory	Crucible	Scrap Preheating	Inoculation	Green Sand Molds	Chemically-bonded Sand Molds	Centrifugal Casting	Permanent Casting	Investment Casting	Expendable Pattern Casting	Shakeout/ Knockout	Finishing/ Grinding	Cleaning/ Coating	Mold & Core Making	Sand Handling	Materials Handling	Scrap Management	Slag Piles
115-07-1	Propylene		○	○	○		○		○	○	○	○	○	○	○		○	○				
463-49-0	Propadiene		○	○	○		○		○	○	○	○	○	○	○		○	○				
106-97-8	n-Butane		○	○	○		○		○	○	○	○	○	○	○		○	○				
75-28-5	Isobutane		○	○	○		○		○	○	○	○	○	○	○		○	○				
106-98-9	1-Butene		○	○	○		○		○	○	○	○	○	○	○		○	○				
107-01-7	2-Butene		○	○	○		○		○	○	○	○	○	○	○		○	○				
115-11-7	Isobutene		○	○	○		○		○	○	○	○	○	○	○		○	○				
590-19-2	1,2-Butadiene		○	○	○		○		○	○	○	○	○	○	○		○	○				
109-66-0	n-pentane		○	○	○		○		○	○	○	○	○	○	○		○	○				
78-78-4	2-Methylbutane		○	○	○		○		○	○	○	○	○	○	○		○	○				
287-92-3	Cyclopentane		○	○	○		○		○	○	○	○	○	○	○		○	○				
591-95-7	1,2-Pentadiene		○	○	○		○		○	○	○	○	○	○	○		○	○				
1574-41-0	1-cis-3-Pentadiene		○	○	○		○		○	○	○	○	○	○	○		○	○				
2004-70-8	1-trans-3-Pentadiene		○	○	○		○		○	○	○	○	○	○	○		○	○				
591-93-5	1,4-Pentadiene		○	○	○		○		○	○	○	○	○	○	○		○	○				
591-96-8	2,3-Pentadiene		○	○	○		○		○	○	○	○	○	○	○		○	○				
598-25-4	3-Methyl-1,2-butadiene		○	○	○		○		○	○	○	○	○	○	○		○	○				
78-79-5	2-Methyl-1,3-butadiene		○	○	○		○		○	○	○	○	○	○	○		○	○				
542-92-7	Cyclopentadiene		○	○	○		○		○	○	○	○	○	○	○		○	○				
110-82-7	Cyclohexane		○	○	○		○		○	○	○	○	○	○	○		○	○				
108-87-2	Methylcyclohexane		○	○	○		○		○	○	○	○	○	○	○		○	○				
142-82-5	Heptane (and isomers)		○	○	○		○		○	○	○	○	○	○	○		○	○				
111-65-9	Octane (and isomers)		○	○	○		○		○	○	○	○	○	○	○		○	○				
67-64-1	Acetone		○	○	○		○		○	○	○	○	○	○	○		○	○				
78-93-3	Methyl ethyl ketone		○	○	○		○		○	○	○	○	○	○	○		○	○				
25551-13-7	Trimethylbenzene(s)		○	○	○		○		○	○	○	○	○	○	○		○	○				
Hazardous Air Pollutants (HAPs)																						
Volatile Organic HAPs																						
75-07-0	Acetaldehyde		○	○	○		○		●	●	●	○	●	●	●		○	●				
107-02-8	Acrolein		○	○	○		○		○	○	○	○	○	○	○		○	○				

CAS Number or Pollutant Code	Substance	Melting							Pouring/ Cooling						Shakeout/ Knockout	Finishing/ Grinding	Cleaning/ Coating	Mold & Core Making	Sand Handling	Materials Handling	Scrap Management	Slag Piles
		Electric Induction	Electric Arc	Cupola	Reverberatory	Crucible	Scrap Preheating	Inoculation	Green Sand Molds	Chemically-bonded Sand Molds	Centrifugal Casting	Permanent Casting	Investment Casting	Expendable Pattern Casting								
62-53-3	Aniline		○	○	○		○		●	○	○	○	○	○	○		○	○				
71-43-2	Benzene		○	○	○		○		●	●	●	○	●	●	●		○	○				
67-66-3	Chloroform		○	○	○		○		○	○	○	○	○	○	○		○	○				
74-87-3	Chloromethane																○	○				
98-82-8	Cumene		○	○	○		○		○	○	○	○	○	○	○		○	○				
111-42-2	Diethanolamine																	○				
100-41-4	Ethylbenzene		○	○	○		○		●	●	●	○	●	●	●		○	○				
50-00-0	Formaldehyde		○	○	○		○		●	●	●	○	●	●	●		○	●				
110-54-3	n-Hexane		○	○	○		○		●	●	●	○	●	●	●		○	●				
67-56-1	Methanol		○	○	○		○		○	●	●	○	●	●	●		○	●				
108-10-1	Methyl isobutyl ketone		○	○	○		○		○	○	○	○	○	○	○		○	○				
100-42-5	Styrene		○	○	○		○		●	○	○	○	○	●	○		○	○				
79-34-5	1,1,2,2-Tetrachloroethane																○					
127-18-4	Tetrachloroethylene																○					
108-88-3	Toluene		○	○	○		○		●	●	●	○	●	●	●		○	○				
79-01-6	Trichloroethylene																○					
121-44-8	Triethylamine																	○				
95-47-6	o-Xylene		○	○	○		○		●	●	●	○	●	●	●		○	○				
108-38-3	m-Xylene		○	○	○		○		●	●	●	○	●	●	●		○	○				
106-42-3	p-Xylene		○	○	○		○		●	●	●	○	●	●	●		○	○				
1330-20-7	Xylenes (total)		○	○	○		○		●	●	●	○	●	●	●		○	○				
Semi-volatile and Non-volatile Organic HAPs (except POMS, dioxins, furans, and polychlorinated biphenyls [PCBs])																						
108-39-4	m-Cresol			○					●	○	○	○	○	○	○			○				
95-48-7	o-Cresol			○					●	○	○	○	○	○	○			○				
106-44-5	p-Cresol			○					●	○	○	○	○	○	○			○				
1319-77-3	Cresols (total)			○					●	○	○	○	○	○	○			○				
	Glycol ethers†																	○				
101-68-8	4,4'-Methylene diphenyl diisocyanate (MDI)								○	○	○	○	○	○	○			○				

CAS Number or Pollutant Code	Substance	Melting							Pouring/ Cooling						Shakeout/ Knockout	Finishing/ Grinding	Cleaning/ Coating	Mold & Core Making	Sand Handling	Materials Handling	Scrap Management	Slag Piles
		Electric Induction	Electric Arc	Cupola	Reverberatory	Crucible	Scrap Preheating	Inoculation	Green Sand Molds	Chemically-bonded Sand Molds	Centrifugal Casting	Permanent Casting	Investment Casting	Expendable Pattern Casting								
26447-40-5*	4,4’-Methylenebis(phenyl isocyanate) [aka, MDI]								○	○	○	○	○	○	○			○				
108-95-2	Phenol		○	○	○		○		●	●	●	○	●	●	●		○	○				
POMs: Compounds that meet the HAP definition of polycyclic organic matter (POM). These compounds are often referred to as polycyclic aromatic hydrocarbons or “PAH.”																						
83-32-9	Acenaphthene $^{\text{16-PAH}}$			○					○	○	○	○	○	○	○							
208-96-8	Acenaphthylene $^{\text{16-PAH}}$			○					○	○	○	○	○	○	○							
120-12-7	Anthracene $^{\text{16-PAH}}$			○					○	○	○	○	○	○	○							
56-55-3	Benzo(a)anthracene $^{\text{7-PAH, 16-PAH}}$			○					○	○	○	○	○	○	○							
50-32-8	Benzo(a)pyrene $^{\text{7-PAH, 16-PAH}}$			○					○	○	○	○	○	○	○							
205-99-2	Benzo(b)fluoranthene$^{\text{7-PAH, 16-PAH}}$			○					○	○	○	○	○	○	○							
192-97-2	Benzo(e)pyrene			○					○	○	○	○	○	○	○							
191-24-2	Benzo(g,h,i)perylene$^{\text{16-PAH}}$			○					○	○	○	○	○	○	○							
207-08-9	Benzo(k)fluoranthene$^{\text{7-PAH, 16-PAH}}$			○					○	○	○	○	○	○	○							
92-52-4	Biphenyl			○					○	○	○	○	○	○	○							
91-58-7	2-Chloronaphthalene			○					○	○	○	○	○	○	○							
218-01-9	Chrysene $^{\text{7-PAH, 16-PAH}}$			○					○	○	○	○	○	○	○							
53-70-3	Dibenz(a,h) anthracene$^{\text{7-PAH, 16-PAH}}$			○					○	○	○	○	○	○	○							
57-97-6	7,12-Dimethylbenz(a) anthracene			○					○	○	○	○	○	○	○							
206-44-0	Fluoranthene $^{\text{16-PAH}}$			○					○	○	○	○	○	○	○							
86-73-7	Fluorene $^{\text{16-PAH}}$			○					○	○	○	○	○	○	○							
193-39-5	Indeno(1,2,3-cd) pyrene$^{\text{7-PAH, 16-PAH}}$			○					○	○	○	○	○	○	○							
56-49-5	3-Methylcholranthrene			○					○	○	○	○	○	○	○							
91-57-6	2-Methylnaphthalene		○	○	○		○		●	●	●	○	●	●	●		○	○				
218-01-9	Chrysene			○					○	○	○	○	○	○	○							
91-20-3	Naphthalene $^{\text{16-PAH}}$		○	○	○		○		●	●	●	○	●	●	●		○	○				

CAS Number or Pollutant Code	Substance	Melting							Pouring/ Cooling						Shakeout/ Knockout	Finishing/ Grinding	Cleaning/ Coating	Mold & Core Making	Sand Handling	Materials Handling	Scrap Management	Slag Piles
		Electric Induction	Electric Arc	Cupola	Reverberatory	Crucible	Scrap Preheating	Inoculation	Green Sand Molds	Chemically-bonded Sand Molds	Centrifugal Casting	Permanent Casting	Investment Casting	Expendable Pattern Casting								
198-55-0	Perylene			○					○	○	○	○	○	○	○							
85-01-8	Phenanthrene [16-PAH]			○					○	○	○	○	○	○	○							
129-00-0	Pyrene [16-PAH]			○					○	○	○	○	○	○	○							
Dioxins/Furans/PCBs																						
1746-01-6	2,3,7,8-Tetrachlorodibenzo-p-dioxin [J]		○	○	○		○															
1746-01-6	2,3,7,8-Tetrachlorodibenzo-p-dioxin		○	○	○		○															
40321-76-4	1,2,3,7,8-Pentachlorodibenzo-p-dioxin		○	○	○		○															
39227-28-6	1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin		○	○	○		○															
57653-85-7	1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin		○	○	○		○															
19408-74-3	1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin		○	○	○		○															
35822-46-9	1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin		○	○	○		○															
3268-87-9	Octachlorodibenzo-p-dioxin		○	○	○		○															
132-64-9	Dibenzofurans [k]		○	○	○		○															
51207-31-9	2,3,7,8-Tetrachlorodibenzofuran		○	○	○		○															
57117-41-6	1,2,3,7,8-Pentachlorodibenzofuran		○	○	○		○															
57117-31-4	2,3,4,7,8-Pentachlorodibenzofuran		○	○	○		○															
70648-26-9	1,2,3,4,7,8-Hexachlorodibenzofuran		○	○	○		○															

CAS Number or Pollutant Code	Substance	Melting							Pouring/ Cooling													
		Electric Induction	**Electric Arc**	**Cupola**	**Reverberatory**	**Crucible**	**Scrap Preheating**	**Inoculation**	**Green Sand Molds**	**Chemically-bonded Sand Molds**	**Centrifugal Casting**	**Permanent Casting**	**Investment Casting**	**Expendable Pattern Casting**	**Shakeout/ Knockout**	**Finishing/ Grinding**	**Cleaning/ Coating**	**Mold & Core Making**	**Sand Handling**	**Materials Handling**	**Scrap Management**	**Slag Piles**
57117-44-9	1,2,3,6,7,8-Hexachlorodibenzofuran		○	○	○		○															
72918-21-9	1,2,3,7,8,9-Hexachlorodibenzofuran		○	○	○		○															
60851-34-5	2,3,4,6,7,8-Hexachlorodibenzofuran		○	○	○		○															
67562-39-4	1,2,3,4,6,7,8-Heptachlorodibenzofuran		○	○	○		○															
55673-89-7	1,2,3,4,7,8,9-Heptachlorodibenzofuran		○	○	○		○															
39001-02-0	Octachlorodibenzofuran		○	○	○		○															
1336-36-3	Polychlorinated biphenyls (total)		○	○	○		○															
Metal HAPs																						
7440-36-0	Antimony	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○					○	○
7440-38-2	Arsenic	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○					○	○
7440-41-7	Beryllium	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○				○	○	○
7440-43-9	Cadmium	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○				○	○	○
18540-29-9	Chromium (hexavalent)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○				○	○	○
7440-47-3	Chromium (total)	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○				○	○	○
7440-48-4	Cobalt	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○				○	○	○
7439-92-1	Lead	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○				○	○	○
7439-96-5	Manganese	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○				○	○	○
7439-97-6	Mercury	●	●	●	●	●	●	●		○	○	○	○	○	○	○				○	○	○
7440-02-0	Nickel	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○				○	○	○
7782-49-2	Selenium	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○				○	○	○
Other Inorganic HAPs																						
75-15-0	Carbon disulfide			○																		
463-58-1	Carbonyl sulfide			○																		

CAS Number or Pollutant Code	Substance	Melting							Pouring/ Cooling						Shakeout/ Knockout	Finishing/ Grinding	Cleaning/ Coating	Mold & Core Making	Sand Handling	Materials Handling	Scrap Management	Slag Piles
		Electric Induction	Electric Arc	Cupola	Reverberatory	Crucible	Scrap Preheating	Inoculation	Green Sand Molds	Chemically-bonded Sand Molds	Centrifugal Casting	Permanent Casting	Investment Casting	Expendable Pattern Casting								
7647-01-0	Hydrogen chloride		○	○					○	○	○	○	○	○	○							
74-90-8	Hydrogen cyanide (& cyanide compounds)		○	○					○	○	○	○	○	○	○							
7723-14-0	Phosphorus	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○						
Other Compounds of Interest																						
74-84-0	Ethane		○	○	○		○		○	○	○	○	○	○	○		○	○				
74-82-8	Methane		○	○	○		○		○	○	○	○	○	○	○		○	○				
7440-39-3	Barium	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○				○	○	○
7440-50-8	Copper	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○				○	○	○
7439-95-4	Magnesium							●												○		
7439-98-7	Molybdenum	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○				○	○	○
7440-62-2	Vanadium	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○				○	○	○
7440-66-6	Zinc	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○				○	○	○
598-56-1	N,N-dimethylethylamine (DMEA)								○									○				
996-35-0	N,N-dimethylisopropylamine (DMIPA)								○													
107-21-1	Ethylene glycol																	○				
78-59-1	Isophorone			○					○	○	○	○	○	○	○							
16984-48-8	Fluorides	●	●	●	●	●																

● Designates pollutants expected to be emitted from foundry unit.

○ Designates pollutants potentially emitted from foundry unit.

[7-PAH] Designates compounds part of the list of seven polycyclic aromatic hydrocarbons

[16-PAH] Designates compounds part of the list of sixteen polycyclic aromatic hydrocarbons

* While the HAP list only includes CAS No. 101-68-8 for “Methylene diphenyl diisocyanate (MDI),” some chemical manufacturers may label this product under CAS No. 26447-40-5, but these are the same compounds.

[j] The listed HAP is 2,3,7,8-Tetrachlorodibenzo-p-dioxin (2378-TCDD); other dioxin isomers are listed because they can be used to calculate a 2378-TCDD toxicity equivalence.

[k] The listed HAP is dibenzofurans; other furan isomers are listed because they can be used to calculate furan toxicity equivalence.

[†] Includes mono- and di- ethers of ethylene glycol, diethylene glycol, and triethylene glycol R-(OCH2CH2)n -OR' where

n = 1, 2, or 3

R = alkyl or aryl groups

R' = R, H, or groups which, when removed, yield glycol ethers with the structure: R-(OCH2CH)n-OH. Polymers are excluded from the glycol category.

Some criteria pollutants, such as PM_{10} or $PM_{2.5}$ have special reporting nomenclatures to indicate the size range of the PM and the fraction of the PM emissions that are filterable or condensable. Other criteria pollutants, such as nitrogen dioxide (NO_2), are often determined or regulated as a combination of chemicals. For example, some foundries may have emission limits in terms of nitrogen oxides (NO_x), which is the sum of NO_2 and nitric oxide (NO) emissions. The inclusion of these additional nomenclatures or groupings in Table 1-1, above, is not intended to suggest that these compounds are criteria pollutants, but that these "pollutants" are emitted by foundries and should be included for completeness in the emissions inventory.

1.4.2 Special Considerations for PM Emission Inventories

This section provides specific information to help inventory developers better understand PM measurements and PM emission inventory nomenclature. In particular, there are a variety of PM test methods that may be used to assess PM emissions and it is important to understand what is measured by the different test methods so that the test results can be used properly in developing emission inventory estimates. As noted previously, there is a special reporting nomenclature for a PM inventory; the PM Emission Inventory Nomenclature text box below provides an overview of this nomenclature. A complete PM emissions inventory would include emission estimates for each of the $PM_{2.5}$ and PM_{10} fractions listed in this text box. Following is a discussion of typical PM test methods and how their measurements relate to this PM nomenclature.

EPA Method 5 (including its variations in Methods 5A through 5I) is the most commonly used test method for measuring PM emission from stationary sources. A typical Method 5 sampling train consists of a sampling probe, a heated line and filter, and a series of impingers that are kept in an ice bath. Method 5 sampling measures PM that is contained in the sampling probe and filter, which is often referred to as the "front-half" or "filterable" PM catch. PM that condenses in the impinger section of the sampling train is often referred to as the "back half" catch or the "condensable" PM. The front-half catch of Method 5 actually measures total filterable PM (PM-FIL) as there is no prefilter or cyclone to remove particulates with a mean aerodynamic diameter of greater than 10 µm. Nonetheless, Method 5 results are often reported as PM_{10}. For controlled sources, this may be a reasonable estimate, but it is likely to overestimate the actual PM_{10}-FIL emission for some sources that might emit larger particles. If EPA Method 5 test data are used, it is good practice to consider this PM-FIL and use the size distribution guidance provided in this Foundry Emissions Protocol document.

PM Emission Inventory Nomenclature

PM emissions inventories have their own nomenclature and structure. A complete PM emissions inventory includes the following components:

- PM_{10}-PRI: "Primary" PM emissions that are 10 µm in diameter or less. PM_{10}-PRI = PM_{10}-FIL + PM-CON.
- PM_{10}-FIL: Filterable (or front-half catch) portion of the PM emissions that are 10 µm in diameter or less.
- PM-CON: Condensable PM (or back-half catch). All condensable PM is assumed to be less than 2.5 microns (µm) in diameter ($PM_{2.5}$).
- $PM_{2.5}$-PRI: "Primary" PM emissions that are 2.5 µm in diameter or less. $PM_{2.5}$-PRI = PM_{25}-FIL + PM-CON.
- $PM_{2.5}$-FIL: Filterable (or front-half catch) portion of the PM emissions that are 2.5 µm in diameter or less.

Although a complete PM emissions inventory includes PM emissions that are 10 µm in diameter or less, some measurement methods also collect PM particles that are greater than 10 µm in diameter. The following nomenclature is used to designate PM emissions that include PM greater than 10 µm in diameter:

- PM-PRI: "Primary" PM emissions of any particle size. PM-PRI = PM-FIL + PM-CON.
- PM-FIL: Filterable (or front-half catch) portion of the PM emissions of any particle size.

EPA Method 17 is similar to Method 5, except that the filter in the Method 17 sampling probe is within the stack so that the "filterable" PM content is measured at the stack temperature. EPA Methods 201 and

201A are similar to Method 17, except that there is also a cyclone or other sizing device to remove particles greater than 10 µm in diameter prior to the filter so that Methods 201 and 201A determine PM_{10}-FIL directly. Any of the Method 5, 17, or 201 variant methods describe only the procedures to determine the front-half or filterable PM catch. EPA Method 202 specifies the procedures to determine the mass of PM that condenses in the impingers (i.e., PM-CON).

Although Method 202 generally references the use of Method 17 (or 201 or 201A) sampling trains, it may also be used in conjunction with EPA Methods 5, 5B, or 5F. As the filter temperature in Method 5 is different from Method 5B and also likely different from the filter temperature when using Method 17, the fraction of PM that is filterable versus condensable, which is a function of the sampling temperature, will also vary depending on the PM sampling method used. To further complicate PM-CON measurements, test specifying the use of Method 202 that were conducted prior to 2010 would measure the PM that condensed in the wet impingers. In 2010, the EPA revised Method 202 to include a dry impinger for the measurement of PM-CON. All Method 202 data used to develop PM-CON emission factors presented in this Foundry Emissions Protocol document are based on the wet impinger method,

1.4.3 Special Considerations for VOC Emission Inventories

This section provides specific information to help inventory developers better understand VOC measurements. As defined in 40 CFR 51.100, VOC means “any compound, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions.” Certain compounds, which have been determined to have negligible photochemical reactivity, are specifically excluded from the definition of VOC, including methane, ethane, methylene chloride, 1,1,1-trichloroethane, and a number of chlorofluorocarbons. There are a variety of test methods that may be used to assess VOC emissions, and it is important to understand what is measured by the different test methods so that the test results can be used properly in developing emission inventory estimates.

EPA Method 25 measures total gaseous nonmethane organics. This method uses a gas chromatography to separate carbon monoxide, carbon dioxide, and methane from the gas sample, oxidizing the remaining compounds to carbon dioxide, reducing this carbon dioxide to methane, and measuring the methane using a flame ionization detector (FID). EPA Method 25 results are typically reported “as carbon” in units of either mass carbon per unit dry gas volume or parts per million by volume (ppmv). Since EPA Method 25 converts the organics to methane prior to analysis, it provides an accurate measure of the mass of carbon without needing to consider the variable response of the FID to different types of organics. EPA Method 25 will include response from ethane, so EPA Method 25 could overestimate VOC concentrations if ethane is present. However, EPA Method 25 is more likely to underestimate the mass concentration of VOC compounds because it considers only the mass of carbon and does not include the mass of hydrogen, oxygen, or other elements that may be in the gaseous compounds.

EPA Method 25A determines the total gaseous organic concentration of a sample by direct FID analysis; EPA Method 25B is similar to EPA Method 25A, but uses a nondispersive infrared analyzer. The results from either method are reported on a volume concentration equivalent to the calibration gas, e.g., “ppmv as propane” or “ppmv as methane.” While different calibration gases have different FID responses, it is common practice to convert concentrations based on the number of carbon atoms, so a concentration reported as 5 ppmv as propane would be equivalent to 15 ppmv as methane (or sometimes reported “as carbon” or “as carbon equivalents”). It is best to use the concentration as measured for the calibration gas and the molecular weight of the calibration gas to convert the concentration to a mass per volume estimate. EPA Method 25A will typically have a high bias as a measure of VOC if methane and ethane are present in the gas stream, since the FID analyzer response will include responses for these non-VOC compounds.

EPA Method 18 uses a gas chromatograph to separate the gaseous compounds and uses an FID or another type of analyzer to determine the concentration of each separate compound. The concentrations are generally reported in volumetric concentrations (i.e., ppmv), as determined for each specific compound. Therefore, the volumetric response of the analyzer to a specific compound is specifically determined when using EPA Method 18. It should be noted that Method 18, as implemented by many testers, may not be sufficient to measure all of the VOC present in the gas stream. The reason is that not all reagents (e.g., charcoals, silica gells, liquid media) retain and then release for analysis all organic compounds present in the gas stream. In addition, not all analytical finishes (analyzers) are sensitive to all of the organic compounds. As a result, a pre-test survey usually is required to select the correct reagent(s) and analytical finish(es) such that an estimated 90+% of the compounds are measured. In addition, Method 18 is typically not used for more than about five individual compounds, and as a result, may yield lower VOC estimates than EPA Method 25 or 25A.

When calculating VOC emissions, it is important to note the test method used and the units for which these VOC concentration data are reported. Volume concentration data will need to be converted to a mass basis to determine the mass VOC emissions. If EPA Method 18 is used, the molecular weight of the specific compound is needed to convert the volume concentration to a mass concentration. If EPA Method 25A or 25B is used and the concentrations are reported “as propane,” then the molecular weight of propane should be used to convert the concentration to a mass basis, regardless of the molecular weight of the compounds actually present in the gas stream. If separate methane and ethane concentrations are available, it is possible to correct the total gaseous organic carbon results from EPA Methods 25A or 25B to VOC concentrations by subtracting out these concentrations, but care must be taken to ensure the units of measure are consistent (i.e., ensure all concentrations are reported “as propane,” for example, or convert the concentrations to “as carbon equivalents” before adjusting the Method 25A/25B results). If a VOC concentration from EPA Method 25 is reported in a mass concentration “as carbon,” this concentration can be used directly determine the mass emission of VOC “as carbon.” Alternatively, if the typical hydrocarbon composition is known, then the concentration “as carbon” can be converted to a mass concentration “as VOC” by multiplying by the molecular weight of the representative compound divided by the mass of carbon per mole of representative compound. For example, if a gas stream contained mostly aromatic compounds reasonably represented by toluene (C_7H_8), then the mass concentration “as carbon” can be converted to a mass concentration “as VOC” by multiplying by 1.095 [(7×12+8)/(7×12)]. These examples illustrate the need to understand the differences in VOC measurement methods and how these differences may impact the VOC emissions calculations.

1.4.4 Consideration of Capture Efficiencies

Many of the emission estimation methodologies provided in this Foundry Emissions Protocol document consider controlled and uncontrolled emission estimates. Control efficiencies are provided by which uncontrolled emission factors can be used to determine the controlled emissions based on the type of control device used. As a general rule, the examples provided in this document apply primarily to either uncontrolled sources or systems that have excellent capture systems venting the emissions to a control device. For systems with less than 99 percent capture efficiency, the emission inventory should specifically account for the uncaptured emissions. This section describes the basic methods for estimating these emissions.

Methodology Ranks 1, 2, or 3 will directly account for the emissions vented to the atmosphere from the capture and control system. If the capture efficiency is low or moderate, a significant portion of the source’s emissions may not be measured. If the capture system does not contain a control device or if a control device is present but is not expected to reduce the emissions of a measured pollutant (e.g., if VOC is measured at the outlet of a baghouse), then the measured emissions can be adjusted for the capture efficiency directly as shown in **Equation 1-1**.

$$\mathrm{E_{Total}} = \frac{\mathrm{E_{Meas}}}{\mathrm{CapEff}}$$

Eqn. 1-1

where:

E_{Total} = total emissions for the source, pounds per hour (lbs/hr)
E_{Meas} = the emissions measured within the stack for the source, lbs/hr
CapEff = estimated capture efficiency, mass fraction

Thus, if the emissions rate from the stack of an uncontrolled source was measured to be 10 lbs/hr and the capture efficiency of the hooding is estimated to be 70 percent, the total emissions would be 10/0.7 or 14 lbs/hr.

If the capture system does have a control device that would influence the emission rate of the measured pollutant, then the total emissions would be calculated using **Equation 1-2**.

$$\mathrm{E_{Total}} = \mathrm{E_{Meas}} + \mathrm{E_{Uncap}} \times (1 - \mathrm{CapEff})$$

Eqn. 1-2

where:

E_{Total} = total emissions for the source, pounds per hour (lbs/hr)
E_{Meas} = the emissions measured within the stack for the source, lbs/hr
E_{Uncap} = the emissions expected from the source if it were entirely uncaptured, lbs/hr
CapEff = estimated capture efficiency, mass fraction

The uncontrolled emissions from the source can be estimated using the default uncaptured emission factor for the source. Alternatively, the measured emissions can be divided by the expected control device efficiency and the capture efficiency to “back-calculate” the uncontrolled emissions from the source. Note for the PM sources, where not all of the uncaptured emissions are expected to be emitted to the atmosphere (i.e., settling of PM within the foundry building), back-calculating the emissions from the measured stack emissions may overstate the total emissions to the atmosphere.

When emissions are estimated based on emission factors, a general approach for estimating the total emissions is presented by **Equation 1-3**.

$$\mathrm{E_{Total}} = \mathrm{E_{Uncap}} \times (1 - \mathrm{CapEff}) + \mathrm{E_{Cap}} \times \mathrm{CapEff}$$

Eqn. 1-3

where:

E_{Total} = total emissions for the source, pounds per hour (lbs/hr)
E_{Uncap} = the emissions expected form the source if it were entirely uncaptured, lbs/hr
E_{Cap} = the emissions expected from the source if it were entirely captured and emitted through the control device, if applicable, lbs/hr
CapEff = estimated capture efficiency, mass fraction

Equation 1-3 will account for the difference in PM emissions when settling occurs within the foundry building area. For organic emissions, the uncaptured emissions are the same as the captured but uncontrolled emissions. In this special case, the total emissions can be calculated using **Equation 1-4**.

$$\mathrm{E_{Total}} = \mathrm{E_{Uncntrld}} \times (1 - \mathrm{CapEff} \times \mathrm{CE_i})$$

Eqn. 1-4

where:

E_{Total} = total emissions for the source, pounds per hour (lbs/hr)
$E_{Uncntrld}$ = the emissions expected from the uncontrolled source (for pollutants that have the same uncontrolled emissions regardless of presence of a capture system), lbs/hr
CapEff = estimated capture efficiency, mass fraction
CE_i = estimated control efficiency of the control device, if present, for pollutant "i", mass fraction

The methods to calculate the various emission terms in Equations 1-1 through 1-4 are provided in this Foundry Emissions Protocol document

1.5 Data Quality

The consistent use of standardized methods and procedures is essential in the compilation of reliable emission inventories. Quality assurance (QA) and quality control (QC) of an emission inventory are accomplished through a set of procedures that ensure the quality and reliability of data collection and analysis. These procedures include the use of appropriate emission estimation techniques, applicable and reasonable assumptions, accuracy/logic checks of computer models, and checks of calculations and data reliability. Depending upon the technical approach used to estimate emissions, a checklist with all of the particular data needs should be prepared to verify that each piece of information is used accurately and appropriately.

Appropriate metadata (data about the data) should be maintained to assist data users with assessing the accuracy of the reported emissions. QA/QC and other metadata records should also be maintained to allow verification of the reported emissions, although this information does not need to be reported unless specifically requested. For continuous emission measurement systems, these metadata include manufacturer's design specifications for accuracy, initial calibrations, periodic calibration checks, and other QA/QC procedures used to ensure the accuracy of the measurement device(s). For source tests used to develop site-specific emission factors, the metadata include the specific sampling and analysis procedures used, the results of field and laboratory blanks, duplicate analyses, method detection limits, isokinetic and cyclonic flow checks (if applicable), and key process operating data (e.g., throughput, temperature, material processed). For some pollutants, there may be different methods by which the emissions can be determined. For example, VOC emissions may be determined using a "total organics" method (e.g., using EPA Method 25, 25A through 25E, or 305) and subtracting any non-VOCs present or by speciating individual VOCs and summing the emissions of these compounds to determine the overall VOC emissions. When reporting VOC emissions, therefore, it should be clearly indicated how the emissions were determined. If the emissions are determined as TOC or from a TOC concentration measurement, it is important to indicate how the emissions are being reported, i.e., "as methane" (or as whatever compound was used to calibrate the total organic analyzer). There are also several PM test methods and the method used can greatly influence the emissions measured due to differences in probe and filter temperatures for the different methods and whether or not condensable PM is measured (see PM Test Method Consideration text box). These metadata assist users of the inventory data and help to ensure that the inventory data are correctly used when performing subsequent analyses.

1.6 Calculations and Significant Digits

The methodology ranking presented in this Foundry Emissions Protocol document is designed to highlight and promote those methods that are expected to yield the most accurate emission data. We recognize that the Methodology Rank 5 methodologies may only provide emission estimates that are within a factor of 2 or 3 from the actual emission rate. Nonetheless, the emission factors presented in this document are generally presented with two significant digits. The two significant digits should not be construed as an expectation that these emission factors are more accurate. The emission factors are provided with two significant digits because it is recommended that all calculations be performed carrying at least one additional significant digit to minimize round-off errors. The emissions calculated using default emission factors may be rounded to one significant digit when reporting the emissions, but at least two significant digits should be carried in the calculations. For methodologies that may have uncertainties in the range of ±10 to 20 percent, at least three significant digits should be carried when performing the calculations, even though the final emission estimate may only warrant two significant digits.

1.7 Sections of Protocol Document

The iron and steel foundry protocol document is organized in the following sections:

- Section 1. Introduction
- Section 2. Fugitive Dust Sources
- Section 3. Melting Operations
- Section 4. Mold and Core Making
- Section 5. Pouring, Cooling, and Shakeout
- Section 6. Finishing Operations
- Section 7. References
- Appendix A Glossary of Foundry Definitions Applicable to this Protocol Document
- Appendix B Development of Emission Factors for Melting Operations
- Appendix C Development of Emission Factors for Mold and Core Making
- Appendix D Development of Emission Factors for Pouring, Cooling, and Shakeout
- Appendix E Development of Emission Factors for Finishing Operations
- Appendix F Control Efficiency and Particulate Matter Size Distribution
- Appendix G List of Suggested SCC for Iron and Steel Foundry Operations

2. Fugitive Dust Sources

There are numerous sources of fugitive dust (or PM) emissions at iron and steel foundries. For the purposes of this Foundry Emissions Protocol document, fugitive dust sources relate to outdoor sources of dust emissions and do not include “uncaptured” emissions from indoor sources of PM emissions. Therefore, this section covers fugitive dust emissions from outdoor materials handling (e.g., material loading and transfer points, scrap piles, slag piles, sand handling systems) and roadways (e.g., vehicle movement on paved and unpaved roads).

Material handling operations include receiving, unloading, storing, and conveying materials for the iron and steel foundry, including metallic raw materials, fluxes, fuels, and sand. Metallic raw materials used by iron and steel foundries include pig iron, iron and steel scrap, foundry returns, metal turnings, and alloys. Fluxes used by iron and steel foundries include limestone, dolomite, soda ash, fluoride (fluorspar), and calcium carbide. Fuels used by iron and steel foundries include coal and coke (iron and steel foundries may also use oil and/or natural gas as fuel, but these are not expected to generate fugitive dust emissions). Other materials used or managed at foundries include sand, sand additives (binders), slag, and scrap returns (gates, risers, and defective castings). Fugitive particulate emissions from materials handling operations are generated from the receiving (unloading), storing, and conveying of these materials. The quantity of dust emissions from materials handling operations varies with the volume of materials processed, the number of transfer points, and the characteristics of the material (moisture content and silt content).

There are no direct emission measurement methodologies commonly employed by foundries for routine measurement of emissions from outdoor fugitive dust sources. Fugitive dust sources are described in Sections 13.2.1, 13.2.2, 13.2.3, and 13.2.4 of Chapter 13 of AP-42 (U.S. EPA, 2006b, 2006c, 2006d, 2011b), which presents general correlation equations for estimating fugitive dust emissions. As such, there is only essentially one methodology (equivalent to a Methodology Rank 4) available for these sources.

As noted in AP-42 (U.S. EPA, 2006c), total dust emissions from aggregate storage piles result from several distinct source activities within the storage cycle:

1. Loading of aggregate onto storage piles (batch or continuous drop operations).
2. Equipment traffic in storage area.
3. Wind erosion of pile surfaces and ground areas around piles.
4. Loadout of aggregate for shipment or for return to the process stream (batch or continuous drop operations).

Section 2.1, *Methodology for Material Handling*, provides emission methodologies for estimating PM emissions from aggregate loading or mixing (items 1 and 4, above). **Section 2.2**, *Methodology for Paved and Unpaved Roads*, provides methodologies for estimating PM emissions from equipment traffic (item 2, above). **Section 2.3,** *Methodology for Estimating HAP Metals Emissions from Fugitive Dust*, describes methods for estimating HAP emissions related to emitted PM from material handling.

For most foundries, wind erosion (item 3) is not expected to be a significant fugitive dust emission source because materials that are likely to be stored outdoors (like scrap metal or slag) have very limited amounts of dust-sized particles (particles less than 30 μm in diameter). As such, the threshold friction velocity needed to make the dust become airborne is typically quite large and is not generally exceeded under typical meteorological conditions. If a foundry stores sand, coke breeze, or other materials that may have a significant dust content, then the methodologies outlined in Section 13.2.5, *Industrial Wind*

Erosion, of Chapter 13 of AP-42 (U.S. EPA, 2006d) should be used to estimate the PM emissions from wind erosion (item 3 above), and the wind erosion PM emission estimates would be added to the loading and loadout emissions to determine the total PM emissions for that materials handling source. For scrap and slag piles, dust emissions from wind erosion may be assumed to be zero. For emissions from equipment traffic (e.g., trucks, front-end loaders, dozers) traveling between or on piles (item 4, above), it is recommended that the equations for vehicle traffic on unpaved surfaces be used (see **Section 2.2** of this Protocol document).

2.1 Methodology for Material Handling

Either adding aggregate material to a storage pile or removing it usually involves dropping the material onto a receiving surface. Truck dumping on the pile or loading out from the pile to a truck with a front-end loader are examples of batch-drop operations. Adding material to the pile by a conveyor stacker is an example of a continuous-drop operation.

Emissions from a material handling "drop" operation (either batch or continuous) are estimated using **Equation 2-1**. If the moisture content is known, the actual moisture content of the material should be used (equivalent to a Methodology Rank 4). If the moisture content is not known, then the default moisture contents found in **Table 2-1** should be used (Methodology Rank 5). The default moisture contents presented in Table 2-1 are highly uncertain as these data are from the late 1970's for integrated iron and steel plants. As such, measurements of moisture content are recommended for more accurate results. While it is reasonable to expect that silt content and emission factors are interrelated, no significant correlation between the two was found during the derivation of the equation, probably because most tests with high silt contents were conducted under lower winds, and vice versa (U.S. EPA, 2006c).

$$E = Q \times k \times \left(\frac{0.0032}{2000}\right) \times \frac{\left(\frac{U}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}$$

Eqn. 2-1

where:

E = emissions for a given materials drop, tons per year (tons/yr)
Q = quantity of material transferred, tons/yr
k = particle size multiplier, dimensionless (see values provided below for k)
U = mean wind speed, miles per hour (mph)
M = material moisture content (percent)
2,000 = Conversion factor, lbs/ton.

The particle size multiplier in the equation, k, varies with aerodynamic particle size range, as follows:

Aerodynamic Particle Size Multiplier (k) For Equation 2-1				
< 30 µm	< 15 µm	< 10 µm	< 5 µm	< 2.5 µm
0.74	0.48	0.35	0.20	0.053

The mean wind speed can be obtained from on-site meteorological station (preferred) or the nearest meteorological station or airport data. Appendix C-2 of AP-42 provides procedures for laboratory analysis of dust samples, including moisture analysis (U.S. EPA, 1993).

Table 2-1. Default Values for Moisture Content for Fugitive Dust Emission Estimates from Materials Handling

Source/Variable Description	Moisture Content Reported Range Value	Moisture Content Recommended Default Value
Scrap metal/pig iron		0.2
Slag piles	0.25 – 2.0[a]	1.0
Sand		0.3
Coal	2.8–11 [a]	5.0
Coke breeze	6.4 – 9.2 [a]	8.0

[a] Based on iron and steel production facility factors in Table 13.2.4-1 in AP-42 (U.S. EPA, 2006c).

Example 2-1: Estimation of PM Emissions from Material Handling

In this example, the required PM emission inventory data are calculated for emissions from sand being transferred from an outdoor sand pile to an open silo. A facility transfers 80,000 tons per year of sand, with a moisture content of 0.3 percent, from an outdoor sand pile to an open silo, where the average wind speed is 7 miles per hour.

Start with Equation 2-1:

$$E = Q \times k \times \left(\frac{0.0032}{2000}\right) \times \frac{\left(\frac{U}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} = \frac{\text{ton}}{\text{year}}$$

where:

E = emissions for a given materials drop, tons/yr
Q = quantity of material transferred, tons/yr
k = particle size multiplier, dimensionless

Aerodynamic Particle Size Multiplier (k) For Equation 2-1		
< 30 µm	< 10 µm	< 2.5 µm
0.74	0.35	0.053

U = mean wind speed, miles per hour (mph)
M = material moisture content (percent)

For fugitive dust sources, PM-CON = 0. Therefore, PM_x-PRI = PM_x-FIL. Using the k-values for PM_{10} and $PM_{2.5}$, the following PM emission inventory data are calculated:

$$PM_{10}\text{-PRI} = PM_{10}\text{-FIL} = 80{,}000 \times 0.35 \times \left(\frac{0.0032}{2000}\right) \times \frac{\left(\frac{7}{5}\right)^{1.3}}{\left(\frac{0.3}{2}\right)^{1.4}} = 0.96\ \frac{\text{ton}}{\text{year}}$$

$$PM_{2.5}\text{-PRI} = PM_{2.5}\text{-FIL} = 80{,}000 \times 0.053 \times \left(\frac{0.0032}{2000}\right) \times \frac{\left(\frac{7}{5}\right)^{1.3}}{\left(\frac{0.3}{2}\right)^{1.4}} = 0.14\ \frac{\text{ton}}{\text{year}}$$

2.2 Methodology for Paved and Unpaved Roads

Emissions from paved and unpaved roads are estimated using equations from Section 13.2.1.3 of AP-42 (U.S. EPA, 2011b) for paved roads and Section 13.2.2.2 of AP-42 for unpaved roads (U.S. EPA, 2006b) and recommended silt contents found in **Table 2-3** and **Table 2-5**.

2.2.1 Methodology for Paved Roads

The quantity of particulate emissions from resuspension of loose material on the road surface due to vehicle travel on a dry paved road may be estimated using the following empirical expression:

$$\mathrm{E} = \mathrm{VMT} \times \mathrm{k} \times (sL)^{0.91} \times (\mathrm{W})^{1.02} \times \frac{1}{2000}$$

Eqn. 2-2

where:

E = particulate emissions, tons/yr
VMT = vehicle miles traveled per year, miles/yr
k = particle size multiplier from **Table 2-2**, pounds per vehicle mile traveled (lb/VMT)
sL = road surface silt loading, grams/square meter ($\mathrm{g/m^2}$)
W = average weight of the vehicles traveling the road, tons.
2,000 = Conversion factor, lbs/ton.

It is important to note that **Equation 2-2** calls for the average weight of all vehicles traveling the road. For example, if 99 percent of traffic on the road are 2 ton cars/trucks, while the remaining 1 percent consists of 20 ton trucks, then the mean weight "W" is 2.2 tons. More specifically, Equation 2-2 is *not* intended to be used to calculate separate emissions for each vehicle weight class. Instead, emissions should be calculated to represent the "fleet" average weight of all vehicles traveling the road.

The particle size multiplier (k) above varies with aerodynamic size range, as shown in Table 2-2. To determine particulate emissions for a specific particle size range, use the appropriate value of k shown in Table 2-2.

Table 2-2. Particle Size Multipliers for Paved Road Equation

Size range[a]	Particle Size Multiplier k[b] lb/VMT
PM-2.5	0.00054
PM-10	0.0022

[a] Refers to airborne particulate matter (PM-x) with an aerodynamic diameter equal to or less than x micrometers.

[b] Units shown are pounds per vehicle mile traveled (lb/VMT).

If the road surface silt loading on the paved road is known (determined), the determined silt loading should be used in Equation 2-2 (equivalent to a Methodology Rank 4). If the road surface silt loading is not known, then a default silt loading from Table 2-3 should be used (Methodology Rank 5). Factors for asphalt batching and concrete batching are provided for area near sand piles. The default silt loading values presented in Table 2-3 are highly uncertain because these data are from the late 1970’s and are not specific to foundry facilities. Consequently, measurements of silt content are recommended for more accurate results. Appendix C-2 of AP-42 provides procedures for laboratory analysis of dust samples, including silt analysis (U.S. EPA, 1993).

Table 2-3. Default Values for Fugitive Dust Emission Estimates from Paved Roads

Source Description	Potential Range for Silt Loading (g/m^2)	Recommended Value for Silt Loading (g/m^2)
Iron and Steel production	0.09 - 79	9.7
Asphalt batching	76 - 193	120
Concrete batching	11 - 12	12

[a] Based on factors in Table 13.2.1-3 in AP-42 (U.S. EPA, 2011b).

Equation 2-2 was developed to predict only the emissions from dust resuspension from paved roads. Additional PM emissions occur from vehicle exhaust, brake wear, and tire wear. The additional emissions from these sources can be obtained from either EPA's MOBILE6.2 (http://www.epa.gov/oms/m6.htm) or MOVES2010 (http://www.epa.gov/otaq/models/moves/index.htm) models and added to the emissions from Equation 2-2 to determine total PM emissions from paved roads.

Example 2-2: Estimation of PM Emissions from Paved Roads

In this example, the PM-PRI, PM_{10}-PRI, and $PM_{2.5}$-PRI emissions from paved roads at a facility are calculated. A facility has an average weight of vehicles of 20 tons traveling a paved road with surface silt loading of 15 g/m^2. The vehicle miles traveled per year on this road is approximately 5,000 miles/yr.

Start with Equation 2-2:

$$E = \text{VMT} \times \text{k} \times (sL)^{0.91} \times (\text{W})^{1.02} \times \frac{1}{2000}$$

where:

E = particulate emissions, tons/yr
VMT = vehicle miles traveled per year, miles/yr
k = particle size multiplier from Table 2-2, pounds per vehicle mile traveled (lb/mile)

Size range	Particle Size Multiplier k lb/VMT
PM-2.5	0.00054
PM-10	0.0022

sL = road surface silt loading, grams/square meter (g/m^2)
W = average weight of the vehicles traveling the road, tons.

For fugitive dust sources, PM-CON = 0.

Since PM-CON = 0, PM_{10}-PRI = PM_{10}-FIL. Using the k-value for PM-10:

$$PM_{10}\text{-PRI} = 5{,}000 \times 0.0022 \times (15)^{0.91} \times (20)^{1.02} \times \frac{1}{2000} = 1.4\ \frac{\text{ton}}{\text{year}}$$

Since PM-CON = 0, $PM_{2.5}$-PRI = $PM_{2.5}$-FIL. Using the k-value for PM-10:

$$PM_{2.5}\text{-PRI} = 5{,}000 \times 0.00054 \times (15)^{0.91} \times (20)^{1.02} \times \frac{1}{2000} = 0.34\ \frac{\text{ton}}{\text{year}}$$

2.2.2 Methodology for Unpaved Roads

The following empirical expressions may be used to estimate the quantity in tons of size-specific particulate emissions from an unpaved road, per vehicle mile traveled (VMT):

For vehicles traveling on unpaved surfaces at industrial sites, emissions are estimated from the following **Equation 2-3**:

$$E = VMT \times k \times \left(\frac{s}{12}\right)^{a} \times \left(\frac{W}{3}\right)^{b} \times \frac{1}{2000}$$

Eqn. 2-3

where:

E = size-specific emission (tons/yr),
VMT = vehicle miles traveled per year,
k = particle size multiplier from **Table 2-4**, lb/VMT)
s = surface material silt content (percent) [use area-specific factors],
W = mean vehicle weight (tons).
2,000 = Conversion factor, lbs/ton.

The source characteristics s and W are referred to as correction parameters for adjusting the emission estimates to local conditions. As noted previously, W refers to the average weight of all vehicles traveling the road. Equation 2-3 is *not* intended to be used to calculate separate emissions for each vehicle weight class. Instead, only one value for W should be calculated to represent the "fleet" average weight of all vehicles traveling the road.

The constants for Equation 2-3 based on the stated aerodynamic particle sizes are shown in Table 2-4.

Table 2-4. Constants for Equation 2-3.

Constant	Industrial Roads	
	PM-2.5	**PM-10**
k (lb/VMT)	0.15	1.5
a	0.9	0.9
b	0.45	0.45

For vehicles traveling primarily on the storage pile, the silt value of the stored material should be used; for vehicles traveling between or around storage piles, the road silt content in these areas should be determined and used because they are expected to differ from the silt values for the stored materials (equivalent to a Methodology Rank 4). If the silt content is not known, then the default silt content for iron and steel production facilities found in Table 2-5 should be used (Methodology Rank 5). Defaults for sand and gravel processing plants and stone quarrying and processing plants are also provided for foundries that may have similar raw materials to those types of facilities.

Table 2-5. Default Values for Fugitive Dust Emission Estimates from Unpaved Roads

Source/Variable Description	Unpaved road: silt content %	
	Potential Range Value[a]	Recommended Value[a]
Iron and steel production	0.2 – 19	6.0
Sand and gravel processing plant road	4.1 – 6.0	4.8
Stone quarrying and processing plant road	2.4 – 16	10

[a] Based on factors in Table 13.2.2-1 in AP-42 (U.S. EPA, 2006b).

Equation 2-3 was developed to exclude emissions from vehicle exhaust, brake wear, and tire wear. However, PM emissions from dust resuspension on unpaved road are expected to be significantly higher than any additional PM emissions from vehicle exhaust, brake wear, and tire wear, so it is acceptable to ignore these sources when determining PM emissions from unpaved roads. Alternatively, PM emissions from vehicle exhaust, brake wear, and tire wear can be estimated from either EPA's MOBILE6.2 or MOVES2010 models and added to the emissions from Equation 2-3 to determine total PM emissions from unpaved roads.

2.3 Methodology for Estimating HAP Metals Emissions from Fugitive Dust

The metal HAP composition of the fugitive dust from materials handling operations can be assumed to be equivalent to the composition of the material stored if the material stored is generally composed of small particles (e.g., sand piles). It is expected that only scrap metal or slag piles will contain significant quantities of HAP, but these materials are generally not composed primarily of fine particles, so the dust emissions from these piles may have significantly different metal HAP composition than the stored material. Sand or coke piles, which are materials containing fine particles, are not expected to contain significant quantities of HAP, so no speciation is necessary for these fugitive dust sources.

In the absence of site-specific dust analysis, the average metal HAP concentration of PM emitted from scrap piles can be determined based on the average composition of the melted metal produced from the furnace, as a worst-case assumption. It is reasonable to adjust that composition based on alloying materials added to the furnace but not stored in the outdoor scrap pile. That is, if you alloy with chromium and add 1 lb of chromium per 99 lb of metal melted and your final melted steel contains 2 weight percent chromium, then you can assume the scrap pile contains approximately 1 weight percent of chromium and your chromium emissions would be 1percent of the PM-FIL emissions determined from the scrap pile (rather than 2 percent).

In the absence of site-specific dust analysis, the chemical composition of the produced slag should be used to speciate the metal HAP emissions from slag piles, as a worst-case assumption. If chemical composition data are not available for the produced slag, then the average chemical composition of the melted metal can be used as a proxy for estimating metal HAP emissions from the slag pile.

3. Melting Operations

Iron and steel foundries include several melting operations, the most common of which are scrap cleaning and preheating, melting furnaces, inoculation, and holding furnaces. These melting operations include point and fugitive sources. Some of these operations are uncontrolled, and some may be controlled using a wet scrubber, fabric filter, or other air pollution control techniques.

The emission estimation methods for melting operations are presented in **Table 3-1**. These methods are ranked according to anticipated accuracy.

Table 3-1. Summary of Typical Hierarchy of Melting Operations Emission Estimates

Rank	Measurement Method	Additional Data Needed
1	Direct measurement (continuous emission monitoring systems [CEMS]) for both flow rate and gas composition	▪ Pressure, temperature, and moisture content (depending on the monitoring system)
2	Direct measurement (CEMS) for gas composition Use engineering calculations to calculate flow rate	▪ Blast air rates, coke addition rates, fan power consumption, etc. as needed for the engineering flow estimates
3a	Source-specific stack testing to calculate source-specific emission factors	▪ Metal melting rate
3b	Source-specific PM emission factors from baghouse catch data	▪ Metal melting rate; baghouse catch data; control device collection efficiency estimates
4a	Default PM emission factors with site-specific metal chemistry	▪ Metal melting rate
4b	Default PM emission factors with default metal chemistry	▪ Metal melting rate

As all foundries have melting furnaces, the methodologies for melting furnaces will be presented first in **Section 3.1**, *Melting Furnaces*. Methodologies for scrap pretreatment and preheating are presented in **Section 3.2,** *Scrap Handling, Preparation and Preheating*. Methodologies for inoculation are presented in **Section 3.3**, *Metallurgical Treatment of Molten Metal*. Methodologies for holding furnaces are presented in **Section 3.4**, *Holding Furnaces.*

3.1 Melting Furnaces

There are several types of melting furnaces used in the iron and steel foundry industry, including, but not limited to electric arc furnace (EAF), electric induction furnace (EIF), cupola furnace, reverberatory furnace, and crucible furnace. The most commonly used melting furnaces are the EAF, EIF, and cupola.

EAFs are large, refractory-lined cylindrical vessels made of heavy welded steel plates. They are equipped with a removable roof through which carbon electrodes mounted on a superstructure above the furnace can be raised and lowered through holes in the furnace roof. For alternating current furnaces, the electrodes are lowered through the roof of the furnace and are energized by three-phase alternating current, creating arcs that melt the metallic charge with their heat. Additional heat is produced by the resistance of the metal between the arc paths. A direct-current furnace uses only one electrode and provides stable electrical current to the metal scrap with less electrode consumption. Once the melting cycle is complete, the carbon electrodes are raised and the roof is removed. The vessel can then be tilted to pour the molten iron (U.S. EPA 2002, 2003).

EIFs are cylindrical or cup-shaped refractory-lined vessels that are surrounded by electrical coils either around or below the main body of the furnaces. Furnaces with the coil around the furnace body are called coreless induction furnaces, and those with the coil below the body are called channel induction furnaces. When these coils are energized with high-frequency alternating current, they produce a fluctuating electromagnetic field that heats the metal charge. The metal is melted by resistance heating produced by the current. Consequently, EIFs may also be referred to as electric resistance furnaces. The coils carrying the electric current are typically cooled with water. Most induction furnace lids are closed when not charging, skimming, or tapping to reduce heat loss. The molten metal is tapped by tilting and pouring through a hole in the side of the vessels (U.S. EPA 2002, 2003).

The cupola is a cylindrical steel shell with a refractory-lined or water-cooled inner wall. Hinged doors at the bottom allow the furnace to be emptied when not in use. When charging the furnace, the doors are closed and a bed of sand is placed at the bottom of the furnace, covering the doors. A charge consisting of coke for fuel, scrap metal, alloying materials, and flux is loaded into the furnace. Flux, often chloride or fluoride salts, is added to the furnace to remove impurities. The flux reacts with impurities to form dross or slag, which rises to the surface of the molten metal and helps to prevent oxidation of the metal. The presence of coke in the melting process raises the carbon content of the metal to the casting specifications. Heat from the burning coke melts the scrap metal and flux, which both then drop to the bottom of the cupola to be tapped. As the melt proceeds, new charges are added at the top. A hole that is level with the top of the sand bed allows molten metal to be drawn off, or tapped. A higher hole allows slag to be tapped. Additional charge is added as needed (U.S. EPA 2002, 2003).

3.1.1 Methodology Rank 1 for Melting Furnaces

Though uncommon, some melt furnaces may have a CEMS for NO_x, CO, and/or SO_2. A CEMS is a comprehensive unit that continually determines gaseous or PM concentrations or emission rates using pollutant analyzer measurements and a conversion equation, graph, or computer program to produce results in the desired units.

There are two main types of CEMS: in-situ and extractive. An in-situ CEMS measures and analyzes the emissions directly in a stack. There is less sample loss associated with the in-situ CEMS compared to the extractive CEMS because the sample lines of an extractive system can leak, freeze, or clog, or pollutants can be lost because of adsorption, scrubbing effects, or condensation. In an extractive CEMS, the sample gas is extracted from the gas stream and transported to a gas analyzer for the measurement of the contaminant concentration. Because an extractive CEMS is located outside the stack, the sampling instruments are not affected by stack conditions, maintenance and replacement are generally simpler, and the cost is lower than with an in-situ CEMS, although extra costs are incurred for the sampling and conditioning system for an extractive CEMS (Levelton Consultants, 2005).

The pollutant concentration recorded by a CEMS is generally on a concentration basis, such as parts per million. The CEMS may also include a diluent monitor (e.g., O_2) for correcting the concentrations to a fixed excess air concentration. For in-situ CEMS, these measurements are made at stack conditions so that the concentrations would be determined on a “wet basis.” That is, the concentrations are based on the total amount of gas, including water vapor. For extractive CEMS, the gas is often conditioned to remove water vapor before analysis, so the concentrations are commonly determined on a “dry basis.” A flow rate monitor is also needed in order to determine mass emission rates directly using a CEMS (Methodology Rank 1). Gas flow measurements are made at stack conditions, so the flow rate will be in terms of actual gas volume on a wet basis. If the gas composition is determined on a dry basis, then a moisture content measurement is needed to convert the flow rate to a dry basis (or convert the composition to a wet basis) so that both measurements are on the same basis, and many gas flow monitors contain temperature and pressure monitors to allow conversion of the flow to standard conditions for this purpose. It is important to note that care must be taken to ensure that the gas and flow measurements are made on the same basis and in the same terms as the permitted limits, if applicable, or that appropriate ancillary measurements are made to perform the necessary unit conversions.

The following general equation (**Equation 3-1**) is used for determining a mass emission rate from a CEMS:

$$E_i = \sum_{n=1}^{N}\left((V)_n \times [1-(f_{H2O})_n] \times \frac{(C_i)_n}{100\%} \times \frac{MW_i}{MVC} \times \left(\frac{T_o}{T_n}\right) \times \left(\frac{P_n}{P_o}\right) \times K\right)$$

Eqn. 3-1

where:

E_i = Emission rate of pollutant “i” (tons/yr).
N = Number of measurement periods per year (e.g., for hourly measurements, N = 8,760 as there are 8,760 hours in a non-leap year).
n = Index for measurement period.
$(V)_n$ = Cumulative volumetric flow for measurement period “*n*” (actual cubic feet per measurement period [acf]). If the flow rate meter automatically corrects for temperature and pressure, then replace “$T_o \div T_n \times P_n \div P_o$” with “1.” If the pollutant concentration is determined on a dry basis and the flow rate meter automatically corrects for moisture content, replace the term $[1-(f_{H20})_n]$ with 1.
$(f_{H2O})_n$ = Moisture content of exhaust gas during measurement period “*n*,” volumetric basis (cubic feet water per cubic feet exhaust gas).
$(C_i)_n$ = Concentration of pollutant “i” in the exhaust gas for measurement period “*n*” (volume percent, dry basis). If the pollutant concentration is determined on a wet basis, then replace the term $[1-(f_{H20})_n]$ with 1.
MW_i = Molecular weight of pollutant “i” (kilogram per kilogram mole [kg/kg-mol]).
MVC = Molar volume conversion factor = 849.5 standard cubic feet per kilogram mole (scf/kg-mol) at 68°F (528°R) and 1 atmosphere (atm).
T_o = Temperature at “standard conditions” = 528 °R.
T_n = Temperature at which flow is measured during measurement period “n” (°R).
P_n = Average pressure at which flow is measured during measurement period “n” (atm).
P_o = Average pressure at “standard conditions” = 1 atm.
K = Conversion factor = 2.2046/2,000 (tons per kilogram [tons/kg] = 0.0011023 tons/kg.

A CEMS records multiple measurements per hour; the frequency depends on the pollutant being measured and the type of CEMS. For example, a CEMS monitoring benzene concentration using gas chromatography may only sample and record a measurement every 15 minutes, while a CEMS monitoring SO_2 concentration may measure concentration multiple times per second and combine these concentrations into a recorded output on a minute basis. These individual measurements can be used to calculate annual emissions in two ways. The most common method is for the CEMS to average the measurements within each hour and develop 8,760 hourly average concentrations and flow rates that can be summed. ***Example 3-1*** demonstrates the calculation of CO emissions for 1 hour for a cupola melting furnace based on an hourly average concentration and flow rate. This method is best suited for measurements that are fairly consistent and stable over the course of an hour. The other method is to determine the emission rate for each recorded measurement based on the concentration and flow rate for that measurement. In other words, if the CEMS records measurements every minute, then the emission rate is determined per minute and hourly emissions are determined by summing the 60 applicable emission rates; if the CEMS records measurements every 5 minutes, then the emission rate is determined for each 5-minute interval and hourly emissions are determined by summing the 12 applicable emission rates. This method is expected to be more accurate than using hourly averages of the individual measurement parameters (i.e. concentration and flow) if the source’s flow rate and concentration vary independently within an hourly time frame.

Example 3-1: Calculation of CO Emissions Using a CEMS

The following example shows the calculation for 1 hour (60 minutes); the total emissions during any period (i.e., day, month, quarter, or year) may be calculated as the sum of the hourly emissions determined by the CEMS. In terms of Equation 3-1, "i" is CO and the index for the period in this example is 1, so the result "E" is in tons per hour.

Calculate hourly CO emissions for a cupola melting furnace given that the following data have been collected:

- The hourly average CO concentration calculated by the CEMS for this hour is 600 parts per million by volume (ppmv), dry basis
- The hourly average flow rate calculated by the CEMS for this hour is 200,000 acfm, wet basis
- The unit continuously operated for the full hour
- The dry bulb temperature and pressure at the monitoring location was 400°F and 0.5 psig, and the moisture content was 3.9 volume percent.

The cumulative volume for the 1 hour time period (60 minutes) is:

$$(\mathrm{V})_{\mathrm{n}} = 50{,}000\ \mathrm{acfm}\ \times 60\ \mathrm{min} = 3{,}000{,}000\ \mathrm{acf}$$

Since the CO concentration was measured on a dry basis and the flow was determined on an actual (wet basis), the moisture content (f_{H2O}) correction must be used. The moisture content term in Equation 3-1 is in units of volume of water per volume of wet gas (i.e., volume of water plus volume of wet gas). From the Ideal Gas Law, a molar ratio is equivalent to a volume ratio. The molecular weight of dry air is 29 kg/kg-mol, and the molecular weight of water is 18 kg/kg-mol. Thus, f_{H2O} can be determined from the mass-based moisture content as follows:

$$\mathrm{f}_{\mathrm{H2O}} = \frac{\text{Moles Water}}{\text{Moles Water+Moles Dry Gas}} = \frac{(0.082\ \text{kg water})/18}{(0.082\ \text{kg water})/18+(1\ \text{kg air})/29} = 0.039$$

$$[1-(\mathrm{f}_{\mathrm{H2O}})_{\mathrm{n}}] = 1-0.039 = 0.961$$

$$(\mathrm{C}_{\mathrm{i}})_{\mathrm{n}} = \frac{600}{1{,}000{,}000} \times 100\% = 0.06\%$$

The temperatures must be converted to an absolute scale (degrees Rankine) as follows:

$$\mathrm{T}_{\mathrm{n}} = \mathrm{T}_{\mathrm{drybulb}} = (400 + 460) = 860°\mathrm{R}$$

The gauge pressure must be converted to an absolute pressure as follows:

$$\mathrm{P}_{\mathrm{n}=} \left[0.5\ \mathrm{psi} \times \frac{1\ \mathrm{atm}}{14.7\ \mathrm{psi}} + 1\ \mathrm{atm}\right] = 1.034\ \mathrm{atm}$$

The molecular weight of carbon monoxide (CO) is 28. Therefore,

$$\mathrm{E}_{\mathrm{CO}} = \sum_{\mathrm{n}=1}^{\mathrm{N}} \left((\mathrm{V})_{\mathrm{n}} \times [1-(\mathrm{f}_{\mathrm{H2O}})_{\mathrm{n}}] \times \frac{(\mathrm{C}_{\mathrm{i}})_{\mathrm{n}}}{100\%} \times \frac{\mathrm{MW}_{\mathrm{i}}}{\mathrm{MVC}} \times \left(\frac{\mathrm{T}_{\mathrm{o}}}{\mathrm{T}_{\mathrm{n}}}\right) \times \left(\frac{\mathrm{P}_{\mathrm{n}}}{\mathrm{P}_{\mathrm{o}}}\right) \times \mathrm{K} \right)$$

$$\mathrm{E}_{\mathrm{CO}} = 3{,}000{,}000 \times 0.961 \times \frac{0.06\%}{100\%} \times \frac{28}{849.5} \times \left(\frac{528}{860}\right) \times \left(\frac{1.034}{1}\right) \times 0.0011023$$

$$\mathrm{E}_{\mathrm{CO}} = 0.040\ \text{tons per hour (tons/hr).}$$

If the cupola melting furnace operated steadily and continuously for an entire year and the emission rate remained perfectly constant over that year, annual emissions would be 0.040 tons/hr × 8,760 hours per year (hr/yr) = 350 tons/yr.

3.1.2 Methodology Rank 2 for Melting Furnaces

Even though some foundries may have CEMS installed to measure a pollutant concentration, many of these foundries may not have a continuous flow monitor. When pollutant concentration data are available from a CEMS, but not flow rates, exhaust flow rates can often be calculated or estimated based on engineering calculations. For example, exhaust gas flow rates can be calculated from fuel combustion measurements. This method is commonly referred to as the "F-factor" method, and procedures for conducting a fuel analysis and calculating estimated emissions are described in EPA Method 19 (40 CFR Part 60, Appendix A-7) and in Appendix F of 40 CFR Part 75. This method is applicable to blast type furnaces, such as a reverberatory furnace, whose flow is primarily combustion air. This method may also be applied for cupola melting furnaces, but with greater uncertainties because not all of the coke used in the process is combusted (some of the carbon remains in the iron). For furnaces where the flow is generated primarily by the use of a capture/ventilation system exhaust fan, such as for EAF and EIF, fan curves may be used to estimate exhaust gas flow rates depending on the design of the ventilation system and presence of dampers (use of variable speed fans and dampers limit the ability to use fan curves for estimating flow rates).

For most common foundry melting furnaces, the engineering methods described in this section are expected to have greater uncertainties than when applied to other sources at the foundry. These methods are described here as Methodology Rank 2, but for cases where these methods have greater uncertainty, the assigned rank level is degraded to a Methodology Rank 3. If a facility has source test data (Methodology Rank 3a for Melting Furnaces), then stack flow rate measurement data will be available for the test runs. These measured flow rates should be compared to the engineering estimates to assess the accuracy of the engineering estimates. If the engineering estimates of the flow rates provide a reasonably accurate estimate of the flow rate as measured during the source tests (within approximately 20 or 25 percent), then the pollutant CEMS concentration and engineering estimates should be used preferentially to the site-specific emission factors. However, if the engineering estimates do not provide a reasonable estimate of the sources exhaust rate, then the site-specific emission factors (Methodology 3) should be used. Even with the uncertainties of these engineering methods as applied to melting furnaces, these engineering estimates are generally expected to provide a more accurate site-specific emission estimate than is obtained by using the default emission factors (Methodology Rank 4).

For blast-type melting furnaces such as reverberatory furnaces and (with greater uncertainties) cupolas, the F-factor method can be used to estimate the stack gas flow rate. When available, ultimate analysis of the fuel used can be used to determine a site-specific F-factor using **Equation 3-2**:

$$\mathrm{F_d} = \frac{[3.64\ (\%\mathrm{H})\ +\ 1.53\ (\%\mathrm{C}) +\ 0.57\ (\%\mathrm{S}) +\ 0.14\ (\%\mathrm{N}) -\ 0.46\ (\%\mathrm{O})] \times 10^6}{\mathrm{HHV}}$$

Eqn. 3-2

where:

F_d = Volume of combustion components per unit of heat content (dry standard cubic feet per million British thermal units; dscf/MMBtu)
%H = hydrogen content of fuel (weight percent)
%C = carbon content of fuel (weight percent)
%S = sulfur content of fuel (weight percent)
%N = nitrogen content of fuel (weight percent)
%O = oxygen content of fuel (weight percent)
HHV = Higher heating value of fuel (Btu/lb)

Table 3-2 provides default F-factors and higher heating values (HHV) for typical fuels used at foundries. It is important to note that these values are for estimating flow on a dry basis (at 0 percent excess air) and are based on the higher heating value of the fuel (referred to as gross calorific value in EPA Method 19).

Table 3-2. F-factor Exhaust Volumes and Heat Content of Common Fuels

Constituent	F-factor[a] (dscf/mmBtu)	HHV[b]
Coal – Bituminous	9,780	24.9 MMBtu/ton
Byproduct Coke (from coke ovens)	10,400 [c]	26.4 MMBtu/ton [c]
Petroleum Coke	9,830	30.0 MMBtu/ton
Natural Gas	8,710	1.028×10^{-3} MMBtu/scf

[a] From Table 1 to Appendix F of 40 CFR Part 75, unless otherwise noted.

[b] From Table C-1 to Subpart C of 40 CFR Part 98, unless otherwise noted .

[c] Determined from ultimate analysis and HHV values reported by Avallone and Baumeister (1978).

The volumetric flow rate of the exhaust gas, $(Q)_n$, can be estimated using the F-factor, the amount of fuel combusted, and the heat content of the fuel using **Equation 3-3**.

$$Q_n = F_d \times Q_f \times HHV \times \frac{20.9}{(20.9 - \%O_{2d})}$$

Eqn. 3-3

where:

Q_n = Volumetric flow rate for measurement period “n” (dry standard cubic feet per hour [dscfh])
F_d = Volume of combustion components per unit of heat content (dscf/MMBtu)
Q_f = Fuel input rate (ton/hour or dscfh)
HHV = Higher heating value of fuel (million British thermal units [MMBtu] per ton or MMBtu/scf])
$\%O_{2d}$ = Concentration of O_2 on a dry basis (percent)

If multiple fuels are consumed, apply Equation 3-3 for each fuel type and add the results together to determine the overall volumetric flow rate. Once the volumetric flow rate is known, the volume of gas exhausted over a time period can be determined and the emissions can be calculated using Equation 3-1 as in Methodology Rank 1 for Melting Furnaces. When using the F-factor method as indicated here, the exhaust gas flow rate will be in units of dry standard cubic feet per minute, so the temperature and pressure correction terms are not needed. A moisture correction term is not needed when the concentration measurement is also made on a dry basis. If the concentration measurements are made on a wet basis, then they must be corrected to a dry basis by dividing by the $[1-(f_{H20})_n]$ term (rather than multiplying by this term as shown in Equation 3-1). ***Example 3-2*** demonstrates how to calculate the exhaust flow rate from an F-factor.

As discussed previously, exhaust flow rates for EAF and EIF may be estimated using fan curves. Depending on the design of the ventilation systems, the use of fan curves to estimate flow rates may be difficult or inaccurate. Side draft hoods or canopy hood systems generally operate with constant flow (constant pressure drop), allowing the use of fan curves. Close fitting hoods that are raised and lowered and/or dampers that are frequently open and closed will significantly alter the pressure drop of the ventilation system, making it more difficult and inaccurate to use fan curves. An example of the use of fan curves is provided in **Section 5.1** *Methodology Ranks 1 and 2 for PCS Operations*.

Example 3-2: Calculation of Exhaust Flow Rate from F Factor

A cupola is equipped with an SO_2 CEMS and O_2 diluent monitor, and outputs SO_2 concentrations in units of ppmv, dry basis, corrected to 0% oxygen, but the cupola does not have a flow monitor. The average SO_2 concentration over a 1-hour period was 22 ppmv (dry basis; corrected to O% O_2). During this 1-hour period, the cupola consumed 8,000 lbs of coke and the afterburner consumed 2,600 scf of natural gas. What are the mass emissions of SO_2 during this 1 hour period?

Given only the above information (with no site-specific analysis of the coke used), the default factors in Table 3-2 are used with Equation 3-2. Since the concentration is already corrected to 0 percent O_2, the O_2 correction term in Equation 3-3 must be applied assuming 0 percent O_2 (the flow rate and concentration measures must be determined on the same basis).

The exhaust flow attributable to the coke combustion is as follows:

$$F_d = 10{,}400 \text{ (default from Table 3-2)}$$

$$Q_f = \frac{8{,}000 \text{ lbs of coke}}{\text{hour}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lbs}} = \frac{8{,}000 \text{ tons}}{2{,}000 \text{ hour}}$$

$$HHV = 26.4 \frac{\text{MMBtu}}{\text{ton}} \text{ (default from Table 3-2)}$$

$$Q_n = F_d \times Q_f \times HHV \times \frac{20.9}{(20.9 - \%O_{2d})}$$

Using $\%O_{2d} = 0$, the O_2 correction term goes to unity, i.e., $\frac{20.9}{(20.9-0)} = 1$

$$Q_n = 10{,}400 \times \frac{8{,}000}{2{,}000} \times 26.4 \times 1 = 1{,}098{,}240 \text{ dscfh}$$

The exhaust flow attributable to the natural gas combustion is as follows:

$$F_d = 8{,}710 \text{ (default from Table 3-2)}$$

$$Q_f = \frac{2600 \text{ scf}}{\text{hour}}$$

$$HHV = 1.028 \times 10^{-3} \frac{\text{MMBtu}}{\text{scf}} \text{ (default from Table 3-2)}$$

The O_2 correction term is 1 (since $\%O_{2d} = 0$).

$$Q_n = 8{,}710 \times 2{,}600 \times 1.028 \times 10^{-3} \times 1 = 23{,}280 \text{ dscfh}$$

Total Q_n = 1,098,240 + 23,280 = 1,121,520 dscfh

In 1 hour, $(V)_n = Q_n \times 1hr$ = 1,121,520 dry standard cubic feet (dscf) of gas would be exhausted (corrected to 0% excess O_2). The emissions for the hour are determined using Equation 3-1 (without pressure, temperature, or moisture content corrections):

$$(C_i)_n = \frac{22}{1{,}000{,}000} \times 100\% = 0.0022\%$$

$$MW_i = 32.066 + (2 \times 15.9994) = 64.06$$

$$K\left[\frac{lb}{kg}\right] = 2.2046 \text{ (to output the mass in lbs rather than tons)}$$

$$E_{SO_2} = \sum_{n=1}^{N}\left((V)_n \times \frac{(C_i)_n}{100\%} \times \frac{MW_i}{MVC} \times K\left[\frac{lb}{kg}\right]\right)$$

$$E_{SO_2} = 1{,}121{,}520 \times \frac{0.0022\%}{100\%} \times \frac{64.06}{849.5} \times 2.2046 = 4.1 \frac{lb}{hr}$$

3.1.3 Methodology Rank 3 for Melting Furnaces

Source testing can provide useful data for developing site-specific emission correlations or emission factors. Source testing provides a measurement of the emissions at a particular point in time, and most tests are performed at conditions representative of normal operation, in which case the emission measurement can provide an estimate of emissions at similar operating conditions. It is important to note that this methodology will be less reliable when the unit is operating at conditions other than those tested Emission factors developed directly from source test data are considered to be Methodology Rank 3a. For melting furnaces that are controlled with a baghouse, site-specific emission factors can be developed based on the baghouse catch data (the measurement of the mass of PM collected over a period of time). While baghouse catch data can be determined over longer periods of time, and thereby can represent the average PM (uncontrolled) emissions over a range of operating conditions, this method requires additional assumptions in order to be used to estimate emissions. Consequently, this methodology is considered Methodology Rank 3b.

3.1.3.1 Site-specfic Emission Factors from Source Test Data

Emission factors are developed by dividing the emission rate by a process parameter such as fuel usage or metal melting rates. Generally, one source test consisting of three runs is performed at a specific set of conditions, and the results for each run can be averaged to determine an emission factor that is assumed to apply at all heat input rates using **Equation 3-4**. The annual emissions can be calculated using **Equation 3-5**. ***Example 3-3*** demonstrates a sample emission factor calculation based on one test with three test runs.

$$\mathrm{EmF_i} = \frac{1}{\mathrm{N}} \times \sum_{\mathrm{r}=1}^{\mathrm{N}} \frac{\mathrm{E_{i,r}}}{\mathrm{Q_r}}$$

Eqn. 3-4

where:

$\mathrm{EmF_i}$ = emission factor of pollutant “i", lbs/ton
N = number of test runs
$\mathrm{E_{i,r}}$ = emissions of pollutant “i” during run “r”, lbs/hr
$\mathrm{Q_r}$ = quantity of metal melted (or other relevant processing rate), tons/hr

$$\mathrm{E_i} = \frac{\mathrm{Q_{Annual}} \times \mathrm{EmF_i}}{2{,}000}$$

Eqn. 3-5

where:

$\mathrm{E_i}$ = emissions of pollutant “i”, tons/yr
$\mathrm{Q_{Annual}}$ = quantity of metal melted (or other relevant processing rate) during the inventory year, tons/yr
$\mathrm{EmF_i}$ = emission factor of pollutant “i", lbs/ton
2,000 = Conversion factor, lbs/ton.

Example 3-3: Site-Specific Emissions Factor from Source Test Data

During a source test, three test runs were conducted to determine the PM emission rate for a controlled EAF melting furnace. The PM emissions rate measured during the source tests were 4.16, 5.29, and 5.33 lbs/hr for tests 1, 2, and 3, respectively. During the three runs, the EAF melted 20.6, 22.0, and 23.5 tons/hr of steel.

First, calculate the appropriate emissions factor for each individual run, and then average the emissions factors with the following calculations:

- Run 1: Emissions/throughput = 4.16 [lbs/hr] ÷ 20.6 [tph] = 0.202 lbs PM/ton
- Run 2: Emissions/throughput = 5.29 [lbs/hr] ÷ 22.0 [tph] = 0.240 lbs PM/ton
- Run 3: Emissions/throughput = 5.33 [lbs/hr] ÷ 23.5 [tph] = 0.227 lbs PM/ton

The average PM emission factor, using Equation 3-4, is

$$EmF_{PM} = (0.202 + 0.240 + 0.227) \div 3 = 0.223 \text{ lbs PM/ton metal melted}$$

The annual operating rate for the EAF was 46,750 tons metal melted for the year. Using Equation 3-5, the annual PM emissions for the EAF is calculated as:

$$E_i = \frac{Q_{Annual} \times EmF_i}{2{,}000}$$

$$E_i = \frac{46{,}750 \times 0.223}{2{,}000} = 5.21 \frac{\text{tons PM}}{\text{year}}$$

3.1.3.2 Site-specfic Emission Factors from Baghouse Catch Data

This method is only useful for estimating PM emissions and can only be used for sources controlled using a baghouse. PM collection quantities for wet collection systems are generally too inaccurate since the dry quantity of PM is difficult to determine in wet collection systems and because the PM collection efficiency of wet systems is generally less than for baghouses. The dry mass of PM collected over a set time period is measured along with the total quantity of metal melted over the same time period. Generally, a longer time period will provide a more accurate estimate of the average emission factor than a shorter time period.

This baghouse catch method provides a site-specific estimate of the captured but uncontrolled PM-FIL emissions; it does not provide a means to determine PM-CON emissions. The uncontrolled PM_{10}-FIL and $PM_{2.5}$-FIL emission as 90 percent and 70 percent of the PM-FIL emissions (based on the default size distribution for melting furnaces as presented in the following section for Methodology Rank 4). The actual emissions must still be calculated based on the control device PM collection efficiency; default values for these are provided in the following section for Methodology Rank 4. ***Example 3-4*** demonstrates the calculation of site-specific emission factors using baghouse catch data. These site-specific factors would then be used in-place of the default uncontrolled emission factors presented in Methodology Rank 4, but would use the general Rank 4 calculation methodologies to determine the actual emissions from the source.

Example 3-4: Site-Specific Emissions Factor from Baghouse Catch Data

A cupola melting furnace is controlled by a baghouse. Over a 1,000-hour period, the mass of PM collected in the baghouse was 16,000 lbs. Over the same 1,000-hour period, 2,000 tons of iron were melted in the cupola. Determine the site-specific "uncontrolled" PM emission factors for this cupola melting furnace.

The uncontrolled PM-FIL emission factor is simply the mass of PM collected divided by the mass of metal melted over the time period.

$$\text{PM-FIL uncontrolled emissions factor} = \frac{16{,}000\ [\text{lbs}]}{2{,}000\ [\text{tons}]} = 8.0\ \text{lbs/ton}$$

The PM_{10}-FIL and $PM_{2.5}$-FIL uncontrolled emission factor is estimated based on the default size distribution for melting furnaces, which is 90% and 70%, respectively (regardless of furnace type).

$$PM_{10}\text{-FIL uncontrolled emissions factor} = 8.0\ [\text{lbs/ton}] \times 90\% = 7.2\ \text{lbs/ton}$$

$$PM_{2.5}\text{-FIL uncontrolled emissions factor} = 8.0\ [\text{lbs/ton}] \times 70\% = 5.6\ \text{lbs/ton}$$

3.1.4 Methodology Rank 4 for Melting Furnaces

When direct emission monitoring or site-specific emission factors are not available, then default emission factors may be the only way to estimate emissions. This section presents the default emission factors applicable to melting furnaces and is divided into four subsections: 1) PM emission factors; 2) "other criteria" (non-PM) emission factors; 3) metal HAP emission factors (or, more accurately, default metal HAP composition of emitted PM); and 4) organic HAP emission factors.

3.1.4.1 PM Emissions Inventory Default Factors

The EPA has developed PM emission factors for various types of melting furnaces, which are provided in AP-42 (U.S. EPA, 1995; 2003), and provides size distribution analysis for iron foundry sources (U.S. EPA, 2003). The EPA also compiled PM emission factors as part of the Background Information Document (BID) to support standards development for iron and steel foundries. Comparing these emission factors, there are several discrepancies between the default factors. The emission factors and methodologies presented in this section reconcile, to the extent possible, these disparate emission factors. Appendix B provides additional details about the PM emission factors developed for melting furnaces. Due to the importance of providing emissions for the appropriate size of PM emitted, general uncontrolled emission factors and size distribution data are provided in this Protocol document, along with default control efficiencies based on the type and design of the control device. This approach is recommended due to the variability in design and performance of different control devices. **Table 3-3** provides the default filterable (by size) and condensable PM emission factors for different types of melting furnaces. For EAF and EIF, two separate emission factors are provided: one for melting and one for charging/tapping. These are provided in the event charging and tapping are conducted without control or with limited control (e.g., the control system may be operating, but the capture system has significantly lower capture efficiencies).

Table 3-3. Summary of PM Emission Factors for Melting Furnace Operations

Suggested SCC for Iron Foundries	Suggested SCC for Steel Foundries	Emission category	PM-FIL[a] emissions factor, lb/ton	PM_{10}-FIL[a] emissions factor, lb/ton	$PM_{2.5}$-FIL[a] emissions factor, lb/ton	PM-CON[b] emissions factor, lb/ton
30400301		Cupolas uncontrolled (or prior to controls)	13.8	12.4	9.7	0.05
30400304	30400701	EAF melting uncontrolled [c]	11.0	9.9	7.7	0.05
30400316		EAF charging & tapping uncontrolled [c]	1.8	1.6	1.3	0.01
30400303	30400705	Induction melting uncontrolled [c]	1.5	1.4	1.1	0.05
30400316		Induction charging & tapping uncontrolled [c]	0.5	0.5	0.4	0.01
30400302		Reverberatory uncontrolled	2.1	1.9	1.5	0.05

[a] Emission factors, in lb of pollutant per ton of grey iron melted, based primarily on data reported in AP-42 (U.S. EPA, 2003), except used an average particle size distribution for all furnace types (e.g., 70 percent of PM-FIL is less than 2.5 μm in diameter).

[b] Derived from test data received from 1998 Foundry ICR.

[c] Separated EAF and EIF emissions between melting and charging/tapping based on date received from 1998 Foundry ICR.

Table 3-4 provides default control efficiencies for different types of emission control systems. When applying the control efficiencies from Table 3-4 to the emission factors of Table 3-3, use the control efficiency reported for the particle size range of 0 to 2.5 μm for the fraction of $PM_{2.5}$-FIL and use the control efficiency reported for the particle size range of 2.5 to 10 μm for the fraction of PM_{10}-FIL. Generally, it can be assumed that the PM collection efficiencies for PM greater than 10 μm in diameter are 100 percent (provided the PM collection efficiency for the 2.5 to 10 μm is 90 percent or greater). Together, the default emission factors in Table 3-3 and control efficiencies from Table 3-4 yield controlled emission factors that agree well with the controlled melting furnace emissions reported in the *Iron and Steel Foundry BID* (U.S. EPA, 2002). To calculate emissions from the default emission factors and control efficiencies, use **Equation 3-6** for each size range of PM.

Note that the PM emission factors in Table 3-3 for PM_{10}-FIL include emissions of $PM_{2.5}$-FIL. $PM_{\text{"coarse"}}$-FIL is the PM between 2.5 and 10 μm in diameter and the emissions factor specifically for PM between 2.5 and 10 μm in diameter is the emissions factor for PM_{10}-FIL minus the emissions factor for $PM_{2.5}$-FIL. Therefore, to calculate PM_{10}-FIL emissions, the emissions for $PM_{\text{"coarse"}}$-FIL is added to the emissions for $PM_{2.5}$-FIL.

$$E_i = \frac{EmF_i}{2{,}000} \times Q \times (1 - CE_i)$$

Eqn. 3-6

where:

E_i = Emissions of pollutant "i" (tons/yr)
EmF_i = Emission factor for pollutant "i" (lb/ton metal melted)
Q = Metal melt rate (tons/yr)
CE_i = Control efficiency (fraction).
2,000 = Conversion factor, lbs/ton.

Condensable PM (PM-CON) is always assumed to be less than 2.5 µm in diameter and it is often not controlled efficiently in PM emission control devices. The key to controlling condensable PM is to sufficiently cool the gases prior to the control device so that the condensable PM is in particulate form as it enters the control device rather than gaseous form. As exhaust gases from melting furnaces with closed capture systems are hot, dry PM control systems may not effectively remove condensable PM. Because wet systems generally have a water quench to cool the gases prior to scrubbing/PM removal, more of the condensable PM is expected to be in particulate phase and amendable to control. The default control efficiencies reported for PM-CON in Table 3-4 generally assume that 30 percent of the PM-CON is in particulate form for the control systems that are designed to operate at approximately 200°F. In addition, it also assumes that 50 percent PM-CON of the PM-CON is in particulate form for controls that are designed to operate at approximately 165°F. So the condensable PM control efficiency is 30 to 50 percent of the control efficiency of PM in the 0 to 2.5 µm range. ***Example 3-5*** demonstrates how to estimate PM emissions using default emission factors.

Table 3-4. Typical Collection Efficiencies of Various Particulate Control Devices[a] (%)

AIRS Code[b]	Type of Collector	Collection Efficiency		
		Condensable PM	Filterable Particle Size (µm)	
			0–2.5	2.5–10
001	Wet scrubber – hi-efficiency	30	90	97
002	Wet scrubber – med-efficiency	10	25	90
003	Wet scrubber – low-efficiency	7	20	85
004	Gravity collector – hi-efficiency	0	3.6	5
005	Gravity collector – med-efficiency	0	2.9	4
006	Gravity collector – low-efficiency	0	1.5	3.4
007	Centrifugal collector – hi-efficiency	0	80	95
008	Centrifugal collector – med-efficiency	0	50	80
009	Centrifugal collector – low-efficiency	0	10	42
010	Electrostatic precipitator – hi-efficiency	0	95	99
011	Electrostatic precipitator – med-efficiency	0	80	93
012	Electrostatic precipitator – low-efficiency	0	70	85
014	Mist eliminator – high velocity >250 FPM	0	10	92
015	Mist eliminator – low velocity <250 FPM	0	5	57
016	Fabric filter – high temperature (>250 °F)	0	99	99.5
017	Fabric filter – med temperature (180 °F ≤T≤250 °F)	33	99	99.5
018	Fabric filter – low temperature (<180 °F)	50	99	99.5
049	Liquid filtration system	15	50	80
050	Packed-gas absorption column	30	90	97
051	Tray-type gas absorption column	10	25	90
052	Spray tower	7	20	85
053	Venturi scrubber (ΔP > 30 inches of water)	33	95	98
053	Venturi scrubber (ΔP ≤ 30 inches of water)	30	88	96
054	Process enclosed	0	1.5	3.4
055	Impingement plate scrubber	0	25	97
056	Dynamic separator (dry)	0	90	97

AIRS Code[b]	Type of Collector	Collection Efficiency		
		Condensable PM	Filterable Particle Size (µm)	
			0–2.5	2.5–10
057	Dynamic separator (wet)	15	50	80
058	Mat or panel filter – mist collector	0	92	95
059	Metal fabric filter screen	0	10	17
061	Dust suppression by water sprays	0	40	77
062	Dust suppression by chemical stabilizer or wetting agents	0	40	77
063	Gravel bed filter	0	0	42
064	Annular ring filter	0	80	93
071	Fluid bed dry scrubber	0	10	55
075	Single cyclone	0	10	42
076	Multiple cyclone w/o fly ash reinjection	0	80	95
077	Multiple cyclone w/fly ash reinjection	0	50	80
085	Wet cyclonic separator	15	50	80
086	Water curtain	0	10	67

[a] Data represent an average of actual efficiencies. Efficiencies are representative of well-designed and well operated control equipment. Site-specific factors (e. g., type of particulate being collected, varying pressure drops across scrubbers, maintenance of equipment) will affect collection efficiencies. Efficiencies shown are intended to provide guidance for estimating control equipment performance when source-specific data are not available. Table derived from Table B.2-3 Typical Collection efficiencies of various particulate control devices of Appendix B.2 of AP-42, Volume I, Fifth Edition (U.S. EPA, 1996)

[b] Control codes in Aerometric Information Retrieval System (AIRS), formerly National Emissions Data Systems.

Example 3-5: Estimating PM Emissions from Melting Furnace

A facility melts 40,000 tons of gray iron in EIFs. Each EIF has a lid that is ducted to a baghouse. Emissions from the EIF are uncontrolled when the lid is off, i.e., during charging and tapping. Calculate the PM emissions from the melting furnace.

The relevant factors from Table 3-3 are as follows:

Pollutant	Uncontrolled Melting Emission Factor (lb/ton metal melted)	Uncontrolled Charging/Tapping Emission Factor (lb/ton metal melted)
PM-FIL	1.5	0.5
PM_{10}-FIL	1.4	0.5
$PM_{2.5}$-FIL	1.1	0.4
PM-CON	0.05	0.01

First, the emissions from the control device must be determined. Without any other information, it is assumed the baghouse operates at moderate temperatures. The default control efficiency for a moderate temperature baghouse (fabric filter) is 33% for PM-CON, 99% for PM < 2.5 µm, and 99.5% for PM between 2.5 and 10 µm. It is generally assumed that the control efficiencies for particles greater than 10 µm in diameter is 100%.

Next, use Equation 3-6 with the melting emission factors:

$$E_i = \frac{EmF_i}{2{,}000} \times Q \times (1 - CE_i)$$

$E_{PM\text{-}CON,melt} = (0.05/2000) \times 40{,}000 \text{ tons/yr} \times (1\text{-}0.33) = 0.67 \text{ tons/yr}$

$E_{PM2.5\text{-}FIL.melt} = (1.1/2000) \times 40{,}000 \text{ tons/yr} \times (1\text{-}0.99) = 0.22 \text{ tons/yr}$

Note to calculate $E_{PM\text{“}coarse\text{”}\text{-}FIL,melt}$ subtract the $PM_{2.5}$-FIL emission factor from the PM_{10}-FIL emission factor and use the control efficiency for particles from 2.5 – 10 µm.

$E_{PM\text{“}coarse\text{”}\text{-}FIL,melt} = ((1.4\text{-}1.1)/2000) \times 40{,}000 \text{ tons/yr} \times (1\text{-}0.995) = 0.03 \text{ tons/yr}$

Recall that to calculate PM_{10}-FIL emissions, calculate $PM_{2.5}$-FIL emissions and $PM_{\text{“}coarse\text{”}}$-FIL emissions and add together.

$E_{PM10\text{-}FIL,melt} = E_{PM2.5\text{-}FIL,melt} + E_{PM\text{“}coarse\text{”}\text{-}FIL,melt} = 0.22 + 0.03 = 0.25 \text{ tons/yr}$

Next, emissions from uncontrolled charging and tapping (C/T) are calculated:

$E_{PM\text{-}CON\ ,C/T} = (0.01/2000) \times 40{,}000 \text{ tons/yr} \times (1) = 0.2 \text{ tons/yr}$

$E_{PM2.5\text{-}FIL,C/T} = (0.4/2000) \times 40{,}000 \text{ tons/yr} \times (1) = 8 \text{ tons/yr}$

$E_{PM\text{-}FIL,C/T} = E_{PM10\text{-}FIL,C/T} = (0.5/2000) \times 40{,}000 \text{ tons/yr} \times (1) = 10 \text{ tons/yr}$

Adding the melting and charging/tapping emissions together, a complete PM inventory for the EIF would be as follows:

$PM\text{-}CON = E_{PM\text{-}CON,melt} + E_{PM\text{-}CON\ ,C/T} = 0.67+0.2 = 0.87 \text{ tons/yr}$

$PM_{10}\text{-}FIL = E_{PM10\text{-}FIL,melt} + E_{PM10\text{-}FIL,C/T} = 0.25 + 10 = 10.25 \text{ tons/yr}$

$PM_{10}\text{-}PRI = PM_{10}\text{-}FIL + PM\text{-}CON = 10.25 + 0.87 = 11.12 \text{ tons/yr}$

$PM_{2.5}\text{-}FIL = E_{PM2.5\text{-}FIL,melt} + E_{PM2.5\text{-}FIL,C/T} = 0.22 + 8 = 8.22 \text{ tons/yr}$

$PM_{2.5}\text{-}PRI = PM_{2.5}\text{-}FIL + PM\text{-}CON = 8.22 + 0.87 = 9.09 \text{ tons/yr}$

3.1.4.2 Other Criteria Pollutant Emissions Inventory Default Factors

For other criteria pollutants (except for lead, which is also a HAP), default emission factors are presented in **Table 3-5**.

Table 3-5. Summary of Non-PM Criteria Pollutant Emission Factors for Melting Furnace Operations[a]

Suggested SCC for Iron Foundries	Suggested SCC for Steel Foundries	Emission category	CO, lb/ton	SO_2, lb/ton	NO_X, lb/ton	VOC, lb/ton
30400301		Cupolas with afterburner and either fabric filter or uncontrolled for PM	3	0.155[b]	ND	ND
30400301		Cupolas with afterburner and wet scrubber control	3	0.019[b]	ND	ND
30400301		Cupola with no afterburner and either fabric filter or uncontrolled for PM	145	0.155[b]		
30400301		Cupolas with no afterburner and wet scrubber control	145	0.019[b]		
30400304	30400701	EAF	18	Negligible	0.3	0.15
30400316		Electric induction furnace (EIF)	Negligible	Negligible	ND	ND
30400302		Reverberatory	ND	ND	ND	ND

[a] Emission factors, in lb of pollutant per ton of grey iron melted, based on data reported in AP-42 (U.S. EPA, 2003), unless otherwise specified; used mid-range value when a range was reported. ND = no data.

[b] Derived from data received during the development of the MACT standards for iron and steel foundries; see EPA Docket No. EPA-HQ-OAR-2002-0034 and Appendix B of this Protocol document.

3.1.4.3 Metal HAP Emissions Inventory Default Factors

Most metal HAP emissions will be associated with the filterable PM emissions. To estimate melting furnaces emissions of these metallic HAP, site-specific metal chemistry should be used to estimate the metal content of the emitted (filterable) PM (Methodology Rank 4A). In the absence of site-specific metal chemistry data, the default metal chemistries provided in **Table 3-6** can be used to estimate HAP metal emissions (Methodology Rank 4B). As noted in Table 3-6, default metal compositions are provided for both filterable and condensable PM. For certain metal HAP, such as mercury (Hg), the metal HAP emissions are expected to be in vapor form and will not be controlled or well correlated with the PM emissions. These pollutants will act like condensable PM and will have limited levels of control in most particulate control devices used with melting furnaces. It is inappropriate to use the chemistry of the melted metal as the composition for the condensable PM. Use **Equation 3-7** to determine the emissions of specific HAP metals from the melting furnace PM emission estimates.

$$E_i = \frac{\%\text{PM-FIL}_i}{100\%} \times \text{PM-FIL} + \frac{\%\text{PM-CON}_i}{100\%} \times \text{PM-CON}$$

Eqn. 3-7

where:

E_i = Emissions of pollutant “i” (tons/yr)
$\%\text{PM-FIL}_i$ = Percent of filterable PM mass contributed by pollutant “i” (weight percent)
PM-FIL = Total filterable PM emissions rate (tons/yr)
$\%\text{PM-CON}_i$ = Percent of condensable PM mass contributed by pollutant “i” (weight percent)
PM-CON = Condensable PM emissions rate (tons/yr).

Table 3-6. Default Metal Composition for PM from Melting Furnace Operations[a]

Suggested SCC for Iron Foundries	Suggested SCC for Steel Foundries	CAS No.	Metal Constituent	% of PM-FIL	% of PM-CON
30400301 30400302 30400303 30400304	30400701 30400705	7440-36-0	Antimony	0.01	0.02
30400301 30400302 30400303 30400304	30400701 30400705	7440-38-2	Arsenic	0.003	0.01
30400301 30400302 30400303 30400304	30400701 30400705	7440-39-3	Barium	0.03	0.1
30400301 30400302 30400303 30400304	30400701 30400705	7440-41-7	Beryllium	0.0001	0.007
30400301 30400302 30400303 30400304	30400701 30400705	7440-43-9	Cadmium	0.02	0.01
30400301 30400302 30400303 30400304		18540-29-9	Chromium (hexavalent) Iron Foundry Melting	0.0024 [b]	0.0015 [b]
	30400701 30400705	18540-29-9	Chromium (hexavalent) Steel Foundry Melting	0.0096 [b]	0.006 [b]
30400301 30400302 30400303 30400304	30400701 30400705	7440-47-3	Chromium (total)	0.08	0.05
30400301 30400302 30400303 30400304	30400701 30400705	7440-48-4	Cobalt	0.001	0.003
30400301 30400302 30400303 30400304	30400701 30400705	7439-92-1	Lead	1	0.3
30400301 30400302 30400303 30400304	30400701 30400705	7439-96-5	Manganese	3	2.9

Suggested SCC for Iron Foundries	Suggested SCC for Steel Foundries	CAS No.	Metal Constituent	% of PM-FIL	% of PM-CON
30400301 30400302 30400303 30400304	30400701 30400705	7439-97-6	Mercury	0.02	0.5–2.0 [c]
30400301 30400302 30400303 30400304	30400701 30400705	7440-02-0	Nickel	0.2	0.04
30400301 30400302 30400303 30400304	30400701 30400705	7723-14-0	Phosphorus	0.2	0.2
30400301 30400302 30400303 30400304	30400701 30400705	7782-49-2	Selenium	0.0015	0.015
30400301 30400302 30400303 30400304	30400701 30400705	7440-66-6	Zinc	9	2

[a] Derived from test data received from 1998 Foundry ICR. See Appendix B for more details on the development of the default metal composition of PM.

[b] Assume hexavalent chromium is 3% of total chromium emissions for Iron foundry melting and 12% of total chromium emissions for steel foundry melting based on Chromium hexavalent percentages reported for iron and steel foundry Standard Classification Codes (SCC) in Appendix D of National-scale Air Toxics Assessment (NATA). For other non-melting operations at Iron and Steel foundries using this table for default values, use 3% of the total chromium emissions (U.S. EPA, 2011a).

[c] Use the lower value if no automobile scrap is used and the higher value if automobile scrap is used as part of the charge material to the furnace.

Example 3-6: Estimating Metal HAP Emissions with Site-specific Metal Chemistries

For the EIF in ***Example 3-5***, what are the metal HAP emissions given the following site-specific metal chemistry details for the melted metal within the furnace?

% Pb	% Mn	% Cd	% Cr	% Ni	% Hg	% Selenium
1.10	7.28	0.0013	0.078	0.013	0.037	0.0094

Use Equation 3-7 with the site-specific composition data above and the default composition data from Table 3-6. From ***Example 3-5***, PM_{10}-FIL = 10.25 tons/yr and PM-CON = 0.87 tons/yr. Since the melting portion is controlled and the charging emission factores for PM and PM_{10} are identical, PM-FIL = PM_{10}-FIL = 10.25 tons/yr

$$\mathrm{E_i} = \frac{\%\text{PM-FIL}_\mathrm{i}}{100\%} \times \text{PM-FIL} + \frac{\%\text{PM-CON}_\mathrm{i}}{100\%} \times \text{PM-CON}$$

$$\mathrm{E_{lead}} = \frac{1.1\%}{100\%} \times\ 10.25 + \frac{0.3\%}{100\%} \times\ 0.87 = 0.115\ \text{tons/yr}$$

$$\mathrm{E_{manganese}} = \frac{7.28\%}{100\%} \times\ 10.25 + \frac{2.0\%}{100\%} \times\ 0.87 = 0.764\ \text{tons/yr}$$

$$\mathrm{E_{cadmium}} = \frac{0.0013\%}{100\%} \times\ 10.25 + \frac{0.02\%}{100\%} \times\ 0.87 = 0.000307\ \text{tons/yr}$$

$$\mathrm{E_{chromium}} = \frac{0.078\%}{100\%} \times\ 10.25 + \frac{0.05\%}{100\%} \times\ 0.87 = 0.00843\ \text{tons/yr}$$

$$\mathrm{E_{CR+6}} = 3\%\ (\text{for iron melting}) \times \mathrm{E_{chromium}} = 0.000253\ \text{tons/yr}$$

$$\mathrm{E_{nickel}} = \frac{0.013\%}{100\%} \times\ 10.25 + \frac{0.04\%}{100\%} \times\ 0.87 = 0.00168\ \text{tons/yr}$$

If automobile scrap is melted in the EIF:

$$\mathrm{E_{mercury}} = \frac{0.037\%}{100\%} \times\ 10.25 + \frac{2.0\%}{100\%} \times\ 0.87 = 0.0212\ \text{tons/yr}$$

If automobile scrap is NOT melted in the EIF:

$$\mathrm{E_{mercury}} = \frac{0.037\%}{100\%} \times\ 10.25 + \frac{0.5\%}{100\%} \times\ 0.87 = 0.00814\ \text{tons/yr}$$

$$\mathrm{E_{selenium}} = \frac{0.0094\%}{100\%} \times\ 10.25 + \frac{0.01\%}{100\%} \times\ 0.87 = 0.00105\ \text{tons/yr}$$

3.1.4.4 Organic HAP Emissions Inventory Default Factors

Organic HAP emission data for cupolas that use afterburners indicate negligible organic HAP emissions, with most HAP present below analytical detection limits (U.S. EPA, 2002) although small, detectable quantities of dioxin have been measured at iron and steel foundries. Recommended dioxin/furan emission factors are provided in **Table 3-7**. Note that the emission factors in Table 3-7 are in units of nanogram (10^{-9} grams) of dioxin toxicity equivalence (TEQ) per kg of metal melted. Other organic compounds generally emitted during the combustion of coke (e.g., benzene, toluene, ethylbenzene, xylenes, naphthalene, and 2-methylnaphalene) are expected to be emitted from a cupola if there is no or inefficient afterburning; however, there are inadequate test data to develop organic HAP emission factors for cupolas with no or poor afterburning.

Table 3-7. Congener-specific Profile for Ferrous Foundries[a]

Suggested SCC for Iron Foundries	Suggested SCC for Steel Foundries	Congener	Mean emission factor (2 facilities) (ng TEQ-WHO$_{05}$/kg of metal melted)	
			Nondetect set to zero	Nondetect set to ½ detection limit
30400301 30400302 30400303 30400304	30400701 30400705	2,3,7,8-TCDD	0.11	0.11
		1,2,3,7,8-PeCD	0.30	0.30
		1,2,3,4,7,8-HxCDD	0.012	0.012
		1,2,3,6,7,8-HxCDD	0.023	0.023
		1,2,3,7,8,9-HxCDD	0.028	0.028
		1,2,3,4,6,7,8-HpCDD	0.0033	0.0033
		OCDD	0.048	0.048
30400301 30400302 30400303 30400304	30400701 30400705	2,3,7,8-TCDF	0.084	0.084
		1,2,3,7,8-PeCDF	0.65	0.65
		2,3,4,7,8-PeCDF	0.13	0.13
		1,2,3,4,7,8-HxCDF	0.1	0.1
		1,2,3,6,7,8-HxCDF	0.0079	0.0079
		1,2,3,7,8,9-HxCDF	0.075	0.075
		2,3,4,6,7,8-HxCDF	0.0082	0.0082
		1,2,3,4,6,7,8-HpCDF	0.0014	0.0014
		1,2,3,4,7,8,9-HpCDF	0.00009	0.00009
		OCDF	0.00007	0.00007
30400301 30400302 30400303 30400304	30400701 30400705	Total TEQ-WHO$_{05}$	1.57	1.57

[a] Data from U.S. EPA, 1999a and 1999b, as reported in U.S. EPA, 2006a. Toxic Equivalent (TEQ) values reported using 2005 World Health Organization (WHO) Toxic Equivalent Factors (TEF).

3.2 Scrap Handling, Preparation, and Preheating

Iron and steel foundries use recycled scrap metals as their primary source of metal and resort to metal ingots as a secondary source when scrap is not available. Scrap metals may require some type of preparation prior to melting, such as cutting or sizing, shot or sand blasting to remove coatings, cleaning with organic solvents to remove oils and grease, and drying. (U.S. EPA, 2002)

Another form of scrap preparation that is commonly used is specification of quality. Iron and steel foundries may use some type of scrap selection, cleaning, or inspection program to ensure the quality of scrap metal used by the foundry. The scrap selection, cleaning, or inspection programs included specifications on the types or grades of scrap used; limits or bans on oil, grease, and/or paint in the scrap; and restrictions on lead, galvanized metals (a source of cadmium), and certain alloys (a source of chromium, nickel, or high manganese) (U.S. EPA, 2002).

Foundries can use preheaters to increase the temperature of the scrap prior to being melted in the furnace (most common for electric induction furnaces). Mechanical processes associated with scrap preheaters (e.g., loading of scrap) generate PM emissions that are of concern only in the work area. Scrap preheating itself can produce both PM and organic emissions. Over 90 percent of preheaters are direct-fired with natural gas. Metal HAP content of the PM is expected to be a function of the composition of the scrap. Organic HAP emissions, which arise from oil and grease contaminants, are assumed to include products of incomplete combustion. Scrap preheating entails loading, heating, and discharging of the scrap, and each individual step can be uncontrolled or controlled with a fabric filter, cyclone, afterburner, or scrubber. (U.S. EPA, 2002)

3.2.1 Methodology Rank 1 and 2 for Scrap Handling, Preparation, and Preheating

Emissions from Scrap Handling, Preparation and Preheating can be directly measured at the stack or outlet of the control device using a CEMS. If CEMS are available for both a pollutant concentration and flow rate, the CEMS data should be used to determine the pollutant emissions as Methodology Rank 1 for Scrap Handling, Preparation, and Preheating. If a CEMS is used to determine a pollutant's concentration, but direct flow measurement is not available, flow rates can often be determined using engineering estimates, such as fan amperage-to-flow correlations, to determine the pollutant emissions as Methodology Rank 2 for Scrap Handling, Preparation and Preheating. Follow the calculation methods provided in **Section 3.1**, *Melting Furnaces*, of this Protocol document as an example.

3.2.2 Methodology Rank 3 for Scrap Handling, Preparation, and Preheating

Source testing can provide useful data for developing site-specific emission correlations or emission factors. Source testing provides a measurement of the emissions at a particular point in time, and most tests are performed at conditions representative of normal operation, in which case, the emission measurement can provide an estimate of emissions at similar operating conditions. Site-specific emission factors are developed by dividing the emission rate by a process parameter, such as metal charge rate or metal processed rate using Equation 3-4. The annual emissions are then estimated using Equation 3-5 following the same steps as in ***Example 3-3***, above. It is important to note that this methodology will be less reliable when the unit is operating at conditions other than those tested.

3.2.3 Methodology Rank 4 for Scrap Handling, Preparation, and Preheating

When direct emission monitoring or site-specific emission factors are not available, then default emission factors may be the only way to estimate emissions. The EPA has developed a PM emission factor for scrap and charge handling; heating for iron and steel foundries in AP-42 Section 12.10; and from scrap handling for steel foundries in AP-42 Section 12.13 (U.S. EPA 1995, 2003). The appropriate default emission factors are provided in **Table 3-8**. For scrap handling (scrap piles indoors) and/or scrap preheating, the emission factors in Table 3-8 should be used. For scrap handling, preparation, and preheating, it is assumed that there are no condensable PM emissions. While scrap preheating may generate some condensable PM, the default condensable PM emission factor for melting furnaces is expected to cover the condensable emissions from the combined preheating/melting operations.

To develop HAP-specific emission estimates from scrap handling, preparation, and preheating, the PM emission factors in Table 3-8 should be used in conjunction with site-specific metal chemistries to estimate HAP metal emissions when site-specific metal chemistry data are available (Methodology Rank 4A). When site-specific metal chemistry data are not available, use the default metal compositions for PM from melting furnace operations provided previously in Table 3-6 (Methodology Rank 4B).

Table 3-8. Particulate Emission Factors for Scrap and Charge Handling, Heating at Iron and Steel Foundries

Suggested SCC for Iron Foundries	Suggested SCC for Steel Foundries	Emission Source	Pollutant	Emission Factor (lb/ton metal processed)
30400315	30400712 30400768	Scrap and charge handling, captured and ducted uncontrolled to atmosphere	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	0.6 [a] 0.5 [b] 0.4 [b]
30400314	30400741	Scrap and charge preheating, captured and ducted uncontrolled to atmosphere	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	0.6 [a] 0.5 [b] 0.4 [b]
30400315	30400712 30400768	Scrap and charge handling, uncaptured fugitive dust to atmosphere	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	0.2 [a] 0.18 [c] 0.17 [c]
30400314	30400741	Scrap and charge preheating, uncaptured fugitive dust to atmosphere	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	0.2 [a] 0.18 [c] 0.17 [c]

[a] Used the default factor for iron foundries (U.S. EPA, 2003).

[b] Assumes approximately 90% of PM is PM_{10} and 70% of PM is $PM_{2.5}$, similar to melting furnace size distribution.

[c] Assumes 90% of PM is PM_{10} , so that the PM_{10}-FIL factor matches that reported for steel foundries (U.S. EPA, 1995) and 85% of PM is $PM_{2.5}$, as smaller particles are more likely to escape to the atmosphere.

In estimating organic emissions from organic solvents used to clean/prepare scrap, use the VOC and HAP content found in the MSDS for the solvent and multiply by the amount of the solvent purchased for the year. The procedure is similar to the procedures for estimating organic emissions from mold and core making (as presented in **Section 4** of this Protocol document); it is assumed that 100 percent of the organics are emitted during scrap cleaning and preparation.

Example 3-7: Default Emissions Factor with Site-specific Metal Chemistries

A facility has an indoor scrap handling operation and preheater. The annual throughput for the scrap handling and preheater was 29,865 tons/yr last year. The scrap handling area is uncontrolled; the scrap preheater is controlled via a cyclone. What are the PM emissions for the scrap handling, preparation, and preheating operations?

The PM emissions can be calculated using the default uncontrolled PM emission factor and the default PM control efficiencies. As noted above, for scrap handling and preheating PM-CON = 0 so PM_{10}-PRI = PM_{10}-FIL. It is generally assumed that the control efficiencies for particles greater than 10 µm in diameter is 100%,. The relevant factors from Table 3-8 are as shown below:

Emission Source	Pollutant	Emission Factor (lb/ton metal processed)
Scrap and charge handling , uncaptured fugitive dust to atmosphere	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	0.2 0.18 0.17
Scrap and charge preheating, captured and ducted uncontrolled to atmosphere	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	0.6 0.5 0.4

Next, use Equation 3-6 with the uncontrolled scrap handling (SH) emission factors:

$$E_i = \frac{EmF_i}{2{,}000} \times Q \times (1 - CE_i)$$

Note that $E_{PM\text{-}CON\ ,SH}$ = 0 tons/yr (so PM-PRI = PM-FIL) and CE_{SH} = 0 (uncontrolled)

$E_{PM2.5\text{-}FIL,SH}$ = (0.4/2000) × 29,865 tons/yr × (1-0) = 5.97 tons/yr

$E_{PM\text{-}FIL,SH}$ = $E_{PM10\text{-}FIL,SH}$ = (0.6/2000) × 29,865 tons/yr × (1) = 8.96 tons/yr

Next, use Equation 3-6 with the uncontrolled scrap preheating (SP) emission factors and control efficiency for medium efficiency cyclone. It is assumed the cyclone operates similarly to a centrifugal collector – medium efficiency. The default control efficiency for a centrifugal collector – med-efficiency is 50% for PM < 2.5 µm and 80% for PM between 2.5 and 10 µm:

$E_{PM\text{-}CON,SP}$ = 0 tons/yr

$E_{PM2.5\text{-}FIL.SP}$ = (0.4/2000) × 29,865 tons/yr × (1-0.50) = 2.99 tons/yr

Note to calculate $E_{PM\text{“coarse”-}FIL,SP}$ subtract the $PM_{2.5}$-FIL emission factor from the PM_{10}-FIL emission factor and use the control efficiency for particles from 2.5 – 10 µm.

$E_{PM\text{“coarse”-}FIL,SP}$ = ((0.5 – 0.4)/2000) × 29,865 tons/yr × (1-0.8) = 0.30 tons/yr

Recall that to calculate PM10-FIL emissions, calculate $PM_{2.5}$-FIL emissions and $PM_{\text{“coarse”}}$-FIL emissions and add together.

$E_{PM\text{-}FIL,SP}$ = $E_{PM10\text{-}FIL,SP}$ = $E_{PM2.5\text{-}FIL,SP}$ + $E_{PM\text{“coarse”-}FIL,SP}$ =2.99 + 0.30 = 3.29 tons/yr

Adding the scrap handling and scrap preheating emissions together, a complete PM inventory for scrap handling and scrap preheating would be as follows:

PM-CON = $E_{PM\text{-}CON,SH}$ + $E_{PM\text{-}CON\ ,SP}$ = 0 + 0 = 0 tons/yr

PM_{10}-FIL = $E_{PM10\text{-}FIL,SH}$ + $E_{PM10\text{-}FIL,SP}$ = 8.96 + 3.29 = 12.25 tons/yr

PM_{10}-PRI = PM_{10}-FIL + PM-CON = 12.25 + 0 = 12.25 tons/yr

$PM_{2.5}$-FIL = $E_{PM2.5\text{-}FIL,SH}$ + $E_{PM2.5\text{-}FIL,SP}$ = 5.97 + 2.99 = 8.96 tons/yr

$PM_{2.5}$-PRI = $PM_{2.5}$-FIL + PM-CON = 8.96 + 0 = 8.96 tons/yr

Example 3-8: Estimating Metal HAP Emissions with Site-specific Metal Chemistries

For the scrap handling and scrap preheating operations in ***Example 3-7***, what are the metal HAP emissions given the following site-specific HAP metal chemistries: Mn, % = 1.03; Pb, % = 0.56; Ni, % = 0.05; and other HAP metals much less than 0.01 %.

Use Equation 3-7 with the site-specific composition data above. From ***Example 3-7***, PM-FIL = 12.25 tons/yr and PM-CON = 0 tons/yr.

$$E_i = \frac{\%\text{PM-FIL}_i}{100\%} \times \text{PM-FIL} + \frac{\%\text{PM-CON}_i}{100\%} \times \text{PM-CON}$$

$$E_{\text{lead}} = \frac{0.56\%}{100\%} \times 12.25 = 0.069 \text{ tons/yr}$$

$$E_{\text{manganese}} = \frac{1.03\%}{100\%} \times 12.25 = 0.13 \text{ tons/yr}$$

$$E_{\text{nickel}} = \frac{0.05\%}{100\%} \times 12.25 = 0.0061 \text{ tons/yr}$$

3.3 Metallurgical Treatment of Molten Metal

Before the molten metal is cast, the chemical composition is adjusted to meet product specifications by inoculation, or refining. Inoculation is the process in which magnesium and other elements are added to molten iron to produce ductile iron. Ductile iron is formed as a steel matrix containing spheroidal particles (or nodules) of graphite. Ordinary cast iron contains flakes of graphite. Each flake acts as a crack, which makes cast iron brittle. Ductile irons have high tensile strength and are silvery in appearance (U.S. EPA, 2003). Metallurgical treatment also includes adding specific alloying materials to the molten metal in a holding furnace or ladle.

3.3.1 Methodology Rank 1 and 2 for Metallurgical Treatment of Molten Metal

Emissions from metallurgical treatment of molten metal can be directly measured at the stack or outlet of the control device using a CEMS. If CEMS are available for both a pollutant concentration and flow rate, the CEMS data should be used to determine the pollutant emissions as Methodology Rank 1 for Metallurgical Treatment of Molten Metal. If a CEMS is used to determine a pollutant’s concentration, but direct-flow measurement is not available, flow rates can often be determined using engineering estimates, such as fan amperage-to-flow correlations, to determine the pollutant emissions as Methodology Rank 2 for Metallurgical Treatment of Molten Metal. Follow the procedures for estimating emissions using a CEMS provided in **Section 3.1**, *Melting Furnaces*, of this Protocol document as an example.

3.3.2 Methodology Rank 3 for Metallurgical Treatment of Molten Metal

Source testing can provide useful data for developing site-specific emission correlations or emission factors. Source testing provides a measurement of the emissions at a particular point in time, and most tests are performed at conditions representative of normal operation, in which case the emission measurement can provide an estimate of emissions at similar operating conditions. Emission factors are developed by dividing the emission rate by a process parameter such as metal charge rate or fuel usage using Equation 3-4. The annual emissions are then estimated using Equation 3-5 following the same steps as in ***Example 3-3***, above. It is important to note that this methodology will be less reliable when the unit is operating at conditions other than those tested.

3.3.3 Methodology Rank 4 for Metallurgical Treatment of Molten Metal

When direct emission monitoring or site-specific emission factors are not available, then default emission factors may be the only way to estimate emissions. The EPA has developed a PM emission factor for metallurgical treatment of molten metal for iron foundries in AP-42 Section 12.10. **Table 3-9** presents the recommended emission factors for PM for metallurgical treatment of molten metal at both iron and steel foundries. The "ducted" emission factor of 1.8 lb/ton from AP-42 (U.S. EPA, 2003) agrees reasonably well with the baghouse catch data reported in the Iron and Steel Foundries BID (U.S. EPA, 2002), which averaged 2.6 lb PM/ton metal processed, so the uncontrolled emission factors reported in AP-42 were selected. Note that for "in pour" magnesium inoculation, the inoculation emissions are expected to be negligible. Thus, the emission factors presented in Table 3-9 should not be used for "in pour" inoculation.

Table 3-9. Particulate Emission Factors for Metallurgical Treatment at Iron and Steel Foundries

Suggested SCC for Iron Foundries	Suggested SCC for Steel Foundries	Emission Source	Pollutant	Emission Factor (lb/ton metal produced)
30400310 30400321 30400322		Inoculation/metal treatment, captured and ducted uncontrolled to atmosphere	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	1.8 [a] 1.6 [b] 1.3 [b]
30400310 30400321 30400322		Inoculation/metal treatment, uncaptured fugitive dust to atmosphere	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	0.4 [a] 0.38 [c] 0.34 [c]

[a] Used the default factor for iron foundries (U.S. EPA, 2003).

[b] Assumes approximately 90% of PM is PM_{10} and 70% of PM is $PM_{2.5}$, similar to melting furnace size distribution.

[c] Assumes 95% of PM is PM_{10} and 85% of PM is $PM_{2.5}$, as smaller particles are more likely to escape to the atmosphere.

The metal HAP contents of the PM emitted from metallurgical treatment are expected to be weighted toward the composition of the inoculants or alloying material with some emissions of the original melted metal. To estimate the HAP emissions from metallurgical treatment, it is recommended that the PM emissions be estimated as comprising 90 percent of the inoculants and 10 percent of the molten metal to which the inoculants (or alloying materials) are added. The default metal composition for PM from melting furnace operations provided previously in Table 3-6 can be used if site-specific metal chemistry data are not available.

3.4 Holding Furnaces

After melting, the molten metal is tapped from the furnace into either a holding furnace or a transfer ladle. A holding furnace is generally an EIF used to maintain the molten metal in the proper condition until the foundry is ready to pour. Generally, emissions from holding furnaces are expected to be small because the holding furnaces are generally covered to retain heat. At times, the melting furnace acts as a holding furnace, in which case, the melting emission factors are expected to include emissions from this temporary holding process. Transfer ladles are generally open, but the molten metal does not remain in the ladles for long, and emissions from the ladle are expected to be small compared to tapping, metallurgical treatment, and pouring emissions, which could generally be considered, at least in part, emissions from the transfer ladle. This section should only be used to estimate emissions from dedicated holding furnaces that are not covered or that are covered and vented to the atmosphere (with or without PM emissions control).

3.4.1 Methodology Rank 1 and 2 for Holding Furnaces

Emissions from holding furnaces can be directly measured at the stack or outlet of the control device using a CEMS. If CEMS are available for both a pollutant concentration and flow rate, the CEMS data should be used to determine the pollutant emissions as Methodology Rank 1 for Holding Furnaces. If a CEMS is used to determine a pollutant's concentration, but direct flow measurement is not available, flow rates can often be determined using engineering estimates, such as fan amperage-to-flow correlations, to determine the pollutant emissions as Methodology Rank 2 for Holding Furnaces. Follow the procedures for estimating emissions using a CEMS provided in **Section 3.1**, *Melting Furnaces*, of this Protocol document as an example. An example of the use of fan curves to estimate exhaust flow rates is provided in **Section 5.1,** *Methodology Ranks 1 and 2 for PCS Operations.*

3.4.2 Methodology Rank 3 for Holding Furnaces

When source testing data are available, a site-specific emission factor can be developed based on either the metal processing rate of the furnace or a direct emission rate per hours of operation of the furnace. Emission factors are developed by dividing the emission rate by a process parameter such as metal charge rate or fuel usage using Equation 3-4. The annual emissions are then estimated using Equation 3-5 following the same steps as in ***Example 3-3,*** above. It is important to note that this methodology will be less reliable when the unit is operating at conditions other than those tested.

3.4.3 Methodology Rank 4 for Holding Furnaces

When direct emission monitoring or site-specific emission factors are not available, then default emission factors may be the only way to estimate emissions. **Table 3-10** presents the recommended emission factors for PM for holding furnaces at both iron and steel foundries. If the holding furnace is ducted to a control device, use the control efficiencies in Table 3-4 along with the captured/uncontrolled emission factors in Table 3-10 to estimate the emissions to the atmosphere (exiting the control device).

Table 3-10. Particulate Emission Factors for Holding Furnaces at Iron and Steel Foundries

Suggested SCC for Iron Foundries	Suggested SCC for Steel Foundries	Emission Source	Pollutant	Emission Factor (lb/ton metal produced)
30400303 30400304	30400701	Holding furnace, captured and ducted uncontrolled to atmosphere	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	0.5 [a] 0.45 [a] 0.35 [a]
30400303 30400304	30400701	Holding furnace, uncovered fugitive dust to atmosphere	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	0.3 [b] 0.29 [c] 0.26 [c]

[a] Used one-third the default factor for melting in induction furnaces (U.S. EPA, 2003).

[b] Assumes approximately 60% of PM released from furnace is emitted to atmosphere.

[c] Assumes 95% of PM is PM_{10} and 85% of PM is $PM_{2.5}$, as smaller particles are more likely to escape to the atmosphere.

The metal HAP contents of the PM emitted from holding furnaces are expected to be similar to the metal HAP contents of the PM emitted from the melting furnace. To estimate the HAP emissions from holding furnaces, the default metal composition for PM from melting furnace operations provided previously in Table 3-6 can be used if site-specific metal chemistry data are not available.

4. Mold and Core Making

The predominant casting operations at iron and steel foundries include sand mold, centrifugal, permanent mold, investment, and expendable pattern casting. Sand molds are bonded using resin-like chemicals or clay plus other materials. Permanent and centrifugal casting operations use metal molds, and investment casting operations use molds made from refractory material. Expendable pattern casting uses molds of unconsolidated sand. A variety of cores can be used with each type of mold. Most cores are made from chemically bonded sand. Others are made from plaster, collapsible metal, or soluble salts.

The emission estimation methods for mold and core making are presented in **Table 4-1**. Most equipment for mold and core making does not include well-defined stacks. Exceptions are baking ovens and cold-box machines that use catalyst gases. For emissions that are captured and emitted through well-defined stacks, direct measurement methods may be used. Direct measurements may be continuous or routinely frequent (e.g., daily or weekly) in nature so that the measurement data can be used directly to determine emissions (Methodology Rank 1). For many pollutants, a one-time or annual source test may be performed, but the emissions are not routinely measured. For these pollutants, the measured data can be used to determine an emission factor based on process throughput (quantity of sand used or quantity of binder/catalyst used), and the annual emissions can be determined using the annual material usage multiplied by the site-specific emission factor (Methodology Rank 2). However, for most mold and core making operations, no direct measurement data will be available. In such cases, emissions will be estimated based on binder composition, usage rates, and default release factors (Methodology Rank 3) or generic emission factors (Methodology Rank 4).

Table 4-1. Summary of Typical Hierarchy of Mold and Core Making Emission Estimates

Rank	Methodology Description	Application	Data Requirements
1	Direct routine measurement	Baking ovens, gas-cured binder systems, and other systems that are well-captured and have well-defined stack emissions	Constituent concentration and exhaust flow rate
2	Site-specific emission factor from one-time or periodic emissions source test data	Baking ovens, gas-cured binder systems, and other systems that are well-captured and have well-defined stack emissions	Constituent concentration and exhaust flow rate; and material usage rate (or throughput) during source test; annual material usage rate (or annual throughput)
3A	Chemical-specific release factors	Chemical binder systems and coating materials	Composition of chemical binder or coating material (from Material Safety Data Sheets) and binder/coating material annual usage quantities
3B	Chemical-specific release factors	Chemical binder systems and coating materials	Composition of chemical binder or coating material (defaults) and binder/coating material annual usage quantities
4	Default emission factors	All sources	Material usage rates

Emissions from mold and core making operations include PM emissions from sand handling and mixing as well as organic emissions from the release or volatilization of constituents in organic binders or coating materials used to make (or coat) the molds and/or cores. The bulk of this section focuses on emission estimating procedures for organic chemical releases during the mixing, setting, and storage of the molds and cores. These procedures are also applicable to mold and core coating materials. PM emissions from the sand handling/mixing system are difficult to assess unless they are well-captured and vented through a defined stack. Otherwise, particles that may become airborne (suspended) within the foundry during sand handling/mixing are likely to redeposit within the foundry, and only a fraction of the PM that becomes suspended will be released “to the atmosphere” (i.e., escape the foundry building). Default PM emission factors (Methodology Rank 4) for sand handling operations are provided in **Section 4.3** of this Protocol document.

Different foundries can have significantly different emissions from mold and core making depending on the type of casting system employed, binder system used to make cores, and whether the sand molds are chemically bonded. For example, permanent and centrifugal molding operations may not use sand at all (if no cores are needed), so they would have no PM emissions from sand handling or mixing. Even if cores are used, permanent and centrifugal molding operations will handle very limited quantities of sand compared to sand casting systems, so their PM emissions will be much smaller. Many sand molds are made from clay-bonded sand, commonly called green sand, which uses clay and water as the binder. While foundries that use green sand molds with little to no cores will have PM emissions from sand handling/mixing, they may have very limited or no organic HAP releases from their mold making operations. Molds that use chemically bonded sand or that require significant quantities of core materials can have significant organic HAP emissions; however, the specific HAP released may vary significantly based on the chemical binder system used. Chemical bonding systems work by polymerization reactions that occur at ambient temperature or are induced by heat or catalysis. The major types of binder systems used for core making are the oil-bake, shell, hot-box, warm-box, no-bake, and cold-box systems. The major system used for mold making is the shell system (U.S. EPA, 2002).

4.1 Methodology Ranks 1 and 2 for Mold and Core Making

Emissions from vented mold and core making processes can be directly measured at the stack or outlet of the control device using the direct measurement methods described in **Section 3**, *Melting Operations*, of this Foundries Emissions Protocol document. If CEMS are available for a pollutant, the CEMS data should be used to determine the pollutant emissions as Methodology Rank 1 for Mold and Core Making. It is more likely, however, that only data from a single source test or a limited number of source tests are available. For this situation, a site-specific emission factor can be developed and used to assess the emissions from the mold and core making process, similar to the methods described in **Section 3**, *Melting Operations*. For some mold and core making systems, the “activity” data are likely to be specific chemical usage rates or sand usage rates (rather than metal charge or melting rates). ***Example 4-1*** provides an example of developing a site-specific emission factor for estimating triethyl amine (TEA) emissions from a wet scrubber used to control a cold-box catalyst gas sweep system.

Example 4-1: Development of Site-Specific Emissions Factor

A source test was performed on an acidic wet scrubber used to control TEA gas catalyst emissions from a cold box core making line. The average TEA emissions rate for the three test runs was 0.03 pounds per hour (lb/hr). The cumulative TEA usage over the 5-hour period encompassing the source test runs was 88 lbs. What is the site-specific emission factor for TEA? If the annual TEA usage rate is 35,500 lbs, what are the annual emissions of TEA from the acidic wet scrubber? What is the annual emissions ir the capture system only captures 90% of the TEA from the cores?

The average TEA usage rate during the source test was: 88 (lbs)/5 (hrs) = 17.6 lbs/hr.

The site-specific emission factor is simply the emissions rate divided by the TEA usage rate:

EmF_TEA = 0.03 (lbs/hr) ÷ 17.6 (lbs/hr) = 0.00171 lb/lb or 3.42 lb/ton.

Given the annual TEA usage of 35,000 lbs = 17.5 tons (per year), the annual average emissions rate for TEA is estimated as: 3.42 lb/ton × 17.5 tons/yr = 59.85 lbs/yr or 0.0299 tons/yr.

If the TEA capture system is only 90 percent, Equation 1-4 can be used to estimate the annual emissions.

$$E_{\mathrm{Total}} = E_{\mathrm{Uncntrld}} \times (1 - \mathrm{CapEff} \times \mathrm{CE_i})$$

E_{Unctrld} = emissions if the source was uncontrolled = TEA usage rate = 35,000 lbs/yr

The capture efficiency, CapEff, is given as 90% or 0.90.

To determine the collection efficiency, CE_{TEA}, the inlet mass loading rate to the scrubber must be calculated given the assumed capture efficiency.

Mass TEA Inlet = TEA Usage Rate × CapEff = 17.6 [bls/hr] × 0.9 = 15.8 lbs/hr.

The control efficiency = 1 – Mass Out/Mass In = 1 – 0.03/15.8 = 0.998

E_{Total} = 35,000 [lbs/yr] × (1 – 0.9×0.998) = 3,560 lbs/yr or 1.78 tons/yr.

In this case, accounting for the capture efficiency of the TEA scrubber is critical for determining the true emissions from thus core-making unit.

The Ohio Cast Metal Association (OCMA) funded a study to assess the emission losses during mold and core-making, including the curing process, by measuring the mass reduction of chemically bonded molds over time (RMT, 1998). While this testing method, commonly referred to as the “OCMA method,” provides useful information for the specific binder formulation used by a facility, the data from these studies are often misapplied and the emission factors derived from this misapplication of the data understates the true emissions from the mold and core-making process. ***Example 4-2*** provides an example of developing site-specific emission factors for OCMA method mass-loss data. When properly applied, emission factors derived from site-specific OCMA method mass-loss data are considered Methodology Rank 2 for Mold and Core Making.

Example 4-2: Development of Site-Specific Emissions Factor from OCMA Test Data

A facility tested the mass loss from a phenolic urethane no-bake cores during the core-making and setting process using the OCMA method (RMT, 1998). The amount of binder used for each core was 180 grams. The mass loss from per core averaged 12 grams for the cores tested. The aggregate composition of the binder, considering the resin and the coreactant, is as follows:

Compound	Concentration (wt%)
Formaldehyde	0.3
Phenol	4.0
Xylene	0.2
Cumene	0.5
Naphthalene	1.0
1,2,4-Trimethylbenzene	1.0
Methylene phenylene isocyanate (MDI)	44.0
Biphenyl	0.1

The overall VOC emission factor is easily determined from the total mass-loss data from the OCMA test.

VOC emission factor = 12 [grams]/180 [grams] = 0.0667 grams VOC/gram binder

To determine the mass loss of specific compounds, it is critical to first account for the compounds that are not available for volatilization. Binders generally consist of reactive compounds and "solvent" compounds. The Form R reporting guidance (AFS and CISA, 2007) provides guidance regarding which compounds are reacted and therefore not available for volatile loss. For phenolic urethane no-bake, the reactive components are formaldehyde, phenol, and MDI (see Table 4-2). These compounds make up 48.3% of the aggregate binder. Since these compounds are assumed to react, only 51.7% of the mass of the binder added is projected to be available for volatile loss. The fraction of the "solvent" portion of the binder that is emitted is calculated as follows:

$$\text{Fraction “Solvent” Emitted} = \text{Mass Loss/”Solvent” Mass} = \frac{12\ [\text{grams}]}{180\ [\text{grams}] \times 0.517} = 0.129$$

This emission factor (12.9%) would be used along with the composition data provided above to determine the mass of each "solvent" compound (i.e., xylene, cumene, naphthalene, 1,2,4-trimethylbenzene, and biphenyl) that is emitted per mass of binder used. Taking naphthalene as an example, the site-specific naphthalene emission factor would be:

Naphthalene emission factor = 1 wt% ×0.129 = 0.00129 lb/lb binder.

While some compounds in the "solvent" fraction may be more volatile than others, there is generally no direct method to further differentiate the chemical-specific losses from OMCA test data. In any case, the key to consideration when applying OMCA test data to specific compounds in the binder system is to first determine the portion of the formulation that does not react and is, therefore, available to be emitted.

4.2 Methodology Rank 3 for Mold and Core Making

Except for mold and core making equipment whose emissions are collected and released through a well-defined stack, the EPA recommends that the emission estimation procedures described in this section be used to calculate air pollutant emissions from organic binders (or coating materials) used when making the molds and cores. The quantity of each chemical binder material/component used should be available from purchase records or direct material usage meters. Binder component composition should also be available from the chemical supplier via material safety data sheets (MSDS) or other information (see inset). Together, this information provides a direct means of determining constituent-specific usage rates (Methodology Rank 3A).

MSDS Data: Composition data are provided typically in either Section 2 or 3 of an MSDS, depending on the manufacturer. MSDS compositional data are commonly reported in the form of a concentration range, which may be fairly wide. Generally, the midpoint of the range is used for concentration estimate for each pollutant. Check to see if the midpoint concentrations add to 100 percent; and adjust the compounds with widest reported concentration ranges so the total concentrations sum to 100%. For example, if a product is made up of two compounds and the MSDS reports the concentration of Compound A as 60 – 100% and Compound B as 10–20% , use 15% for the concentration of Compound B and 85% (rather than 80%) for Compound A. Occasionally, Section 15 of the MSDS sheet contains more specific compositional data (direct values rather than ranges). ***The use of the direct composition data is preferable to estimating composition from ranges reported in MSDS sheets***.

The emission factors (reported as percent emitted) in **Table 4-2** can then be used to determine the annual emissions for each constituent from the mold and core making process using **Equation 4-1**:

$$E_i = \sum_{x=1}^{N}\left(Q_x \times \frac{C_{x,i}}{100\%} \times \frac{\%\text{emitted}_{x,i}}{100\%}\right)$$

Eqn. 4-1

where:

E_i = emissions for compound i, tons/yr
Q_x = quantity of binder material “x” used at the foundry, tons/yr
$C_{x,i}$ = concentration of compound “i” in binder material “x”, weight percent
$\%\text{emitted}_{x,i}$ = percent of compound “i” in binder material “x” emitted (see Table 4-2)

Table 4-2. HAP Emitted from Chemical Binder Systems Used for Sand Cores and Molds (AFS and CISA, 2007)

Binder system	HAP and component in which it is used	Percent reacted	Percent emitted during core and mold making [1]	Percent remaining in mold or core
Alkyd oil	Methylene phenylene isocyanate, coreactant	99.99	0.001[2]	0.009[2]
	Cobalt, resin	0	0	100
	Lead, resin[3]	0	0	100
Acrylic/Epoxy/SO_2	Cumene hydroperoxide	97	0.3[2]	2.7[2]
	Cumene	0	1.5	98.5
Furan hotbox	Formaldehyde, resin	95	5	0
Furan nobake	Phenol, resin	98	0.2[2]	1.8[2]
	Formaldehyde, resin	98	2	0
	Methanol, resin	0	50	50
	Methanol, catalyst	0	50	50
	Sulfuric acid, catalyst	100	0	0
Furan/SO_2	Formaldehyde, resin	98	2	0

Binder system	HAP and component in which it is used	Percent reacted	Percent emitted during core and mold making [1]	Percent remaining in mold or core
	Methanol, resin	0	50	50
	Dimethyl phthalate, oxidizer	0	50	50
	Methyl ethyl ketone, oxidizer	0	50	50
Furan warmbox	Formaldehyde, resin	95	5	0
	Methanol, catalyst	0	100	0
Phenolic baking	Phenol, Part I	95	0.5[2]	4.5[2]
	Formaldehyde, Part I	95	5	0
Phenolic ester nobake	Formaldehyde, resin	98	2	0
	Phenol, resin	98	0.2[2]	1.8[2]
Phenolic ester coldbox	Formaldehyde, resin	98	2	0
	Phenol, resin	98	0.2[2]	1.8[2]
	Glycol ethers, resin	0	50	50
	Methanol, co-reactant	0	50	50
Phenolic CO_2 cure	Diethylene glycol butyl ether (112-34-5), resin	0	0.5	99.5
	Ethylene glycol monophenyl ether (122-99-6), resin	0	0.5	99.5
Phenolic hotbox	Formaldehyde, resin	95	5	0
	Phenol, resin	95	0.5[2]	4.5[2]
Phenolic nobake (acid catalyzed)	Phenol, resin	98	0.2[2]	1.8[2]
	Formaldehyde, resin	98	2	0
	Methanol, resin	0	50	50
	Methanol, acid	0	50	50
	Sulfuric acid, acid	100	0	0
Phenolic Novolac flake (hot coating operations)	Phenol, resin	95	0.5[2]	4.5[2]
Phenolic Novolac liquid (warm-coating operations)	Phenol, Part I	0	20	80
	Formaldehyde, Part I	95	5	0
	Methanol, Part I	0	100	0
Phenolic Novolac flake (resin-coated sand)	Phenol, resin	99	0.1[2]	0.9[2]
	Ammonia, catalyst (Assume ammonia = 40% of hexamethylenetetramine)	50	50	0
Phenolic urethane nobake	Formaldehyde, Part I	98	2	0
	Phenol, Part I	98	0.2[2]	1.8[2]
	Xylene, Part I	0	16[4]	84[4]
	Cumene, Part I	0	16[4]	84[4]
	Naphthalene, Part I	0	16[4]	84[4]
	1,2,4-Trimethylbenzene, Part I	0	16[4]	84[4]
	Methylene phenylene isocyanate, Part II	99.99	0.001[2]	0.009[2]
	Xylene, Part II	0	16[4]	84[4]
	Cumene, Part II	0	16[4]	84[4]
	Naphthalene, Part II	0	16[4]	84[4]
	1,2,4-Trimethylbenzene, Part II	0	16[4]	84[4]
Phenolic urethane coldbox	Formaldehyde, Part I	98	2	0
	Phenol, Part I	98	0.2[2]	1.8[2]

Binder system	HAP and component in which it is used	Percent reacted	Percent emitted during core and mold making[1]	Percent remaining in mold or core
	Xylene, Part I	0	9[4]	91[4]
	Naphthalene , Part I	0	9[4]	91[4]
	Cumene, Part I	0	9[4]	91[4]
	1,2,4-Trimethylbenzene, Part I	0	9[4]	91[4]
	Methylene phenylene isocyanate, Part II	99.99	0.001[2]	0.009[2]
	Xylene, Part II	0	9[4]	91[4]
	Naphthalene, Part II	0	9[4]	91[4]
	Cumene, Part II	0	9[4]	91[4]
	Biphenyl, Part II	0	9[4]	91[4]
	Triethyl amine or diethyl amine, catalyst gas	0	100[5]	0
Urea formaldehyde	Formaldehyde, Part I	98	2	0

[1] Percent emitted up to the time that metal is poured.

[2] Revised from Form R Reporting Guidance provided by AFS and CISA (2007); assumes 10% of unreacted chemical is released during mold/core making and storage. Note that of the Phenolic Novolac liquid system, the Form R Reporting Guidance suggests 20% of the unreacted phenol is emitted.

[3] Compound not listed in 4th Edition (AFS and CISA, 2007) but listed in previous versions (AFS and CISA, 1998)

[4] Revised from Form R Reporting Guidance provided by AFS and CISA (2007); the emission factors in the Form R Reporting Guidance of 5.85% and 3.25% are based on weight loss measurements of the molds upon storage (RMT, 1998). However, considering the components reacted that were not available for emissions, 16% and 9% of the unreacted components for the nobake and coldbox systems, respectively, would have to be released to provide the 5.85% and 3.25% weight losses observed.

[5] Assumed 100% of catalyst used is emitted. If a sulfuric acid wet scrubber with pH less than 4 is used, a control efficiency of 99% can be assumed.

If direct chemical composition data are available for the specific binder formulation used, that information should be used in Equation 4-1 (Methodology Rank 3A). If specific chemical usage rates are available, but chemical-specific composition data are not available, the default composition data in **Table 4-3** can be used in Equation 4-1 to estimate the emissions from the system (Methodology Rank 3B). Tables 4-2 and 4-3 provide data for specific HAP, which will typically be only a small portion of the total VOC emitted. As illustrated in ***Example 4-2***, OMCA test data can be used to develop an overall VOC emission factor. If OMCA test data are not available, the "solvent" faction of the binder formulation (i.e., the portion of the binder not chemically reacted) can be determined and the HAP portion of the "solvent" fraction calculated. Using the data from ***Example 4-2***, the "solvent" fraction in this example was 51.7 wt% and the HAP content of the "solvent" fraction was 5.4 wt% (2.8%/0.517). In this example, the HAP emissions are expected to be 5.4% of the total VOC emissions. The VOC emissions can be projected from the HAP emissions by dividing the "solvent" fraction's cumulative HAP emissions associated by 0.054 (i.e, 5.4%).

Table 4-3. Default Content of Sand Binder System Components[1, 2]

Binder system	Component	HAP present	Amount of pollutant in component, percent	
			Range	Typical
Alkyd oil	coreactant	MDI	No data	80.[3]
Acrylic/epoxy/SO_2	Resin	Cumene	5. minimum[4]	5.

			Amount of pollutant in component, percent	
Binder system	**Component**	**HAP present**	**Range**	**Typical**
Furan hot box	Resin	Formaldehyde	2.–5.	3.
Furan nobake	Resin	Phenol	0.–4.	1.
		Formaldehyde	0.–1.	0.1
		Methanol	2.–4.	3.
	Catalyst	Methanol	20.–30.	27.
Furan/SO_2	Resin	Formaldehyde	1.–4.	2.
		Methanol	1.–3.	2.
	Oxidizer	Dimethyl phthalate	40.–50.	45.
		Methyl ethyl ketone	0.–2.	2.
Furan warm box	Resin	Formaldehyde	0.–1.	0.5
	Catalyst	Methanol	45.–55.	50.
Phenolic baking	Resin	Phenol	3.–14.	8.
		Formaldehyde	0.–2.	1.
Phenolic ester nobake	Resin	Phenol	2.–8.	4.
		Formaldehyde	0.–2.	0.5
Phenolic ester cold box	Resin	Phenol	2.–8.	4.
		Formaldehyde	0.–2.	0.5
		Glycol ethers	No data	0.1 [3]
	Co-reactant	Methanol	No data	27. [3]
Phenolic CO_2 cure	Resin	Diethylene glycol butyl ether	No data	1. [3]
		Ethylene glycol monophenyl ether	No data	1. [3]
Phenolic hot box	Resin	Phenol	2.–8.	5.
		Formaldehyde	1.–4.	2.
Phenolic nobake (acid catalyzed)	Resin	Phenol	8.–14.	12.
		Formaldehyde	0.–2.	0.5
		Methanol	2.–4.	3.
	Catalyst	Methanol	20.–30.	27.
Phenolic Novolac flake (hot coating operations)	Resin	Phenol	1.5–8.0 [4]	5.5 [5]
Phenolic Novolac liquid (warm-coating operations)	Resin	Phenol	1.–4.	2.
		Formaldehyde	0.–3.	0.5
		Methanol	0.–15.	5.
Phenolic Novolac flake (resin-coated sand)	Resin	Phenol	1.5–8.0 [4]	5.5 [5]
	Catalyst	Ammonia	No data	40. [6]

Binder system	Component	HAP present	Amount of pollutant in component, percent	
			Range	Typical
Phenolic urethane nobake and cold box	Resin	Phenol	3.–8.	6.
		Formaldehyde	0.–1.	0.1
		Naphthalene	0.–2.	1.
		Cumene	0.–2.	0.5
		Xylene	0.–1.	0.1
	Coreactant	Naphthalene	0.–3.	1.
		Cumene	0.–1.	0.1
		Xylene	0.–1.	0.1
		Biphenyl (only in cold box system)	0.–1.	0.1
		MDI	60.–95.	80.
Urea formaldehyde	Resin	Formaldehyde	1.–4.	1.

[1] Source: Stone, 1999, and Jonathan A. Stone, Delta Resins and Refractories, Delta-HA (private communication to J. H. Maysilles, U.S. EPA., November 15, 1999) except where noted.

[2] Only HAP that could be emitted because of incomplete reaction or nonreaction are listed.

[3] No data. Concentrations estimated based on other binder systems.

[4] Information supplied by Joe Fox, Ashland Chemical, Inc. Private communication to J. H. Maysilles, U.S. EPA, August 16, 2000.

[5] Information is based on Material Safety Data Sheets from foundries that use this system.

[6] Assume catalyst is 99+% of hexamethylenetetramine and 40% of hexamethylenetetramine converts to ammonia.

Example 4-3: Estimating Mold and Core Making Emissions using Methodology Rank 3

A facility uses a phenolic urethane cold box (PUCB) system. During 2011, the facility used 400,000 lbs of Part I and 340,000 lbs of Part II and 70,000 lbs of TEA gas (> 99.9% purity). Calculate the HAP emissions from the PUCB mold and core making system given that the composition of the Part 1 and Part II binder chemicals are as follows (based on MSDS sheets):

Compound	**Concentration (wt%)**	
	Part I	**Part II**
Formaldehyde	0.5	—
Phenol	6	—
Xylene	0.2	0.1
Cumene	0.5	—
Naphthalene	1.0	2.0
1,2,4-Trimethylbenzene	1.0	—
Methylene phenylene isocyanate (MDI)	—	80
Biphenyl	—	0.2

Apply Equation 4-1 for each binder component and compound of interest using the direct composition data (Methodology Rank 3A for Mold and Core Making). The calculation for naphthalene follows:

$$E_i = \left(400{,}000 \text{ lbs} \times \frac{1\%}{100\%} \times \frac{9\%}{100\%}\right) + \left(340{,}000 \text{ lbs} \times \frac{2\%}{100\%} \times \frac{9\%}{100\%}\right) = 972 \text{ lbs in 2011}$$

Converting to tons per year, $E_{naphthalene}$ = 972/2,000 = 0.486 tons/yr

Similar calculations are used for the other compounds to yield the following results:

$E_{formaldehyde}$ = 0.02 tons/yr

E_{phenol} = 0.024 tons/yr

E_{xylene} = 0.051 tons/yr

$E_{trimethylbenzene}$ = 0.18 tons/yr

E_{MDI} = 0.00136 tons/yr

$E_{biphenyl}$ = 0.0306 tons/yr

TEA gas catalyst emissions from a cold box system should also be calculated. If the emissions from the catalyst gas are not controlled, then the emissions from the PUCB mold and core making system is:

E_{TEA} = 70,000 lbs/(2,000 lbs/ton) = 35 tons/yr

If the TEA emissions are controlled with an sulfuric acid wet scrubber (pH<4), a control efficiency of 99% can be assumed, so the TEA emissions would be 1% of the uncontrolled case, or 0.35 tons/yr.

4.3 Methodology Rank 4 for Mold and Core Making

4.3.1 Pollutant Emissions from Chemical Binder Systems

It is anticipated that most facilities will not have direct routine measurement data or site-specific source test data for their mold and core making operations and will have to use Methodology Rank 4. If specific binder chemical usage rates are not known, but the sand usage rates are known for each type of chemically bonded mold and core making process, then the factors in **Table 4-4** can be used to estimate emissions (Methodology Rank 4). The chemical content provided in Table 4-4 considers the average composition of the compound in the combined binder system when multiple components are used. **Equation 4-2** is used to estimate emissions based on the information in Table 4-4.

$$E_i = \sum_{x=1}^{N} \left(\frac{S_x \times EmF_{x,i}}{2{,}000} \right)$$

Eqn. 4-2

where:

E_i = emissions for compound i, tons/yr)
S_x = quantity of sand used with binder system “x”, tons/yr
$EmF_{x,I}$ = emission factor for compound “i” for binder system “x”, from **Table 4-4**, lbs/ton
2,000 = Conversion factor, lbs/ton.

The emission factors in Table 4-4 were derived from typical binder usage rates by binder component (from U.S. EPA, 1998), the default composition data in Table 4-3, and the percent emitted values in Table 4-2. For more information about how the factors were developed, see **Appendix C**.

Table 4-4. Default Pollutant Emission Factors for Sand Binders

Binder system	Binder-to-Sand Concentration (lbs/ton sand)	Pollutant	Emission Factor (lb/ton sand)
Alkyd oil	30	MDI	1.1×10^{-4}
Acrylic/epoxy/SO_2	34	Cumene	2.6×10^{-2}
Furan hot box	40	Formaldehyde	6.0×10^{-2}
Furan nobake	24	Phenol Formaldehyde Methanol	3.4×10^{-4} 3.4×10^{-4} 1.22
Furan/SO_2	30	Formaldehyde Methanol Dimethyl phthalate Methyl ethyl ketone	6.6×10^{-3} 0.165 3.04 0.135
Furan warm box	32	Formaldehyde Methanol	6.4×10^{-3} 3.2
Phenolic baking	30	Phenol Formaldehyde	1.2×10^{-2} 1.5×10^{-2}
Phenolic ester nobake	33	Phenol Formaldehyde	2.6×10^{-3} 3.3×10^{-3}

Binder system	Binder-to-Sand Concentration (lbs/ton sand)	Pollutant	Emission Factor (lb/ton sand)
Phenolic ester cold box	33	Phenol Formaldehyde Glycol ethers Methanol	2.6×10^{-3} 3.2×10^{-3} 1.6×10^{-2} 0.405
Phenolic CO_2 cure	30	Diethylene glycol butyl ether Ethylene glycol monophenyl ether	1.5×10^{-3} 1.5×10^{-3}
Phenolic hot box	30	Phenol Formaldehyde	7.5×10^{-3} 3.0×10^{-2}
Phenolic nobake (acid catalyzed)	27	Phenol Formaldehyde Methanol	4.4×10^{-3} 1.8×10^{-3} 1.44
Phenolic Novolac flake (hot coating operations)	50	Phenol	1.4×10^{-2}
Phenolic Novolac liquid (warm-coating operations)	50	Phenol Formaldehyde Methanol	0.20 1.3×10^{-2} 2.5
Phenolic Novolac flake (resin-coated sand)	50	Phenol Ammonia	2.8×10^{-3} 2.0
Phenolic urethane nobake	25	Phenol Formaldehyde Naphthalene Cumene Xylene MDI	1.7×10^{-3} 2.8×10^{-4} 4.0×10^{-2} 1.3×10^{-2} 4.0×10^{-3} 9.0×10^{-5}
Phenolic urethane cold box	30	Phenol Formaldehyde Naphthalene Cumene Xylene Biphenyl MDI	2.0×10^{-3} 3.3×10^{-4} 2.7×10^{-2} 8.6×10^{-3} 2.7×10^{-3} 1.2×10^{-3} 1.1×10^{-4}
Urea formaldehyde	30	Formaldehyde	6.0×10^{-3}

Example 4-4: Estimating Binder System Emissions using Methodology Rank 4

A facility uses furan nobake system to make cores for its castings. The facility used 200,000 tons of sand in its core process in 2011. Calculate the 2011 annual HAP emissions from the core making system.

Without specific chemical usage rates, the default emission factors in Table 4-4 would be used (Methodology Rank 4). The relevant factors from Table 4-4 are as follows:

Binder system	Pollutant	Emission Factor (lb/ton sand)
Furan nobake	Phenol Formaldehyde Methanol	3.4×10-4 3.4×10-4 1.22

Apply Equation 4-2 for the single binder system used at the facility. The calculation for phenol follows:

$$E_{phenol} = \left(200{,}000 \text{ tons} \times \frac{3.4\times10^{-4}}{2{,}000}\right) = 0.034 \text{ tons/yr}$$

Similar calculations are used for the other compounds to yield the following results:

$E_{formaldehyde} = 0.034$ tons/yr

$E_{methanol} = 122$ tons/yr.

4.3.2 PM Emissions from Sand Handling Operations Associated with Mold and Core Making

Table 12.3-1 of Section 12.13 of AP-42 (U.S. EPA, 1995) reports an emission factor for sand grinding/handling in mold and core making at steel foundries of 0.54 lb PM_{10}-FIL/ton of sand processed. Table 12.10-7 of Section 12.10 of AP-42 (U.S. EPA, 2003) contains an emission factor of 3.6 lbs PM (TSP)/ton of sand for uncontrolled sand handling systems and provides factors of 0.046 and 0.20 lb/ton of sand for sand handling systems controlled by a wet scrubber and baghouse, respectively. It is unusual that a baghouse would be less efficient than a wet scrubber, so these differences may be in PM loading rates to the control devices. As the PM emissions from sand handling systems are expected to be similar between iron and steel foundries, the differences in these factors were initially considered to be due to the fact that the steel foundry emission factor was specific to mold and core-making operations and the iron foundry emission factor considered both sand reclamation and mold and core-making operations. Baghouse catch data from mold sand mullers and automated (Disamatic) molding lines suggested that the iron foundry emission factor was more appropriate than the steel foundry factor when considering only mold sand operations. Baghouse catch data for core sand mullers suggested even higher emission factors may be appropriate for core sand handling. Nonetheless, a single set of emission factors is presented in **Table 4-5** for use for sand handling operations associated with mold and core making for both iron and steel foundries. The default captured but uncontrolled PM emission factor for mold and core making is based on the default factor reported for iron foundries. Use of site-specific baghouse catch data to determine the captured but uncontrolled PM emission factor for the specific mold and core making operations would be the preferred to use of the Table 4-5 defaults. The default emission factors can be used in Equation 4-2 to determine the PM mass emissions. For controlled sand handling operations, it is recommended that sources use the ducted uncontrolled emission factors and adjust the emissions based on the expected control efficiencies of the control device as provided in Table 3-4 of **Section 3.1**, *Melting Furnaces*, of this Protocol document.

As with the PM emission factor for melting furnaces in Table 3-3, the PM emission factors in Table 4-5 for PM_{10}-FIL include emissions of $PM_{2.5}$-FIL. As well, the $PM_{\text{"coarse"}}$-FIL emissions factor is the emissions factor for PM_{10}-FIL minus the emissions factor for $PM_{2.5}$-FIL. Therefore, to calculate PM_{10}-FIL emissions, the emissions for $PM_{\text{"coarse"}}$-FIL is added to the emissions for $PM_{2.5}$-FIL.

Table 4-5. Default PM Emission Factors for Sand Handling Operations Associated with Mold and Core Making

Suggested SCC for Iron Foundries	Suggested SCC for Steel Foundries	Emission Source	Pollutant	Emission Factor (lb/ton sand)
30400350	30400716	Sand grinding/handling, captured and ducted uncontrolled to atmosphere	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	3.6 [1] 3.0 [1] 2.6 [1]
30400350	30400716	Sand grinding/handling, uncaptured fugitive dust to atmosphere	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	1.8 [2] 1.5 [2] 1.3 [2]

[1] Used the default factor for iron foundries, which was mid-range of the factors reported for steel foundries, for PM-FIL. Used the size distribution ratios for steel foundries casting shakeout exhausted, prior to controls, to determine PM_{10}-FIL and $PM_{2.5}$-FIL values.

[2] Assumes 50% of ducted emissions would be released as fugitive emissions that escape to the atmosphere for uncaptured units.

Example 4-5: Estimating PM Emissions from Green Sand Mold Making

A facility processes 500,000 tons of sand per year for their green sand molds. Calculate the PM emissions for the green sand molding operations if the system is uncaptured/uncontrolled. What are the emissions if the facility controls these emissions using a fabric filter?

For the existing uncaptured/uncontrolled system, the default emission factors for uncaptured fugitive emissions from Table 4-5 would be used (Methodology Rank 4). The relevant factors from Table 4-5 are as follows:

Emission Source	Pollutant	Emission Factor (lb/ton sand)
Sand grinding/handling, uncaptured fugitive dust to atmosphere	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	1.8 1.5 1.3

Note that PM-CON for sand handling systems is 0, so PM-PRI = PM-FIL.

Apply Equation 4-2 for the green sand system used at the facility. The calculation for PM-FIL follows:

$$E_{PM-FIL} = E_{PM-PRI} = \left(500{,}000 \text{ tons} \times \frac{1.8}{2{,}000}\right) = 450 \text{ tons/yr}$$

Similar calculations are used for PM_{10}-FIL and $PM_{2.5}$-FIL to yield:

$$E_{PM10\text{-}FIL} = 375 \text{ tons/yr}$$

$$E_{PM2.5\text{-}FIL} = 325 \text{ tons/yr.}$$

If the facility installs a capture system and fabric filter control system, the PM at the inlet to the control device will be twice the uncaptured emissions (based on the emission factors in Table 4-5). Thus, the inlet PM rates are 650 tons/yr and 750 tons/yr for $PM_{2.5}$-FIL and PM_{10}-FIL, respectively. Consequently, there are 100 tons/yr of PM between 2.5 and 10 µm.

The default control efficiency for a fabric filter control device is 99% for PM < 2.5 µm and 99.5% for PM between 2.5 and 10 µm. It is generally assumed that the control efficiencies for particles greater than 10 µm in diameter is 100%, so that PM-PRI = PM-FIL = PM_{10}-FIL.

First, calculate the $PM_{2.5}$-FIL emissions as follows:

$$E_{PM2.5\text{-}FIL} = 650 \times (1-0.99) = 6.5 \text{ tons/yr}$$

Next, calculate the PM emissions between 2.5 and 10 µm ("coarse" PM) as follows:

$$E_{PM\_\text{"coarse"}} = 100 \times (1-0.995) = 0.5 \text{ tons/yr}$$

The PM_{10}-FIL emissions equal the sum of these emissions, i.e., 7.0 tons/yr.

5. Pouring, Cooling, and Shakeout

The processes discussed in this section include pouring of molten metal into molds, cooling of the casts in the molds, and shakeout of the casts from the molds. Emissions from these processes are commonly considered together, and the collective process is referred to as pouring, cooling, and shakeout (PCS).

Emissions from pouring are primarily PM and metal fumes released as the molten metal is poured into the molds. In sand casting operations, organic emissions are typically released as the molten metal contacts organics or coke used in sand mold and cores. Even in green sand systems, coke is commonly added to ensure a reducing atmosphere and prevent oxidation of the metal as it cools. As the mold cools, pyrolysis products continue to be generated and released as the heat from the metal penetrates further into the sand mold. As it is difficult to distinguish organics generated from pouring from those generated during cooling, organic emissions are commonly estimated for the combined pouring/cooling process. The emission factors presented in this section were generally developed for automated pouring, cooling lines where the molds are expected to light off automatically or manually.

When the castings are sufficiently cooled (solidified), they are removed from the molds using mechanical tools or vibrating grids or conveyors to knock off or shake loose the sand from the casting. As such, this process is commonly referred to as “knock-out” or “shakeout.” This process will be referred to simply as shakeout in the Protocol document regardless of the means used to remove/loosen the sand. Emissions from shakeout are PM associated with the loosened sand and additional organic vapor emissions. The organic vapors include pyrolysis vapors generated during pouring/cooling that did not diffuse out of the mold during pouring/cooling, but are released as the mold is broken apart. Organic vapors may also be generated as organics (or coke) contained in the outer portions of the mold come in contact with the hot casting and pyrolyze during the shakeout process.

There are five typical casting types for iron and steel foundries: sand (includes green sand molds and chemically bonded sand molds), centrifugal, permanent, investment, and expendable pattern casting. The primary difference in the emissions from the different casting systems is the amount of sand used in the casting process. Centrifugal, permanent, and investment casting operations use little to no sand (depending on whether cores are needed), so these systems do not have large PM emissions associated with sand system shakeout, nor do they have significant organic emissions from the pyrolysis of binders and additives commonly used in sand systems.

Expendable pattern castings use sand molds compressed about a polystyrene pattern. When molten metal is poured into the mold, the molten metal volatilizes the polystyrene pattern and replaces it, forming a casting of the same shape as the pattern. Vapors generated in the process escape through the sand that surrounds first the pattern and then the casting. Castings are removed from the loose sand and then finished in much the same manner as those made by sand casting. Emissions from expendable pattern castings are similar to green sand systems, but have specific organic emissions generated from the pyrolysis of the polystyrene patterns.

The emission estimation methods for PCS operations are presented in **Table 5-1**. Emissions from some PCS operations may be captured and vented through well-defined stacks, especially for shakeout. For emissions that are captured and emitted through well-defined stacks, direct measurement methods may be used. Direct measurements may be continuous or routinely frequent (daily or weekly) in nature so that the measurement data can be used directly to determine emissions (Methodology Rank 1 or 2). For many pollutants, a one-time or annual source test may be performed, but the emissions are not routinely measured. For these pollutants, the measured data can be used to determine an emission factor based on process throughput (quantity of metal poured or sand used), and the annual emissions can be determined using the annual material usage multiplied by the site-specific emission factor (Methodology Rank 3).

For some PCS operations, no direct measurement data will be available. In such cases, emissions are estimated based on the type of casting system employed, the molten metal throughput, and default emission factors provided in this section (Methodology Rank 4).

Table 5-1. Summary of Typical Hierarchy of Pouring, Cooling, and Shakeout Emission Estimates

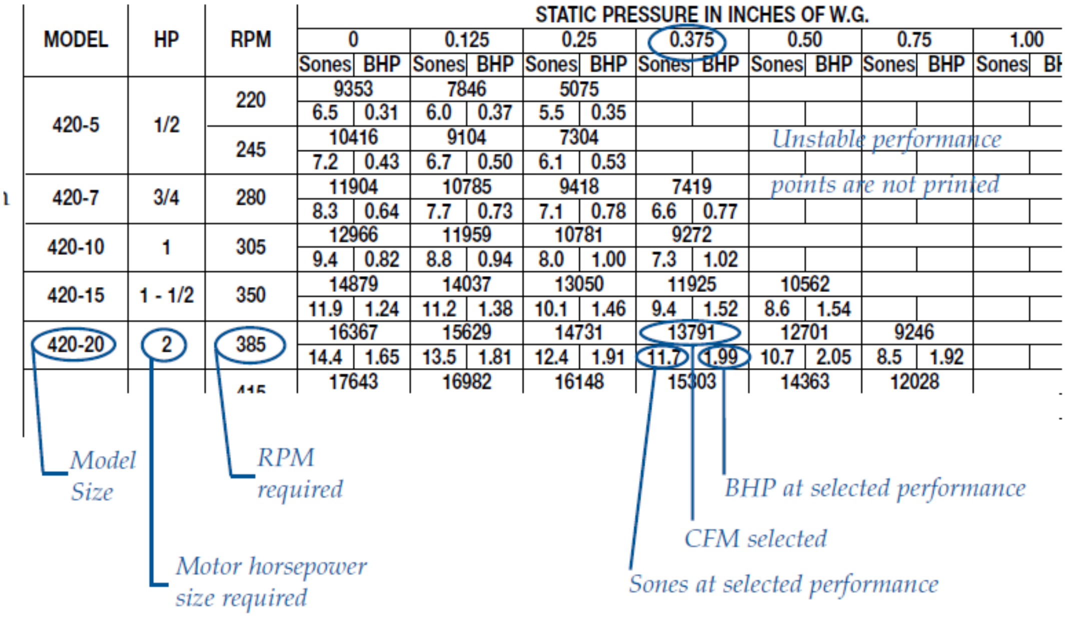
Rank	Methodology Description	Application	Data Requirements
1	Direct routine concentration and flow measurement	Pouring, cooling, and shakeout that are well-captured and have well-defined stack emissions	Constituent concentration and exhaust flow rate
2	Direct routine concentration measurement with engineering flow estimates	Pouring, cooling, and shakeout that are well-captured and have well-defined stack emissions	Constituent concentration and operating parameters needed for estimating flow rate (e.g., fan curve and amp usage)
3	Site-specific emission factor from one-time or periodic emissions source test data	Pouring, cooling, and shakeout that are well-captured and have well-defined stack emissions	Constituent concentration and exhaust flow rate and molten metal throughput during source test; annual molten metal throughput
4	Default emission factors	All sources	Material usage rates

5.1 Methodology Ranks 1 and 2 for PCS Operations

Emissions from vented PCS operations can be directly measured at the stack or outlet of the control device using the direct measurement methods as described in **Section 3**, *Melting Operations*, of this Foundries Emissions Protocol document. If CEMS are available for both a pollutant concentration and exhaust gas flow rate, the CEMS data should be used to determine the pollutant emissions as Methodology Rank 1 for PCS (using Equation 3-1 from **Section 3.1,** *Melting Furnaces*). If a CEMS is used to determine a pollutant's concentration, but direct-flow measurement is not available, flow rates can often be determined using engineering estimates, such as fan amperage-to-flow correlations, to determine the pollutant emissions as Methodology Rank 2 for PCS. ***Example 5-1*** demonstrates how to estimate the flow measurement using fan curves.

Example 5-1: Estimation of Flow Measurement Using Fan Curves

A pouring/cooling ventilation line is equipped with a VOC CEMS with a concentration output in ppmv as methane as sampled (i.e., wet basis). The ventilation line does not have a flow monitor, but the ventilation rate is driven by a single speed Model 420-20 fan. The fan manufacturer's fan chart is provided below. If the VOC monitor measures 70 ppmv and the ventilation system pressure drop averages 0.375 inch of water gauge, what is hourly emission rate for the system?



MODEL	HP	RPM	STATIC PRESSURE IN INCHES OF W.G.													
			0		0.125		0.25		0.375		0.50		0.75		1.00	
			Sones	BHP	Sones	BHP	Sones	BHP	Sones	BHP	Sones	BHP	Sones	BHP	Sones	BH
420-5	1/2	220	9353		7846		5075									
			6.5	0.31	6.0	0.37	5.5	0.35								
		245	10416		9104		7304									
			7.2	0.43	6.7	0.50	6.1	0.53								
420-7	3/4	280	11904		10785		9418		7419							
			8.3	0.64	7.7	0.73	7.1	0.78	6.6	0.77						
420-10	1	305	12966		11959		10781		9272							
			9.4	0.82	8.8	0.94	8.0	1.00	7.3	1.02						
420-15	1 - 1/2	350	14879		14037		13050		11925		10562					
			11.9	1.24	11.2	1.38	10.1	1.46	9.4	1.52	8.6	1.54				
420-20	2	385	16367		15629		14731		13791		12701		9246			
			14.4	1.65	13.5	1.81	12.4	1.91	11.7	1.99	10.7	2.05	8.5	1.92		
		415	17643		16982		16148		15303		14363		12028			

Use Equation 3-1 to determine the emission rate.

$$E_i = \sum_{n=1}^{N} \left((V)_n \times [1 - (f_{H2O})_n] \times \frac{(C_i)_n}{100\%} \times \frac{MW_i}{MVC} \times \left(\frac{T_o}{T_n}\right) \times \left(\frac{P_n}{P_o}\right) \times K \right)$$

Given the fan model size and system pressure, the flow rate for the ventilation system is 13,791 acfm (see above). The cumulative volume for the 1 hour time period (60 minutes) is:

$$(V)_n = 13{,}791 \text{ acfm } \times 60 \text{ min} = 827{,}460 \text{ acf}$$

As the concentration is measured on the same basis as the flow rate, the moisture correction factor is not needed: $[1 - (f_{H2O})_n] = 1$. The system operates essentially at atmospheric conditions (note: 1 inch water gauge = 0.0025 atm). Although not specified, the temperature is likely to be near room temperature. As such, the pressure $\left(\frac{P_n}{P_o}\right)$ and temperature $\left(\frac{T_n}{T_o}\right)$ corrections can be assumed to be 1 without introducing significant error.

$$(C_i)_n = \frac{70}{1{,}000{,}000} \times 100\% = 0.007\%$$

Use the molecular weight of methane (16 kg/kg-mol), since the concentration is measured as methane.

$$K\left[\frac{\text{lb}}{\text{kg}}\right] = 2.2046 \text{ (to output the mass in lbs rather than tons)}$$

$$E_{VOC} = 827{,}460 \times 1 \times \frac{0.007\%}{100\%} \times \frac{16}{849.5} \times 1 \times 1 \times 2.2046$$

$$E_{VOC} = 2.40 \text{ pounds per hour (lb/hr).}$$

5.2 Methodology Rank 3 for PCS Operations

When CEMS data are not available, but data from a single source test or a limited number of source tests are available, a site-specific emission factor can be developed and used to assess the emissions from PCS operations for the pollutants tested, similar to the methods described in **Section 3**, *Melting Operations* (using Equation 3-4*)*. Emission of metal HAP and PM from pouring and cooling operations are generally correlated with quantity of metal poured. Similarly, metal HAP emissions from shakeout are expected to be correlated with quantity of metal poured. PM emissions from shakeout may be correlated with the quantity of metal poured or the quantity of sand used. ***Example 5-2*** demonstrates how to calculate emission factors for PM emissions from shakeout using the different activity data.

For PCS operations that are controlled with a baghouse, site-specific emission factors can be developed based on the baghouse catch data (the measurement of the mass of PM collected over a period of time). To determine the captured, uncontrolled PM emissions from baghouse catch data, see ***Example 3-4***, above. Many PCS operations may have canopy hoods or similar capture systems, so the captured, uncontrolled emissions estimated from baghouse catch data should be corrected for the capture efficiency of the ventilation system to account for uncaptured PM emissions.

Baghouse dust analyses can also be used to determine the metal HAP concentration of the emitted PM, particularly for shakeout. Baghouse dust analysis is expected to be less accurate for determining metal HAP content associated with pouring emissions as the metal fumes emitted from the baghouse may have a different composition than the metal particles collected in the baghouse. However, the baghouse dust composition data is preferred to the default metal HAP compositions provided in Methodology Rank 4 for PCS Operations.

Example 5-2: Development of Site-Specific Emissions Factor for PM Emissions from Shakeout

During its most recent source test, three test runs were conducted using Method 5 to determine the PM emission rate from shakeout operations. The PM emissions rate measured during the source tests were 20.2, 25.1, and 17.6 lbs/hr for tests 1, 2, and 3, respectively. The processing rates during the three runs were measured for metal poured/hour and sand used/hr: 16, 17, and 15 tons of metal poured/hr; 64, 74, and 59 tons of sand used/hr, respectively.

Calculate the appropriate emission factor for each individual run for metal poured/hour and sand used/hr, and then average the emission factors for each processing rate as follows:

For processing rate of metal poured/hr

Run 1: Emissions/metal throughput = 20.2 [lbs/hr] ÷ 16 [tons/hr] = 1.26 lbs/ton metal

Run 2: Emissions/metal throughput = 25.1 [lbs/hr] ÷ 17 [tons/hr] = 1.48 lbs/ton metal

Run 3: Emissions/metal throughput = 17.6 [lbs/hr] ÷ 15 [tons/hr] = 1.17 lbs/ton metal

Average: Emissions/metal throughput = (1.26 + 1.48 + 1.17)/3 = 1.30 lbs/ton metal

For processing rate of sand used/hr

Run 1: Emissions/sand use = 20.2 [lbs/hr] ÷ 64 [tons/hr] = 0.316 lbs/ton sand

Run 2: Emissions/sand use = 25.1 [lbs/hr] ÷ 74 [tons/hr] = 0.339 lbs/ton sand

Run 3: Emissions/sand use = 17.6 [lbs/hr] ÷ 59 [tons/hr] = 0.298 lbs/ton sand

Average: Emissions/sand use = (0.316 + 0.339 + 0.298)/3 = 0.318 lbs/ton sand

There are a variety of ways to determine which emission factor is most appropriate. One method is to compare the range of the test runs compared to the three-run average. For the metal throughput–based emissions factors, the highest single run emission factor is 14% [100%×(1.48-1.30)/1.30] higher than the average and the lowest single run emission factor is 10% lower than the average. For the sand use–based emissions factors, the highest single run emission factor is 6.6% [100%×(0.339-0.318)/0.318] higher than the average, and the lowest single run emission factor is 6.3% lower than the average. The smaller range for the sand use emission factors (as a percentage of the average) suggests that normalizing the emissions by sand use accounts for more of the differences in the observed emissions than does throughput. Consequently, the sand use emission factor would be preferred to the metal throughput based emission factor in this example.

For organic emissions, the “activity” data may be the quantity of metal poured per type of mold system used. The annual emissions can be estimated using similar methods, as described in **Section 3**, *Melting Operations* (using Equation 3-5). ***Example 5-3*** provides an example of developing a site-specific emission factor for organic emissions from PCS operations and annual emissions of organics from PCS operations.

Example 5-3: Development of Site-Specific Emissions Factor

A series of source tests were performed to determine the non-methane, non-ethane organic carbon (NMNEOC) emissions from PCS operations while producing two castings using: green sand molds with no cores and green sand molds with phenolic urethane cold box cores. The average NMNEOC emissions rate for the test runs performed with the green sand only system was 12 lbs/hr, and the average NMNEOC emissions rate for the test runs performed with the green sand and chemically bonded cores was 35 lbs/hr. The average metal pouring rates for both tests were 15 tons/hr. The facility pours 30,000 tons of gray iron per year, and 30 percent of their castings (by weight) do not require cores. Using the site-specific data, what are the VOC emissions from the PCS operations at this facility?

First, NMNEOC measurements are an excellent proxy for total VOC. As such, the NMNEOC measurements can be used directly to determine the site-specific VOC emission factors for green sand–only castings and for cored castings. The site-specific emission factor is determined using Equation 3-4

$$EmF = \text{emissions rate} / \text{activity rate}$$

For the green sand only system:

$$EmF_{VOC,GS} = 12 \text{ lbs/hr} / 15 \text{ tons/hr} = 0.8 \text{ lbs/ton}$$

For the green sand system with cores:

$$EmF_{VOC,GS\&Cores} = 35 \text{ lbs/hr} / 15 \text{ tons/hr} = 2.33 \text{ lbs/ton}$$

To calculate the annual emissions, first determine the total quantity of metal poured for each type of mold system. Based on the information provided, 30% of 30,000 tons/yr or 9,000 tons/yr of castings are produced using the green sand only molds. Therefore, 21,000 (30,000 – 9,000) tons/yr of castings are poured using the green sand molds with chemically bonded cores. The total VOC emission from the PCS operations are then determined using Equation 3-5 as follows:

$$E_{VOC,PCS} = EmF_{VOC,GS} \times Q_{GS} + EmF_{VOC,GS\&Cores} \times Q_{GS\&Cores}$$

$$E_{VOC,PCS} = 0.8 \times 9{,}000 + 2.33 \times 21{,}000 = 56{,}130 \text{ lbs/yr}$$

$$E_{VOC,PCS} = 56{,}130/2000 = 28.1 \text{ tons/yr}$$

5.3 Methodology Rank 4 for PCS Operations

5.3.1 Organic Pollutant Emission from PCS Operations

Different foundries can have significantly different emissions from PCS depending on the type of casting system employed. Even within sand casters, emissions are dependent on whether the molds are made from green sand or chemically bonded mold sand and on the relative amount of cores needed for the specific castings. The Casting Emission Reduction Program (CERP) has also demonstrated that emissions of benzene (typically the most prevalent HAP emitted from PCS operations) from green sand molds are strongly correlated with percent loss on ignition (percent LOI), which relates to the concentration of seacoal in the mold sand, the mass of metal cast (at constant mass to surface area ratio), and to the surface area of the casting (at constant cast weight) (Technikon, 2006). As PCS emissions are primarily caused by the pyrolysis of organics contained within the mold and/or cores, the larger the contact area and the more organics in the sand, the greater the emissions.

Technikon (2006) provides a series of total HAP emission factors for various types of molds and binder systems. These factors, while helpful, do not provide speciation needed for a proper HAP emission inventory. For the most part, the emissions from green sand systems with cores were essentially equivalent to the emission of green sand systems alone plus emissions from cored systems with no seacoal in the mold sand. Based on the data from the various CERP studies, the emission factors and concentration profiles provided in **Tables 5-2 and 5-3**, respectively, were developed. See Appendix D for more information about the development of the factors. Using these factors, **Equation 5-1** is recommended for estimating organic emissions from PCS operations.

$$E_i = Q_{MS}\left[\left(MS_{VOC} \times C_{i,MS}\right) \times GSCF + \left(CS_{VOC} \times C_{i,CS}\right)\right]/2{,}000$$

Eqn. 5-1

where:

E_i = Emission of pollutant "i" (tons/yr).
Q_{MS} = Quantity of metal poured into a given type of mold system, tons/yr.
MS_{VOC} = VOC emission factor for the mold system used, lb VOC/ton metal poured (from Table 5-2).
CS_{VOC} = VOC emission factor for the cores used, lb VOC/ton metal poured (from Table 5-2).
$C_{i,MS}$ = Concentration profile of pollutant "i" in emissions from mold system used, lb pollutant/lb VOC (from Table 5-3).
$C_{i,CS}$ = Concentration profile of pollutant "i" in emissions for core system used, lb pollutant/lb VOC (from Table 5-3).
GSCF = Green sand correction factor, unitless; for green sand systems, GSCF = percent LOI/5.1 percent; for all other types of mold systems, GSCF = 1.
%LOI = Percent of green sand lost on ignition, weight percent using ASTM D7348 or similar methods .
2,000 = Conversion factor, lbs/ton.

For foundries that operate several different types of mold systems, Equation 5-1 should be applied separately for each type of mold system. The total PCS emissions for the facility would then be the sum of the emissions for each type of mold system. The application of Equation 5-1 is illustrated in ***Example 5-4***.

Table 5-2. VOC Emission Factors by Casting Type for PCS Operations[a,b]

Type of Mold/Core System	Factor Designation	VOC Emission Factor, (lb/ton metal poured)
Green Sand	MS_{VOC}	1.9[a]
Phenolic Urethane Bonded Mold Sand	MS_{VOC}	7.4[b]
Other Chemically Bonded Mold Sand	MS_{VOC}	4.0[b]
Chemically Bonded Cores (all)	CS_{VOC}	1.6[a]
Mold systems without cores	CS_{VOC}	0
Expendable Pattern Casting (Lost Foam)	MS_{VOC}	4.8[c]
Permanent, Centrifugal, or Investment Casting	MS_{VOC}	0.12[d]

[a] Developed from Casting Emission Reduction Program (CERP) baseline testing (CERP 1999b, 2000; Technikon 2000, 2001a, 2003).

[b] Developed from CERP testing of chemically bonded mold systems (Technikon, 2001b; 2001d; 2001f; 2001g; 2004).

[c] Based on data reported by Twarog (1991).

[d] Developed from CERP "background baseline" (CERP, 1999b).

Table 5-3. Default HAP Composition Profiles for PCS Operations

HAP Compound	Concentration Ratio, lb HAP per lb VOC					
	Green Sand Molds[a]	Phenolic Urethane Bonded Molds[b]	Other Chemically Bonded Molds[b]	Cores[a]	Expendable Pattern Casting[c]	Permanent, Centrifugal, or Investment[d]
Acetaldehyde	0.005	0.00075	0.018	0.0025	0	0.07
Aniline	0.0075	0.0013	0	0.035	0	0
Benzene	0.065	0.028	0.14	0.073	0.07	0.05
Cresols (total)	0.0015	0.04	0.013	0.01	0	0
N,N-Dimethylaniline	0.0025	0	0	0.0075	0	0
Ethylbenzene	0.005	0.0005	0.0005	0.001	0	0.005
Formaldehyde	0.00075	0.0025	0.015	0.0005	0	0.013
n-Hexane	0.01	0	0	0.002	0	0
Naphthalene	0.0075	0.0018	0.0025	0.0075	0.0025	0.01
Non-Naphthalene Other POM[e]	0.01	0.0025	0.013	0.015	0.0025	0.005
Phenol	0.0075	0.078	0.023	0.025	0	0.0025
Propianaldehyde	0	0.00025	0.0025	0	0	0
Styrene	0.0013	0.0013	0.00025	0.0013	0.12	0
Toluene	0.045	0.005	0.02	0.018	0.023	0.025
Xylenes (total)	0.033	0.0025	0.005	0.0075	0	0.02

[a] Developed from CERP baseline testing (CERP, 1999b, 2000; Technikon, 2000, 2001a, 2003).

[b] Developed from CERP testing of chemically bonded mold systems (Technikon, 2001b, 2001d, 2001f, 2001g, 2004).

[c] Based on data reported by Twarog (1991).

[d] Developed from CERP “background baseline” (CERP, 1999b).

[e] POM other than naphthalene, predominately methylnaphthalenes and dimethylnaphthalenes.

Example 5-4: Organic Emissions from PCS Operations

A foundry melts 54,000 tons of gray iron per year. They pour 30,000 tons/yr of metal into green sand molds that do not have cores, 12,000 tons/yr of metal into phenolic urethane nobake molds, and 12,000 tons/yr of metal into green sand molds that have chemically bonded cores. The facility’s green sand has an average loss on ignition of 4.5% for all green sand applications. What are the VOC emissions and HAP emissions from the PCS operations at this facility?

The emission for each mold system is calculated using Equation 5-1:

$$E_i = Q_{MS}\left[\left(MS_{VOC} \times C_{i,MS}\right) \times GSCF + \left(CS_{VOC} \times C_{i,CS}\right)\right]/2{,}000$$

For the green sand-only castings, Q_{MS} = 30,000; MS_{VOC} = 1.9 (from Table 5-2); and GSCF = 4.5%/5.1% = 0.88. When calculating VOC emissions, $C_{i,MS} = 1$. Since no cores are used, CS_{VOC} = 0 (from Table 5-2), the second term in the equation will be zero.

$$E_{VOC,GSonly} = 30{,}000[(1.9 \times 1) \times 0.88 + (0)]/2{,}000 = 25.1 \text{ tons/yr}$$

Example 5-4: Organic Emissions from PCS Operations (continued)

For the green sand molds with cores, Q_{MS} = 12,000; MS_{VOC} = 1.9 (from Table 5-2); GSCF = 4.5%/5.1% = 0.88, $C_{i,MS}$ = $C_{i,CS}$ =1 (for VOC); and CS_{VOC} = 1.6 (from Table 5-2).

$$E_{VOC,GS+cores} = 12{,}000[(1.9 \times 1) \times 0.88 + (1.6 \times 1)]/2{,}000 = 19.6 \text{ tons/yr}$$

For the chemically bonded molds, Q_{MS} = 12,000; MS_{VOC} = 7.4 (from Table 5-2); GSCF=1; $C_{i,MS}$ =1 (for VOC); and CS_{VOC} = 0 (from Table 5-2).

$$E_{VOC,ChemMold} = 12{,}000[(7.4 \times 1) \times 1 + (0)]/2{,}000 = 44.4 \text{ tons/yr}$$

So the total VOC emissions are the sum of the VOC emissions determined from each on the three mold systems used at the facility.

$$E_{VOC} = 25.1 + 19.6 + 44.4 = 89.1 \text{ tons/yr}$$

To determine the benzene emissions, $C_{i,MS}$ = 0.065 for the green sand mold (with or without cores), $C_{i,MS}$ = 0.028 for the phenolic urethane bonded molds, and $C_{i,CS}$ =0.073 for the cored systems (from Table 5-3). The emission calculation for benzene is as follows:

$$E_{Bz,GSonly} = 30{,}000[(1.9 \times 0.065) \times 0.88 + (0)]/2{,}000 = 1.63 \text{ tons/yr}$$

$$E_{Bz,GS+cores} = 12{,}000[(1.9 \times 0.065) \times 0.88 + (1.6 \times 0.073)]/2{,}000 = 1.35 \text{ tons/yr}$$

$$E_{VOC,ChemMold} = 12{,}000[(7.4 \times 0.028) \times 1 + (0)]/2{,}000 = 1.24 \text{ tons/yr}$$

$$E_{Bz} = 1.63 + 1.35 + 1.24 = 4.22 \text{ tons/yr}$$

Emissions of other HAP are calculated in a similar fashion. The results are summarized below:

	Emissions (tons/yr)			
HAP Compound	**Green Sand only Molds**	**Green Sand with Cores**	**Chemically Bonded Molds**	**Facility Total**
Acetaldehyde	0.12	0.07	0.03	0.23
Aniline	0.19	0.41	0.06	0.66
Benzene	1.61	1.34	1.22	4.22
Cresols (total)	0.04	0.11	1.78	1.93
N,N-Dimethylaniline	0.06	0.10	0	0.16
Ethylbenzene	0.12	0.06	0.02	0.21
Formaldehyde	0.02	0.01	0.11	0.14
n-Hexane	0.25	0.12	0	0.37
Naphthalene	0.19	0.15	0.08	0.42
Non-Naphthalene Other POM[e]	0.25	0.24	0.11	0.60
Phenol	0.19	0.31	3.44	3.97
Propianaldhyde	0	0	0.01	0.01
Styrene	0.03	0.03	0.06	0.12
Toluene	1.12	0.61	0.22	1.97
Xylenes (total)	0.81	0.39	0.11	1.34

5.3.2 PM Emissions from PCS Operations

Table 5-6 of the NESHAP Iron and Steel Foundry BID (U.S. EPA, 2003) reports emission factors for pouring, cooling, and shakeout for foundries. **Table 5-4** summarizes the default emission factors PCS operations for both iron and steel foundries. See **Appendix D** for more information about the development of these factors. These emission factors can be used in **Equation 5-2** to determine the PM mass emissions. For controlled PCS operations, it is recommended that sources use the captured, uncontrolled emission factors and adjust the emissions based on the expected control efficiencies of the control device, as provided in Table 3-3 of **Section 3.1**, *Melting Furnaces*, of this Protocol document. Site-specific captured/uncontrolled emission factors can be determined using baghouse catch data. If available, these site-specific captured/uncontrolled emission factors are preferred to the default factors in Table 5-4.

As with the PM emission factor for melting furnaces in Table 3-3, the PM emission factors in Table 5-4 for PM_{10}-FIL include emissions of $PM_{2.5}$-FIL. As well, the $PM_{\text{"coarse"}}$-FIL emissions factor is the emissions factor for PM_{10}-FIL minus the emissions factor for $PM_{2.5}$-FIL. Therefore, to calculate PM_{10}-FIL emissions, the emissions for $PM_{\text{"coarse"}}$-FIL is added to the emissions for $PM_{2.5}$-FIL.

$$E_i = \frac{M \times EmF_i}{2{,}000}$$

Eqn. 5-2

where:

E_i = emissions for compound i, tons/yr
M = quantity of metal poured, tons/yr
EmF_i = emission factor for compound "i", from Table 5-4, lbs/ton
2,000 = Conversion factor, lbs/ton.

Table 5-4. Summary of PM Emission Factors for PCS Lines

Suggested SCC for Iron Foundries	Suggested SCC for Steel Foundries	Emission category	PM-FIL emissions factor, lb/ton metal poured	PM_{10}-FIL emissions factor, lb/ton metal poured	$PM_{2.5}$-FIL emissions factor, lb/ton metal poured	PM-CON emissions factor, lb/ton metal poured
30400320	30400708	Pouring, captured, uncontrolled	0.087[a]	0.071[b]	0.063[b]	0.23[c]
30400325	30400713	Cooling, captured, uncontrolled	0.29[a]	0.24[b]	0.21[b]	0.77[c]
30400331	30400709	Shakeout, captured, uncontrolled	79.3[a]	65[b]	57[b]	

[a] Derived from Table 5-6 of NESHAP Iron and Steel Foundry BID.

[b] Used the size distribution ratios for steel foundries casting shakeout exhausted, prior to controls, to determine PM_{10}-FIL and $PM_{2.5}$-FIL values.

[c] Developed from CERP testing (Technikon, 2001a; 2001b; 2001c; 2001d; 2001e; 2001f; 2001g). Note that the CERP testing did not use EPA Method 202, and it is uncertain how well the CERP procedure would compare with EPA Method 202 in quantifying condensable PM.

5.3.3 HAP Metal Emissions from PCS Operations

Most metal HAP emissions will be associated with the filterable PM emissions. Although there are some metal HAP emissions associated with condensable PM emissions, based on the very limited data available, there was not enough data to develop PM-CON fractions. The most accurate method for determining the metallic HAP composition for emitted PM, particularly for cooling and shakeout, where there are fewer metal fumes, would be to analyze the metal HAP composition of the collected baghouse dust, if applicable., Site-specific metal chemistry should be used to estimate the metal content of the emitted (filterable) PM for pouring emissions. In the absence of site-specific baghouse dust or metal chemistry data, the default metal chemistries provided in **Table 5-5** can be used to estimate HAP metals. See Appendix D for more information about the development of these factors. It can be expected that for certain metal HAP, such as mercury, the metal HAP emissions will be primarily associated with the melting furnace, where most of these volatile HAP will be released from the metal, so there would not be appreciable amounts of mercury or similar HAP in the emissions associated with pouring, cooling, and shakeout. For shakeout emissions, the metal HAP content of the PM is highly dependent on the relative amounts of sand compared to metal particles are in the emitted dust. Shakeout systems with higher PM emissions are likely to have lower metal HAP concentrations as these high PM emitting systems are expected to have more sand fines than metal fines as compared to lower PM emitting systems. Because the shakeout system for which metal HAP concentrations were determined in Table 5-5 had lower PM emissions than the average factor in Table 5-4, the combination of these default factors are expected to result in a conservatively high metal HAP emission estimate for shakeout.

Table 5-5. Summary of HAP Content of PM from PCS Components[a]

Suggested SCC for Iron Foundries[c]	Suggested SCC for Steel Foundries[c]	CAS No.	Metal Constituent	HAP% of PM-FIL Pouring	HAP% of PM-FIL Cooling	HAP% of PM-FIL Shakeout	HAP% of PM-FIL PCS Total
30400320	30400708	7440-36-0	Antimony	ND	0.0097	0.0022	0.0049
30400320	30400708	7440-38-2	Arsenic	0.0046	ND	ND	0.00072
30400320	30400708	7440-43-9	Cadmium	0.011	0.019	0.014	0.016
30400320	30400708	18540-29-9	Chromium (hexavalent)	0.0036[b]	0.0066[b]	0.0045[b]	0.0051[b]
30400320	30400708	7440-47-3	Chromium (total)	0.12	0.22	0.15	0.17
30400320	30400708	7440-48-4	Cobalt	1.77	0.050	0.074	0.33
30400320	30400708	7439-92-1	Lead	0.43	0.21	0.63	0.18
30400320	30400708	7439-96-5	Manganese	2.01	0.49	0.29	0.64
30400320	30400708	7440-02-0	Nickel	0.28	0.18	0.27	0.23
30400320	30400708	7782-49-2	Selenium	ND	0.0039	ND	0.0016

[a] Derived from test data from 1999 CERP Foundry Mexico Baseline Testing (CERP, 1999a).

[b] Assume hexavalent chromium is 3% of total chromium emissions based on Chromium hexavalent percentages reported for Pouring, Cooling, and Shakeout for Iron and Steel Foundry SCC in Appendix D of NATA (U.S. EPA, 2011a).

[c] Report all emissions under pouring SCC as there is not an SCC for total PCS emissions.

ND = Non-Detect

5.3.4 Other Criteria Pollutant Emissions from PCS Operations

It can be expected that PCS emissions from chemically bonded molds will have carbon monoxide emissions. The default emission factors are presented below in Table 5-6. See **Appendix D** for more information about the development of this factor.

Table 5-6. Summary of Non-PM Criteria Pollutant Emission Factors for PCS Operations[a]

Suggested SCC for Iron Foundries[b]	Suggested SCC for Steel Foundries[b]	HAP Compound	Emission Factor, lb/ton
			Chemically Bonded Molds (all)
30400320	30400708	Carbon Monoxide	3.7

[a] Developed from CERP testing of chemically bonded mold systems (Technikon, 2001b, 2001d, 2001f, 2001g, 2004).

[b] Report all emissions under pouring SCC as there is not an SCC for total PCS emissions.

6. Finishing Operations

All castings typically undergo some type of mechanical finishing. Finishing operations begin once the casting is removed from the mold and cooled. Hammers, band saws, abrasive cutting wheels, flame cut-off devices, and air-carbon arc devices may be used to remove the risers, runners, and sprues of the metal transfer system. Metal fins at the parting lines (i.e., lines on a casting corresponding to the interface between the cope and drag of a mold) are removed with chipping hammers and grinders. Residual refractory material and oxides are typically removed by sand blasting or steel shot blasting, which can also be used to give the casting a uniform and more attractive surface appearance (U.S. EPA, 2002).

The cleaning of castings precedes any coating operations to ensure that the coating will adhere to the metal. Scale, rust, oxides, oil, grease, and dirt can be chemically removed from the surface of a casting using organic solvents, emulsifiers, pressurized water, abrasives, or alkaline agents (caustic soda, soda ash, alkaline silicates, and phosphates). Molten salt baths are also used to clean complex interior passages in castings (U.S. EPA, 2002).

Castings are often given a coating to inhibit oxidation, resist deterioration, or improve appearance. Common coating operations include painting, electroplating, electroless nickel plating, hard facing, hot dipping, thermal spraying, diffusion, conversion, porcelain enameling, and organic or fused dry-resin coating (U.S. EPA, 2002).

The emission estimation methods for finishing operations are presented in **Table 6-1**. Some equipment for finishing operations, such as shotblasting equipment, are enclosed; other equipment for finishing operations would require a hooding or ventilation system to direct the emissions to a well-defined stack. For emissions that are captured and emitted through well-defined stacks, direct measurement methods may be used. Direct measurements may be continuous or routinely frequent (e.g., daily or weekly) in nature so that the measurement data can be used directly to determine emissions (Methodology Rank 1 or 2). For some pollutants, a one-time or annual source test may be performed or, for PM, baghouse catch quantities can be determined even though emissions are not routinely measured. For these pollutants, the measured data can be used to determine an emission factor based on process throughput (e.g., metal produced, tons of castings cleaned, number of castings, gallons of coating used, etc.), and the annual emissions can be determined using the annual material usage multiplied by the site-specific emission factor (Methodology Rank 3). However, for most finishing operations, no direct measurement data will be available. In such cases, emissions will be estimated based on default release factors (Methodology Rank 4a) or generic emission factors (Methodology Rank 4b).

Table 6-1. Summary of Typical Hierarchy of Finishing Operations Emission Estimates

Rank	Methodology Description	Application	Data Requirements
1	Direct routine concentration and flow measurement	Finishing, grinding, cleaning, and coating operations that are well-captured and have well-defined stack emissions	Constituent concentration and exhaust flow rate
2	Direct routine concentration measurement with engineering flow estimates	Finishing, grinding, cleaning, and coating operations that are well-captured and have well-defined stack emissions	Constituent concentration and operating parameters needed for estimating flow rate (e.g., fan curve and amp usage)

Rank	Methodology Description	Application	Data Requirements
3	Site-specific emission factor from one-time or periodic emissions source test data	Finishing, grinding, cleaning, and coating operations that are well-captured and have well-defined stack emissions	Constituent concentration and exhaust flow rate and material usage rate (or throughput) during source test; annual material usage rate (or annual throughput)
4a	Chemical-specific release factors	Organic emissions from cleaning and coating materials	Composition of cleaning and coating material (from MSDS) and cleaning and coating material annual usage quantities
4b	Default emission factors	All PM and metal HAP sources	Material usage rates

Emissions from finishing operations include PM emissions from the mechanical finishing operations (e.g., cutting, grinding, shot blasting), which may contain metal HAPs as well as organic emissions from the release or volatilization of constituents in cleaning and coating materials used to clean and coat the metal casts. The PM produced by mechanical finishing is anticipated to be mainly coarse material that would not remain airborne. That is, uncontrolled PM produced by mechanical finishing would not generally escape the foundry building or be transported outside the facility boundaries. The cleaning and coating operations may generate VOC and organic HAPs from painting; coating, and solvent cleaning and acid and metal ion mists from anodizing; plating; polishing; hot-dip coating, etching; and chemical conversion coating.

6.1 Methodology Ranks 1 and 2 for Finishing Operations

Emissions from finishing operations can be directly measured at the stack or outlet of the control device using the direct measurement methods described in **Section 3**, *Melting Operations*, of this Foundries Emissions Protocol document. If CEMS are available for both a pollutant concentration and flow rate, the CEMS data should be used to determine the pollutant emissions as Methodology Rank 1 for Finishing Operations. If a CEMS is used to determine a pollutant's concentration, but direct-flow measurement is not available, flow rates can often be determined using engineering estimates, such as fan amperage-to-flow correlations, to determine the pollutant emissions as Methodology Rank 2 for Finishing Operations.

6.2 Methodology Rank 3 for Finishing Operations

When CEMS data are not available, but data from a single source test or a limited number of source tests are available, a site-specific emission factor can be developed and used to assess the emissions from finishing operations for the pollutants tested, similar to the methods described in **Section 3**, *Melting Operations*. For the finishing operations, the "activity" data will be the mass of metal poured or castings produced. Site-specific emission factors include those developed from baghouse catch data. The method to determine the captured, uncontrolled PM emissions from baghouse catch data was provided previously in ***Example 3-4***. The captured, uncontrolled emissions estimated from baghouse catch data should be corrected for the capture efficiency, particularly for sources that employ canopy hoods or similar capture systems. Baghouse dust analyses is the preferred source of metal HAP concentration for the emitted PM.

6.3 Methodology Rank 4 for Finishing Operations

When no emission measurement data are available, pollutant emissions will need to be estimated using default factors and either material-specific composition (Methodology Rank 4a for Finishing Operations) or default composition profiles (Methodology Rank 4b for Finishing Operations).

6.3.1 Organic Pollutant Emission from Finishing Operations

Organic air pollutant emissions from cleaning and coating materials will vary widely depending on the specific chemicals used during the cleaning and coating finishing operations. As such, chemical-specific compositional data should always be used when estimating the emissions from these operations (Methodology Rank 4a for Finishing Operations). The quantity of each cleaning and coating material used should be available from purchase records or direct material usage meters. Cleaning and coating material component composition should also be available from MSDS received from the chemical supplier (as described in **Section 4.2** of this Protocol document). Together, this information provides a direct means of determining constituent-specific usage rates. The organic emissions emitted to the atmosphere from the cleaning and coating materials can be assumed to be 100 percent of the volatile constituents (as listed in Table 1-1 of the Emissions Protocol document). The annual emissions for each volatile pollutant contained in the materials used in cleaning and coating can be estimated using the following general equation (**Equation 6-1**):

$$E_i = \sum_{x=1}^{N} \left(Q_x \times \frac{C_{x,i}}{100\%} \right)$$

Eqn. 6-1

where:

E_i = emissions for compound i, tons/yr
Q_x = quantity of material “x” used at the foundry, tons/yr
$C_{x,I}$ = concentration of compound “i” in material “x”, weight percent

6.3.2 PM Emissions from Finishing Operations

The EPA has developed PM emission factors for finishing operations, which are provided in Table 12.10-7 of Section 12.10 of AP-42 (U.S. EPA, 2003) and Table 12.13-2 of Section 12.13 of AP-42 (U.S. EPA, 1995), and provides size distribution analysis for iron foundry sources in Table 12.10-8 of Section 12.10 of AP-42 (U.S. EPA, 2003). Data collected through the Foundry Information Collection Request (ICR) were also used to assess the AP-42 emission factors and to refine the default emission factors for iron and steel foundries based on the available data. Table 12.13-2 of Section 12.13 of AP-42 (U.S. EPA, 1995) reports one emission factor for casting cleaning at steel foundries of 1.7 lb PM_{10}-FIL/ton of metal processed. Table 12.10-7 of Section 12.10 of AP-42 (U.S. EPA, 2003) contains a generic emission factor of 17 lbs PM (TSP)/ton of gray iron produced for uncontrolled cleaning and finishing but indicates that only 0.1 lbs/ton of PM is released to the atmosphere (with 99+ percent of the PM settling within the foundry building). The discrepancy between these factors is likely to be due to the size of the castings produced rather than the types of metal cast. Grinding/finishing of small parts can be expected to produce more PM per ton of cast metal than grinding/finishing of larger parts. Unfortunately, no data exists to correlate the PM emissions to the size of the parts produced. Bag house catch data collected from the Foundry ICR (see Table C-17 in Appendix C of the Foundry BID, [U.S. EPA, 2002]) was used to calculate separate emission factors for cutting, grinding, and shot blasting. See **Appendix E** for more information about the development of the factors. The data show significant variability across different facilities, indicating that the default PM emission factors for finishing operations are highly uncertain.

Based on the Foundry ICR data, the emission factors presented in **Table 6-2** are recommended for finishing operations at both iron and steel foundries. For finishing operations, it is assumed that there are no condensable PM emissions so that PM-FIL emissions equal PM-PRI emissions. These emission factors can be used in **Equation 6-2** to determine the PM mass emissions for uncontrolled units. For controlled finishing operations, it is recommended that sources use the ducted uncontrolled emission factors and adjust the emissions based on the expected control efficiencies of the control device as provided in Table 3-4 of **Section 3.1,** ***Melting Furnaces*****,** of this Protocol document. When applying the control efficiencies from Table 3-4 to the emission factors of Table 6-2, use the control efficiency reported for the particle size range of 0 to 2.5 µm for the fraction of $PM_{2.5}$-FIL and use the control efficiency reported for the article size range of 2.5 to 10 µm for the fraction of PM_{10}-FIL. It can be assumed that the PM collection efficiencies for PM greater than 10 µm in diameter are 100 percent (provided the PM collection efficiency for the 2.5 to 10 µm is 90 percent or greater).

As with the PM emission factor for melting furnaces in Table 3-3, the PM emission factors in Table 6-2 for PM_{10}-FIL include emissions of $PM_{2.5}$-FIL. As well, the $PM_{\text{"coarse"}}$-FIL emissions factor is the emissions factor for PM_{10}-FIL minus the emissions factor for $PM_{2.5}$-FIL. Therefore, to calculate PM_{10}-FIL emissions, the emissions for $PM_{\text{"coarse"}}$-FIL is added to the emissions for $PM_{2.5}$-FIL.

$$E_i = \frac{M \times EmF_i}{2{,}000}$$

Eqn. 6-2

where:

E_i = emissions of pollutant “i”, tons/yr
M = quantity of metal produced, tons/yr
EmF_i = emission factor of pollutant “i", from Table 6-2, lbs/ton
2,000 = Conversion factor, lbs/ton.

Table 6-2. Default PM Emission Factors for Finishing Operations

Suggested SCC for Iron Foundries	Suggested SCC for Steel Foundries	Emission Source	Pollutant	Emission Factor (lb/ton metal produced)
30400360	30400715 30400765	Cutting, captured and uncontrolled	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	6.0[a] 3.0[b] 1.2[b]
30400340	30400711	Grinding, captured and uncontrolled	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	16.0[a] 8.0[b] 3.2[b]
		Shot blasting or sand blasting, captured and uncontrolled	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	16.0[a] 8.0[b] 3.2[b]
30400360	30400715 30400765	Cutting, uncaptured and uncontrolled	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	0.06[c] 0.054[c] 0.048[c]
30400340	30400711	Grinding, uncaptured and uncontrolled	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	0.16[c] 0.14[c] 0.13[c]
		Shot blasting or sand blasting, uncaptured and uncontrolled	PM-FIL PM_{10}-FIL $PM_{2.5}$-FIL	0.16[c] 0.14[c] 0.13[c]

[a] Used data collected from Foundry ICR.

[b] Used the size distribution ratios of for steel foundries pouring and cooling uncontrolled, to determine PM_{10}-FIL (50%) and $PM_{2.5}$-FIL (20%) values.

[c] Assumes 1% of ducted emissions would be released as fugitive emissions that escape to the atmosphere for uncaptured units to roughly agree with the atmospheric release factor reported for finishing operations at iron foundries reported in AP-42 (U.S. EPA, 2003). Assumed that 90% of PM is PM_{10} and 80% of PM is $PM_{2.5}$ as smaller particles are more likely to escape to the atmosphere.

6.3.3 Metal HAP Emissions from Finishing Operations

The metal HAP emissions from finishing operations will be associated with the filterable PM emissions from finishing operations. Use **Equation 6-3** to determine the emissions of specific HAP metals from the melting furnace PM emission estimates. The PM generated during cut-off and grinding is expected to be primarily the same composition of the cast metal; the PM generated during shot blasting is expected to be primarily sand with some contribution from the cast metal. Baghouse dust analyses suggest that the concentrations of metals in the collected PM from shot blasting operations are approximately one-fifth that of dust collected from cut-off or grinding operations. The factor of 5 associated with the PM generated from shot blasting is included to account for the lower metal content of PM emissions from shot blasting. If baghouse dust analysis is available, the factor of 5 correction to adjust the shot blasting metal HAP emissions in Equation 6-3 should not be used.

$$E_i = \left(\text{PM-FIL}_{\text{cutoff}} + \text{PM-FIL}_{\text{grinding}} + \frac{\text{PM-FIL}_{\text{shot blast}}}{5}\right) \times \frac{\%\text{PM-FIL}_i}{100\%}$$

Eqn. 6-3

where:

E_i = Emissions of pollutant “i” (tons/yr)
$\text{PM-FIL}_{\text{cutoff}}$ = Total filterable PM emissions rate from cutoff (tons/yr)
$\text{PM-FIL}_{\text{grinding}}$ = Total filterable PM emissions rate from grinding (tons/yr)
$\text{PM-FIL}_{\text{shot blast}}$ = Total filterable PM emissions rate from shot or sand blasting (tons/yr)
$\%\text{PM-FIL}_i$ = Percent of filterable PM mass contributed by pollutant “i” (weight, percent)

When available, baghouse dust analyses should be used to determine the metal HAP content of the filterable PM, i.e., “$\%\text{PM-FIL}_i$”. If baghouse dust analyses are note available, site-specific metal chemistry data should be used to estimate the metal content of the emitted (filterable) PM. In the absence of site-specific metal chemistry data, the default metal chemistries for filterable PM provided in **Table 3-6** of **Section 3.1.4.3** of this Protocol document can be used to estimate HAP content of the emitted PM, i.e., “$\%\text{PM-FIL}_i$”.

Example 6-1: Estimating PM Emissions from Finishing Operations

A facility pours 35,500 tons of steel per year to produce 31,000 tons of finished castings. The facility has a shot blasting unit that is controlled by a high-efficiency cyclone and a grinding station that is uncaptured/uncontrolled. The facility does not have a cut-off station. Calculate the PM emissions for the finishing operations for this facility.

For the uncaptured/uncontrolled grinding station, use the default emission factors for uncaptured/uncontrolled emissions from Table 6-2 in Equation 6-2. For Equation 6-2, the mass of metal produced refers to the total mass of metal cast, not just the mass of final metal product.

The calculation for PM-FIL for grinding follows:

$$\mathrm{E_{PM\text{-}FIL,Grinding}} = \mathrm{E_{PM\text{-}PRI}} = \left(35{,}500 \text{ tons} \times \frac{0.16}{2{,}000}\right) = 2.84 \text{ tons/yr}$$

[Note that PM-CON for finishing operations is 0, so PM-PRI = PM-FIL.]

Similar calculations are used for PM$_{10}$_FIL and PM$_{2.5}$-FIL for grinding to yield:

$\mathrm{E_{PM10\text{-}FIL,Grinding}}$ = 2.49 tons/yr

$\mathrm{E_{PM2.5\text{-}FIL,Grinding}}$ = 2.31 tons/yr

For the shot blasting unit, first determine the inlet loading to the control device using the captured/uncontrolled emission factors from Table 6-2 in Equation 6-2 as follows:

$$\mathrm{E_{PM\text{-}FIL,SB,uncontrolled}} = \left(35{,}500 \text{ tons} \times \frac{16.0}{2{,}000}\right) = 284 \text{ tons/yr}$$

$\mathrm{E_{PM10\text{-}FIL,SB,uncontolled}}$ = 142 tons/yr

$\mathrm{E_{PM2.5\text{-}FIL,\ SB\ ,uncontrolled}}$ = 56.8 tons/yr.

Next, the control device efficiency for the different size fractions is selected from Table 3-4. For a high-efficiency cyclone (centrifugal collector), the collection efficiency for PM$_{2.5}$ is 80%. For PM between 2.5 and 10 µm, the collection efficiency is 95%.

Calculate the PM$_{2.5}$-FIL emissions based on the control device efficiency using Equation 3-4 as follows:

$\mathrm{E_{PM2.5\text{-}FIL,SB}} = 56.8 \times (1-0.80) = 11.36$ tons/yr

Similarly, calculate the PM emissions between 2.5 and 10 µm as follows:

$\mathrm{E_{PM\text{-}``coarse",SB}} = (142-56.8) \times (1-0.95) = 4.26$ tons/yr

The PM$_{10}$-FIL emissions are the sum of the PM$_{2.5}$-FIL and PM “coarse” emissions. Given the high PM10 collection efficiency, it can be assumed that the collection efficiency for PM greater than 10 µm in diameter is effectively 100%. Therefore,

$\mathrm{E_{PM\text{-}FIL,SB}} = \mathrm{E_{PM10\text{-}FIL,SB}} = 11.36 + 4.26 = 15.62$ tons/yr.

Example 6-2: Estimating HAP Metal Emissions from Finishing Operations

For the facility in ***Example 6-1***, calculate the HAP metal emissions for the finishing operations. The facility does not have site-specific metal chemistry data available and does not have a cut-off station.

Since the facility does not have site-specific metal chemistry data available, use the default values in Table 3-6 of this protocol document and Equation 6-3.

Metal Constituent	% of PM-FIL
Antimony	0.02
Arsenic	0.003
Beryllium	0.0001
Cadmium	0.02
Chromium (hexavalent)	0.01
Chromium (total)	0.10
Cobalt	0.0006
Lead	1.0
Manganese	3.0
Mercury	0.02
Nickel	0.2
Phosphorus	0. 3
Selenium	0.01

$$E_i = \left(\text{PM-FIL}_{\text{cutoff}} + \text{PM-FIL}_{\text{Grinding}} + \frac{\text{PM-FIL}_{\text{SB}}}{5}\right) \times \frac{\%\text{PM-FIL}_i}{100\%}$$

$$E_{\text{Antimony}} = \left(0 + 2.84 + \frac{15.62}{5}\right) \times \frac{0.02}{100\%} = 0.0012 \text{ ton/yr}$$

Similarly,

$E_{\text{Arsenic}} = 0.00018$ ton/yr

$E_{\text{Beryllium}} = 0.0000060$ ton/yr

$E_{\text{Cadmium}} = 0.0012$ ton/yr

$E_{\text{Chromium (hexavalent)}} = 0.00060$ ton/yr

$E_{\text{Chromium (total)}} = 0.0060$ ton/yr

$E_{\text{Cobalt}} = 0.000036$ ton/yr

$E_{\text{Lead}} = 0.060$ ton/yr

$E_{\text{Manganese}} = 0.18$ ton/yr

$E_{\text{Mercury}} = 0.0012$ ton/yr

$E_{\text{Nickel}} = 0.012$ ton/yr

$E_{\text{Phosphorus}} = 0.018$ ton/yr

$E_{\text{Selenium}} = 0.00060$ ton/yr

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Appendix A:
Foundry Glossary Terms

http://www.atlasfdry.com/glossary.htm

Addition Agent: Any material added to a charge of molten metal in bath or ladle to bring alloy to specifications. A reagent added to the plating bath.

Additives: Any material added to molding sand for reasons other than bonding or improvement of bond is considered an additive. Bonds can be of varying types: carbonaceous (sea coal, pitch, fuel oil, graphite, gilsonite); cellulose (wood flour, cereal hulls); fines (silica flour, iron oxide, fly ash); cereals (corn flour, dextrine, sugar); and chemical (boric acid, sulfur, ammonium compounds, diethylene glycol).

Alloy: A substance having metallic properties and composed of two or more chemical elements of which at least one is metal. A metallic material formed by mixing two or more chemical elements. Usually possess properties different from those of the components. As examples, Brass is an alloy of copper and zinc and Cast Iron contains iron, carbon and silicon.

Alloy Steel: Steel containing significant quantities of alloying elements other than carbon and the commonly accepted amounts of manganese, silicon, sulfur, and phosphorus.

Alloying: Procedure of adding elements other than those usually comprising a metal or alloy to change its characteristics and properties.

Alloying Elements: Elements added to nonferrous and ferrous metals and alloys to change their characteristics and properties.

Ambient Air: The surrounding air.

Ambient Temperature: Temperature of the surrounding air.

American Foundry Society: Association that provides and promotes knowledge and services that strengthen the metal casting industry for the ultimate benefit of its customers and society.

Anodizing: Forming a conversion coating on a metal surface by electrolytic oxidation with the work forming the anode. This process is most frequently applied to aluminum.

Antimony: One of the elements; its chemical symbol is Sb. Its formula weight is 121.76, specific gravity 6.62, and melting point 630.5°C.

Assembling (Assembly) Line: Conveyor system where molds or cores are assembled.

Bake: Heat in an oven to a low controlled temperature to remove gases or to harden a binder.

Baked Core: A core which has been heated through sufficient time and temperature to produce the desired physical properties attainable from its oxidizing or thermal-setting binders as opposed to a green-sand core, which is used in the moist state.

Baked Permeability: Property of a molded mass of sand heated at a temperature above 230° F until dry and cooled to room temperature, to permit passage of gases through it; particularly those generated during pouring of molten metal into a mold.

Baked Strength: Compressive, shear, tensile or transverse strength of a mold sand mixture when baked at a temperature above 231°F (111°C) and then cooled to room temperature.

Batch: Amount or quantity of core or mold sand or other material prepared at one time.

Bed Charge: The charge of iron placed on the coke bed in a cupola.

Bed Coke: Coke placed in the cupola well to support the following iron and coke charges.

Binder: The bonding agent is a material used as an additive to mold or core sand to impart strength or plasticity in a "green" or dry state. May be cereal, oil, clay, resin, pitch, etc.

Binder, Plastic (Resin): Synthetic resin material used to hold grains of sand together in molds or cores; may be phenol formaldehyde or urea formaldehyde thermosetting types.

Blast: Air driven into the cupola or furnace for combustion of fuel.

Blast Cleaning: Removal of sand or oxide scale from castings by the impinging action of sand, metal shot, or grit projected under air, water, or centrifugal pressure.

Blended Molding Sands: Naturally bonded molding sands which have been mixed or modified by the supplier to produce desirable properties.

Blended Sand: Mixture of sands of different grain sizes, clay content, etc., to produce one possessing characteristics more suitable for foundry use.

Blower, Core Or Mold: A machine or device using compressed air to inject sand into a core box or a flask.

Bond: (a) A bonding substance or bonding agents - any material other than water, which, when added to foundry sands, imparts bond strength. The overlapping of brick so as to give both longitudinal and transverse strength. (b) Cohesive material in sand.

Bottom Pour Ladle: Ladle in which metal, usually steel, flows through a nozzle in the bottom.

Bottom Pour Mold: A mold that is gated at the bottom.

Bottom Running Or Pouring: Filling of the mold cavity from the bottom by means of gates from the runner.

Bottom Sand: Layer of molding sand rammed into place on the doors at the bottom of a cupola.

C: Degrees Centigrade or Celsius.

Casting (verb): A process where molten metal is poured into a mold and solidification is allowed to take place. The act of pouring metal.

Casting (noun): A metal object obtained by pouring molten metal into a mold. The metal shape, exclusive of gates and risers, that is obtained as a result of pouring metal into a mold.

Casting Process: A forming process in which a molten metal, polymer, or other heated liquid or plastic material is poured into a mold or onto a substrate with little or no pressure applied; the substance cools, solidifies, and the formed object is removed.

Cavity, Mold Or Die: Impression or impressions in a mold or die that give the casting its shape.

Centrifugal Casting (verb): Process of filling molds by pouring the metal into a sand or metal mold revolving about either its horizontal or vertical axis, or pouring the metal into a mold that subsequently is revolved before solidification of the metal is complete. Molten metal is moved from the center of the mold to the periphery by centrifugal action.

Centrifugal Casting (noun): Casting made in molds which are rotating so as to produce a centrifugal force in the molten metal.

Chip (verb): To remove extraneous metal from a casting with hand or pneumatically operated chisels.

Chromium: Alloying element used as a carbide stabilizer.

Cleaning: Process of removing sand, surface blemishes, runners, risers, flash, surplus metal, and sand etc., from the exterior and interior surfaces of castings. Includes degating, tumbling, or abrasive blasting, grinding off gate stubs, etc.

Cobalt: Blue-white metal, melting at 2,715°F (1,492°C), used in very hard alloy such as stellite, and a binder in carbide cutting tools.

Coke: Coal derivative resulting from the distillation of bituminous coal in the absence of air. The distillation process removes all of the volatile material from the coal so it can be used as a very intense source of fuel in cupola melting. Source of some carbon found in iron.

Coke Bed: First layer of coke placed in the cupola. Also the coke used as the foundation in constructing a large mold in a flask or pit.

Coke Breeze: Fines from coke screening, used in blacking mixes after grinding; also briquetted for cupola use.

Cold Box Process: A rapid coremaking process which does not require application of heat to cure the cores. Hardening of the cores is accomplished by chemical reaction rather than by conventional baking. A phenolic resin is added to the sand used to make the core. This resin reacts chemically when exposed to an accelerator, typically an active organic gas, and hardens very quickly, forming an organic bond in the core sand. This reaction occurs at room temperature and does not require special coreboxes or equipment. Additionally, since the bond is organic, the sand collapses readily during shakeout and can be recovered easily from the casting.

Combustion: Chemical change as a result of the combination of the combustible constituents of the fuel with oxygen, producing heat.

Combustion Chamber: Space in furnace where combustion of gaseous products from fuel takes place.

Combustion Efficiency: The amount of heat usefully available divided by the maximum amount which can be liberated by combustion; usually expressed in percentage.

Continuous Tapping: A furnace or holding ladle that is made of discharge molten metal continuously during normal operation.

Conveyor: A mechanical apparatus for carrying or transporting materials from place to place. Types include apron, belt, chain, gravity, roller, monorail, overhead, pneumatic, vibrating, etc.

Conveyor Belt: A continuously moving belt used in an automated or semiautomatic foundry to move materials from one station to another.

Core: A bonded sand insert placed in the mold to form an undercut or hollow section in the casting which cannot be shaped by the pattern. A core is frequently used to create openings and various shaped cavities in the casting. The shaped body of sand which forms interior of casting and also selected external features.

Core Assembly: A complex core made from a number of cores or sections.

Core Binder: Any material used to hold the grains of core sand together.

Core Compound: A commercial mixture used as a binder in core sand.

Core Knockout Machine: A mechanical device for removing cores from castings.

Crucible: A ceramic pot or receptacle made of materials such as graphite or silicon carbide, with relatively high thermal conductivity, bonded with clay or carbon, and used in melting metals; sometimes applied to pots made of cast iron, steel, or wrought steel. The name derives from the cross, the Crux, with which ancient alchemists adorned it.

Crucible Furnace: A furnace fired with coke, oil, gas, or electricity in which metals are melted in a refractory crucible.

Cupola: A cylindrical straight shaft furnace usually lined with refractories, for melting metal in direct contact with coke by forcing air under pressure through openings near its base. Vertical shaft furnace lined with refractories used to produce cast iron by high temperature melting of metallic and mineral charge materials.

Cure: To harden.

Curing Time (No Bake): That period of time needed before a sand mass reaches maximum hardness.

Cut: Defect in a casting resulting from erosion of the sand by metal flowing over the mold or cored surface.

Cutoff Machines, Abrasive: A machine using a thin abrasive wheel and employed in cutting off gates and risers from casting or in similar operations.

Cyclone (Centrifugal Collector): In air pollution control, a controlled descending vortex created to spiral objectionable gases and dust to the bottom of a collector core.

Die: A metal block used in forming materials by casting, molding, stamping, threading, or extruding. A metal form used as a permanent mold for die casting or lost wax process.

Die Casting: (a) Forcing molten metal into permanent molds, dies. Die Casting is also called Pressure Casting. See Pressure Die Casting. (b) *noun* Casting resulting from die-casting process. (c) *verb* Pouring molten metal under pressure into metal molds.

Direct-Arc Furnace: Electric furnace in which the material is heated directly by an arc established between the electrodes and the work. See Dielectric Furnace.

Draw: A term used to temper, to remove pattern from mold, as an external contraction defect on surface of mold.

Draw (verb): To remove a pattern from a mold.

Dried Sand: Sand which bas been dried by mechanical dryer prior to use in core making.

Dual Metal Centrifugal Casting: Centrifugal castings produced by pouring a different metal into the rotating mold after the first metal poured.

Ductile Iron: A type of iron in which the graphite content takes spherical rather than flake form. Ductile iron is produced by adding magnesium. The spherical form of the graphite provides greater tensile strengths and flexibility than other types of iron. An iron/graphite composite in which the graphite exists in spheres or nodules, allowing the material to deform rather than fracture when placed under mechanical stress. Also called Nodular Iron. Iron in which carbon is in the form of spherical nodules.

Electric Arc Furnace: A crucible furnace that uses an electric arc, similar to an electric arc welding operation, to melt metal.

Electrode: Compressed graphite or carbon cylinder or rod used to conduct electric current in electric arc furnaces, arc lamps, carbon arc welding, etc.

Expendable Pattern: In investment molding, the wax or plastic pattern that is left in the mold and later melted and burned out. This also called a disposable pattern.

Ferroalloys: Alloys consisting of certain elements combined with iron, and used to increase the amount of such elements in ferrous metals and alloys. In some cases the ferroalloys may serve as deoxidizers.

Finish (verb): The hand work on a mold after the pattern has been withdrawn.

Flux: Any substance used to promote fusion. Also any material which reduces, oxidizes, or decomposes impurities so that they are carried off as slags or gases.

Foundry (Foundries, plural): The act, process, or art of casting metals. The buildings and works for casting metals.

Foundry Ladle: A vessel for holding molten metal and conveying it from cupola to the molds.

Foundry Returns: Metal in the form of sprues, gates, runners, risers and scrapped castings, with known chemical composition that are returned to the furnace for remelting. Sometimes referred to as "revert ".

Foundry Sand: Foundry sand is used in creating cores and molds used in the casting of iron, steel, copper and aluminum products. In construction, steel and iron beams-known as girders-are used in the building of bridges, large office buildings and some homes. Copper pipes, aluminum supports and even the hardware and hand tools used in construction had their origins at the foundry. Foundry sand is the second largest industrial use of sand in terms of tons consumed.

Gray Iron: Iron in which a large percentage of the carbon content is in the form of graphite flakes. Traditionally referred to as “Cast Iron”. The graphite flakes cause it to have low shock resistance, but high damping ability. It has a gray fracture. Gray Iron is by far the oldest and most common form of cast iron. As a result, it is assumed by many to be the only form of cast iron and the terms "cast iron" and "gray iron" are used interchangeably. Cast iron containing graphite in flake form and typically consisting of 2 to 4 percent carbon and 1 to 3 percent silicon. Gray iron is widely used for engine components in automobiles and trucks.

Gray Iron Melting: The process of melting gray iron, especially as it is done in a foundry on a commercial scale.

Green Sand: Natural sands combined with water and organic additives, such as clay, to proper consistency for creating molds.

Green Sand Core: A core that is made of molding sand but not baked.

Grinding: Removing gate stubs, fins, and other projections on castings by an abrasive wheel.

Holding Furnace: Usually a small furnace for maintaining molten metal at the proper pouring temperature, and which is supplied from a large melting unit.

Holding Ladle: Heavily lined and insulated ladle in which molten metal is placed until it can be used.

Hot Box Process: Method of making and curing cores within a heated corebox. To form and cure the core, the corebox is heated to approximately 500 degrees F. The sand used in this process contains a catalyst which hardens the binders in the core upon contact with the hot corebox. Complete curing while the core is still in the box results from the residual heat in the core, eliminating the need for conventional dryers or ovens. Frequently, cores created with the Hot Box process are shell cores.

Indirect-Arc Furnace: An AC, Alternating Current, electric-arc furnace in which the metal is not one of the poles. An electric furnace in which the arc is struck between two horizontal electrodes, heating the metal charge by radiation.

Induction Furnace: An AC melting furnace which utilizes the heat of electrical induction.

Investment Casting: A pattern casting process in which a wax or thermoplastic pattern is used. The pattern is invested (surrounded) by a refractory slurry. After the mold is dry, the pattern is melted or burned out of the mold cavity, and molten metal is poured into the resulting cavity.

Investment Casting Process: A pattern casting process in which a wax or thermoplastic pattern is used. The pattern is invested (surrounded) by a refractory slurry. After the mold is dry, the pattern is melted or burned out of the mold cavity, and molten metal is poured into the resulting cavity.

Investment Molding: Method of molding using a pattern of wax, plastic, or other material which is "invested" or surrounded by a molding medium in slurry or liquid form. After the molding medium has solidified, the pattern is removed by subjecting the mold to heat, leaving a cavity for reception of molten metal. This is also called the lost-wax process or precision molding.

Iron: A metallic element, mp 1535°C (2795°F). Also irons that do not fall into the steel categories, such as Gray Iron, Ductile Iron, Malleable Iron, White Iron, Ingot, and Wrought Iron.

Knock Out: To remove sand and casting from a flask.

Ladle: Metal receptacle frequently lined with refractories used for transporting and pouring molten metal. Different types of ladles include hand bull, crane, bottom-pour, holding, teapot, shank, lip-pour.

Lead: One of the elements; its chemical symbol is Pb. Its formula weight is 207.2 and melting point is 327.5°C.

Manganese: One of the elements; its chemical symbol is Mn. Its formula weight is 54.93; specific gravity 7.2, and melting point is 1260°C. Metallic manganese is used in the nonferrous industry both as a deoxidizing agent and as an essential constituent to improve physical properties of certain alloys.

Melting Rate: Amount of metal melted in a given period of time, usually one hour.

Mill Sale: Iron oxide scale formed on steel during hot working processes, cooled in air.

Mold: Normally consists of a top and bottom form, made of sand, metal, or any other investment material which contains the cavity into which molten metal is poured to produce a casting of definite shape and outline.

Mold Coating: Coating to prevent surface defects, i.e., metal penetration and improve casting finish.

Nickel: An element used for alloying iron and steel as well as nonferrous metals; melting point 1455°C (2651°F). Nickel is also a base metal for many casting alloys resistant to corrosion and high temperature oxidation. Nickel's chemical symbol is Ni. Its formula weight is 58.69, the specific gravity is 8.90, and nickel's melting point 1,452°C.

Nobake Binder: A synthetic liquid resin sand binder that hardens completely at room temperature, generally not requiring baking, used in the Cold Setting process.

No-Bake Process: Molds/cores produced with a resin bonded air setting sand. Also known as the air set process because molds are left to harden under normal atmospheric conditions.

Particulate Matter: In air pollution control, solid or liquid particles, except water, visible with or without a microscope, that make up the obvious portion of smoke.

Pattern: An original used as a form to produce duplicate pieces. Pattern dimensions are slightly enlarged to counteract the shrinkage of the casting as it solidifies and cools in the mold. Although patterns can be made in one piece, a complicated casting may consist of two or more parts. The pattern may be made out of wood, plastic, metal, or other material.

Permanent Mold: A long-life mold into which metal is poured by gravity. It is used repeatedly to produce many castings from the same mold. It is not an ingot mold.

Pouring: Filling the mold with molten metal. Transferring the molten metal from the furnace to the ladle, ladle to ladle, or ladle into the molds.

Preheating: A general term for heating material, as a die in die casting, as a preliminary to operation, to reduce thermal shock and prevent adherence of molten metal.

Psi: Abbreviation for pounds per square inch.

Reverberatory Furnace: Melting unit with a roof arranged to deflect the flame and heat toward the hearth on which the metal to be melted rests.

Sand: In metal casting, a loose, granular material high in SiO_2, resulting from the disintegration of rock. The name sand refers to the size of grain and not to mineral composition. Diameter of the individual grains can vary from approximately 6 to 270 mesh. Most foundry sands are made up principally of the mineral quartz (silica). Reason for this is that sand is plentiful, refractory, and cheap; miscellaneous sands include zircon, olivine, chromite, $CaCO_3$, black sand (lava grains), titanium minerals and others.

Sand Mulling: A method of evenly distributing the bond around the sand grain by a rubbing action.

Scrap Metal: Metal to be remelted; includes scrapped machinery fabricated items such as rail or structural steel and rejected castings (metal to be re-melted, castings that have to be re-melted).

Sea Coal: Term applied to finely ground bituminous coal which is mixed with sands for foundry uses.

Selenium: A metalloid melting at 220°C (428°F) added to stainless steel to improve machinability.

Separator: A mechanical unit which separates or grades ground materials into constituent parts, used in the foundry to remove fines from the system sand and dust from the air.

Shakeout: The process of separating the solidified casting from the mold material. The stage in the casting process where the sand from the mold is cleaned off of the newly formed castings through vigorous vibration.

Shakeout Machinery: Equipment for mechanical removal of castings from molds.

Shell Process: Process in which clay-free silica sand coated with a thermosetting resin or mixed with resin is placed on a heated metal pattern for a short period of time to form a partially hardened shell. The bulk of the sand mixture inside the resulting shell is removed for further use. The pattern and shell are then heated further to harden or polymerize the resin-sand mix, and the shell is removed from the pattern. Frequently, shell cores are made using the Hot Box process.

Shot: Metallic abrasive commonly used for cleaning casting surfaces. In die-casting, it is the phase of the die-casting cycle when molten metal is forced into the die.

Shotblasting (Shot peening): Casting cleaning process employing a metal abrasive (grit or shot) propelled by centrifugal or air force.

Silica: Silicon dioxide, SiO_2, occurring in nature as quartz, opal, etc. Molding and core sands are impure silica. The prime ingredient of sand and acid refractories.

Silica Sand: Sand with a minimum silica content of 95% used for forming casting molds.

Slag: A fused nonmetallic material used to protect molten metal from the air and to extract certain impurities. The nonmetallic covering on molten metal resulting from the combination of impurities in the initial charge like ash from fuel, and any silica and clay eroded from the refractory lining. It is skimmed off prior to pouring the metal.

Split Pattern: A pattern that is parted for convenience in molding.

Sprue: A vertical passageway that takes the molten metal from the pouring basin to the runner.

Steel: An alloy of iron and carbon, containing no more than 1.74% carbon. It must be malleable at some temperature while in the as-cast state.

Tap: To withdraw a molten charge from the melting unit.

Tap Hole: Opening in a furnace through which molten metal is tapped into the forehearth or ladle.

Temperature: Degree of warmth or coldness in relation to an arbitrary zero measured on one or more of accepted scales, as Centigrade, Fahrenheit, etc.

Temperature, Holding: Temperature above the critical phase transformation range at which castings are held as a part of the heat treatment cycle. The temperature maintained when metal is held in a furnace, usually prior to pouring.

Temperature, Pouring: The temperature of the metal as it is poured into the mold.

Transfer Ladle: A ladle that may be supported on a monorail or carried in a shank and used to transfer metal from the melting furnace to the holding furnace or from furnace to pouring ladles.

Trimming: Removing fins, gates, etc. from castings.

Vanadium: A white, hard, metallic element, mp 1800°C (3272°F), used as an alloy in iron and steel; a powerful carbide stabilizer and deoxidizer.

Wax Pattern: A precise duplicate, allowing for shrinkage, of the casting and required gates, usually formed by pouring or injecting molten wax into a die or mold. Wax molded around the parts to be welded by a termite welding process.

Wet Scrubber (Gas Washer): In air pollution control, a liquid (usually water) spray device for collecting pollutants in escaping foundry gases.

Appendix B:
Development of Emission Factors for Section 3 Melting Operations

Particulate matter (PM) test data reported in the literature, U.S. Environmental Protection Agency (EPA) source test data, and test data reported by the industry in response to EPA's detailed information collection request (ICR) were compiled, and emission factors based on tons of metal melted (or tons of metal poured) were calculated (see Appendix C of the Iron and Steel Foundries BID, U.S. EPA, 2002). A summary of the PM emission factor data for melting operations was provided in the BID (see Table 5-2, U.S. EPA, 2002); this table, with additional rows for AP-42 factors, is presented as **Table B-1** in this appendix.

The summary of data in Table B-1 indicates that there is significant variability among the reported data. Furthermore, there appear to be some discrepancies between the different sources. For example, most of the ICR test data suggested that the PM emission factors for controlled wet scrubbers are less than those reported in AP-42 (overall cited as U.S. EPA, 1995, in the BID, but the iron foundry chapter was updated in 2003), but the baghouse catch data suggests that the uncontrolled emission factor for cupolas is understated in AP-42. In general, these data were considered along with the expected emission control efficiency for specific control devices (as reported in Table B.2-3 in Appendix B-2 of AP-42, which is also provided as Table 3-4 in Chapter 3 of this Emission Protocol document) to develop recommended emission factors. This appendix provides documentation of some of the specific comparisons and analyses performed to provide the recommended emission factors provided in Chapter 3 of this Emission Protocol document.

Table B-1. Summary of PM Emission Factors for Melting Furnace Operations

Emission category/ source of data	Basis of reported values	Range of emissions factors, lb/ton	Median emissions factor, lb/ton	Average emissions factor, lb/ton
Cupolas controlled with wet scrubbers				
GM - Saginaw (U.S. EPA, 1999b)	4 Run EPA source test	0.038 - 0.21	0.110	0.117
ICR PM Tests	11 Source tests	0.090 - 1.46	0.56	0.580
AP-42 (U.S. EPA, 2003)	4 Values for different scrubber types	0.8** - 5.0		3.0
Cupolas controlled with fabric filters				
Waupaca - Tell City (U.S. EPA, 1999a)	2 of 3 Run EPA source test	0.010 - 0.017		0.014
ICR PM Tests	3 Source tests	0.030 - 0.082	0.077	0.063
AP-42 (U.S. EPA, 2003)	As reported	0.70		0.70
Cupolas uncontrolled (or prior to controls)				
Waupaca - Tell City (U.S. EPA, 1999a)	3 Run EPA source test	3.45 - 9.7	7.7	7.0
GM -Saginaw (U.S. EPA, 1999b)	4 Run EPA source test	3.6 - 4.9	4.1	4.3
ICR - Baghouse catch	Data for 17 cupola	8.14 - 64.1	24.0	26.1

Emission category/ source of data	Basis of reported values	Range of emissions factors, lb/ton	Median emissions factor, lb/ton	Average emissions factor, lb/ton
Kearney (1971)	Data for 24 cupola	7.5 - 66.3	21.9	30.2
AP-42 (U.S. EPA, 2003)***	As reported			13.8
EAF melting controlled with fabric filters				
ICR PM Tests	4 Source tests	0.037 - 0.56	0.15	0.22
EAF - BID (EPA, 1980)	Data for 11 EAF	0.052 - 0.69	0.15	0.23
AP-42 (EPA, 2003)***	As reported			0.4
EAF melting uncontrolled				
ICR PM Tests	1 Source test (3 runs)	20.2 - 25.9	23.9	25.7
ICR - Baghouse catch	Data for 13 EAF	3.3 - 29.5	8.4	11.0
Kearney (1971)	Data for 19 EAF	4.0 - 40.0	12.7	13.8
AP-42 (EPA, 2003)**	As reported			12.7
AP-42 (EPA, 1995)**	As reported	4. - 40.		13
EAF charging & tapping uncontrolled				
EAF - BID (EPA, 1980)	As reported	1.4 iron, 1.6 steel	1.4	1.6
EAF steel - BID (EPA, 1983)	As reported	1.6 - 2.0		1.8
Induction furnace with PM control				
ICR PM Tests	5 Source tests	0.080 - 0.67	0.13	0.30
AP-42 (EPA, 2003)	As reported	0.20		0.20
Induction furnaces uncontrolled				
ICR PM Tests	2 Source tests	0.44 - 8.94		4.7
ICR - Baghouse catch	Data for 8 furnaces	0.33 - 4.0	1.75	2.0
BCIRA (Shaw, 1982)	Data for 14 furnace tests	0.26 - 3.3	0.62	0.9
AP-42 (EPA, 2003)***	As reported			0.9
AP-42 (EPA, 1995)***	As reported for total filterable PM			0.1
AP-42 (EPA, 1995)***	As reported for PM_{10}-FIL			0.09

[*] From Table 5-2 in Iron and Steel Foundry BID (U.S. EPA, 2002) unless otherwise noted. Emissions factors selected for estimating baseline emissions in the BID are presented in bold.

[**] There is a typographical error in Table 5-2 of the Iron and Steel Foundry BID (U.S. EPA, 2002); the best performing wet scrubber type had an emission factor of 0.8 (not 0.08) lb/ton metal melted.

[***] Not directly included in Table 5-2 of the Iron and Steel Foundry BID (U.S. EPA, 2002). Most of these additional AP-42 factors were based on the same data set presented by Kearney (1971) or Shaw (1982).

Development of PM Filterable Emission Factors for Cupola Melting Furnaces

For cupola melting furnaces, AP-42 provides emission factors by particle size for controlled and uncontrolled cupolas. The PM distribution for controlled units is very different than what would be anticipated using the control device PM control efficiencies provided in Table B.2-3 in Appendix B-2 of AP-42 (U.S. EPA, 1996); the primary control device control efficiencies are provided here in **Table B-2**. **Table B-3** provides a comparison of the emission factors reported in AP-42 to those calculated from the uncontrolled emission factor on control device emission factors.

Table B-2. Typical Collection Efficiencies of Various Particulate Control Devices[a] (%)

AIRS Code[b]	Type of Collector	Collection Efficiency for: Filterable Particle Size (µm)		
		0 – 2.5	2.5 - 6	6 – 10
001	Wet scrubber – hi-efficiency	90	95	99
002	Wet scrubber – med-efficiency	25	85	95
003	Wet scrubber – low-efficiency	20	80	90
053	Venturi scrubber	90	95	99
053	Venturi scrubber (ΔP >30 inches of water) [b]	95	98	99
053	Venturi scrubber (ΔP ≤30 inches of water) [b]	88	94	99
007	Centrifugal collector – hi-efficiency	80	95	95
008	Centrifugal collector – med-efficiency	50	75	85
009	Centrifugal collector – low-efficiency	10	35	50
010	Electrostatic precipitator – hi-efficiency	95	99	99.5
011	Electrostatic precipitator – med-efficiency	80	90	97
012	Electrostatic precipitator – low-efficiency	70	80	90
016	Fabric filter – high temperature (>250 °F)	99	99.5	99.5
017	Fabric filter – med temperature (180 °F ≤T≤250 °F)	99	99.5	99.5
018	Fabric filter – low temperature (<180 °F)	99	99.5	99.5

[a] Data from Table B.2-3 in Appendix B-2 of AP-42 (U.S. EPA, 1996) representing an average of actual efficiencies. Efficiencies are representative of well designed and well operated control equipment. Site-specific factors (e. g., type of particulate being collected, varying pressure drops across scrubbers, maintenance of equipment, etc.) will affect collection efficiencies. Efficiencies shown are intended to provide guidance for estimating control equipment performance when source-specific data are not available

[b] These factors are not in Table B.2-3 in Appendix B-2 of AP-42 (U.S. EPA, 1996) , but are recommended values considering the default venturi scrubber control efficiencies.

Table B-3. Comparison of AP-42 PM Emission Factors for Melting Furnace Operations

Emission category	PM-FIL emissions factor, lb/ton	PM_{10}-FIL emissions factor, lb/ton	$PM_{2.5}$-FIL emissions factor, lb/ton
Cupolas uncontrolled (U.S. EPA, 2003)	13.8	12.4	11.6
Cupolas controlled by baghouse (U.S. EPA, 2003)	0.80	0.76	0.76
Cupolas controlled by baghouse (calculated [a])	0.12	0.12	0.12
Cupolas controlled by venturi scrubber (U.S. EPA, 2003)	3.0	2.34	2.34
Cupolas controlled by venturi scrubber (calculated [a])	1.2	1.2	1.2

[a] Calculated from the uncontrolled emission factors reported in AP-42 (U.S. EPA, 2003) and the control efficiencies in Table B-2; assumes 100% control efficiency for PM greater the 10 µm in diameter.

It is clear that using the uncontrolled emission factors along with the control device collection efficiencies yield emission estimates that are much lower than those reported for controlled units in AP-42. However, the calculated emission factors are slightly higher that the emissions reported for controlled units from source test data collected in the foundries ICR. If the uncontrolled emission factor for uncontrolled cupolas recommended in the foundries BID (from the baghouse catch data) were used, the calculated controlled emissions for cupolas would further exceed those observed in the ICR test data. Therefore, the uncontrolled cupola emission factor from AP-42 of 13.8 lb/ton was selected as the recommended emission factor for uncontrolled cupolas.

PM distribution data were available for cupola and electric arc furnace (EAF) melting furnaces. A single distribution for melting furnaces were developed from these distributions, based on the average of the relative fraction of PM that is less than 10 µm and the fraction less than 2.5 µm. Table 12.10.9 of the Gray Iron Foundry section (12.10) of AP-42 indicates that PM_{10} emissions account for 90% of the uncontrolled cupola furnace PM emissions; it also indicates that PM_{10} emissions account for 90% of the uncontrolled EAF PM emissions. Table 12.10.9 of the Gray Iron Foundry section (12.10) of AP-42 indicates that $PM_{2.5}$ is 84.0 percent for uncontrolled cupolas and 61.6 percent (interpolated between 2.0 µm and 5.0 µm size distribution) for uncontrolled EAF. Therefore, the average distribution was determined to be 90% for PM_{10} emissions and 70% for $PM_{2.5}$. This average distribution was applied for all furnace types because it provided better agreement between the ICR test data results and the calculated emission factors by particle size.

Due to the variability of PM emission factors for cupolas with venturi scrubbers, separate venturi scrubber control efficiencies were recommended for venturi scrubbers operating at pressure drops exceeding 30 inches of water and venturi scrubbers operating at pressure drops less than 30 inches of water using the default venturi scrubber control efficiencies as a guide. **Table B-4** shows the revised PM emission factors for uncontrolled cupolas based on 70% of the PM being less than 2.5 µm and the separate PM control efficiencies for venturi scrubbers. As seen in Table B-4, the calculated emission factors for baghouses did not change appreciably. The combination of change in particle size and control efficiencies yields an average emission factor for high-energy venturi scrubbers to agree well with the ICR test average, while the lower-energy wet scrubber factor agrees well with the lower performing wet scrubbers from the ICR test data and agrees reasonably well with the cupola venturi scrubber emission factor in AP-42. Together, these observations were used to provide the emission factors and methodologies recommended in the Protocol document for cupola melting furnaces.

Table B-4. Recommended PM Emission Factors for Melting Furnace Operations

Emission category	PM-FIL emissions factor, lb/ton	PM_{10}-FIL emissions factor, lb/ton	$PM_{2.5}$-FIL emissions factor, lb/ton
Cupolas uncontrolled (recommended in Protocol)	13.8	12.4	9.7
Cupolas controlled by baghouse (calculated [a])	0.11	0.11	0.10
Cupolas controlled by venturi scrubber ΔP>30” (calculated [a])	0.60	0.60	0.58
Cupolas controlled by venturi scrubber ΔP≤30” (calculated [a])	1.44	1.44	1.39

[a] Calculated from the recommended uncontrolled emission factors and the control efficiencies in Table B-2; assumes 100% control efficiency for PM greater the 10 µm in diameter.

Development of PM Filterable Emission Factors for Other Melting Furnaces

The emission factors for uncontrolled EAF melting as presented in Table B-1are fairly consistent. It is not always clear if the reported melting emission factors cover all phases of the EAF melting process, including charging and tapping. As charging and tapping emissions may have different levels of capture and control than the melting cycle, separate emission factors were desired for these processes. Emission factors for charging and tapping (1.8 lbs/ton) are available from the EAF BID (U.S. EPA, 1983). It is not always clear if the baghouse catch data or the AP-42 emission factors include charging and tapping emissions, but the EAF emissions factor from these data averaged 11 lb/ton. The AP-42 emission factors for EAFs were 12.7 and 13 lb/ton for iron foundries and steel foundries, respectively (U.S. EPA, 2003 and 1995). Based on these data, a single emission factor of 12.8 lb/ton for all EAF, regardless of the foundry type, appears reasonable. The AP-42 foundry emission factors do not indicate a charging/tapping emission factor for EAF melting furnaces; however, the sum of the emission factor for charging and tapping and for uncontrolled EAF melting from the baghouse catch data is essentially equal to the emission factors reported in AP-42 (1.8 lb/ton + 11 lb/ton = 12.8 lb/ton). As such, this Protocol document recommends the use of 1.8 lb/ton for EAF charging and tapping and 11 lb/ton for direct melting. Combined, these emission factors represent the total emissions from and uncontrolled EAF and are consistent with the overall emissions from an EAF as suggested by the AP-42 emission factors. .

While there is significant variability in the emissions data for electric induction furnaces (EIF), the more recent source test data and baghouse catch data suggest that the AP-42 emission factor for EIF developed from Shaw (1982) is too low. Consequently, the baghouse catch data from the ICR was used to estimate the overall filterable PM emissions from EIF as 2 lb/ton. Because charging and tapping emissions may have different controls than during the primiary melting cycle, separate charging and tapping emissions factors were desired, but none were directly available. While the charging and tapping emissions for EIF may be expected to be similar to that for EAF, the overall emission factors reported for EIF are often less than the EAF charging and tapping emission factor. Again, it is not always clear what steps of the melting cycle are included in the baghouse catch data or emissions test data. A 1 lb/ton emission factor split was considered for each process (1 lb/ton for charging and tapping and 1 lb/ton for melting) based on the average emission factor from Shaw (1982), assuming this represented the pure melting cycle only, and the average emission factor from the baghouse catch data, assuming this represented the total melting, charging, and tapping emissions. However, when considering the relative duration of these different cycles, a 1 to 1 split of emissions was expected to understate the relative magnitude of the melting emissions compared to the charging and tapping emissions. Unfortunately, no data are available to specifically determine the appropriate proportion between EIF charging and tapping emissions and EIF melting emissions. When considering the cycle times, a 0.5 lb/ton emission factor for EIF charging/tapping and a 1.5 lb/ton emission factor for EIF melting was recommended for use in the Protocol.

Reverberatory furnaces are not that prevalent for iron and steel foundries, and there are limited data for these furnaces. The emission factor of 2.1 lb/ton for an uncontrolled reverberatory furnace from Table 12.10-3 of the Gray Iron Foundry Section (12.10) of AP-42 was used.

As discussed previously, PM distribution data were available for cupola and EAF melting furnaces. A single distribution for melting furnaces were developed from these distributions, based on the average of the relative fraction of PM that is less than 10 µm and the fraction less than 2.5 µm. Table 12.10.9 of the Gray Iron Foundry section (12.10) of AP-42 indicates that PM_{10} emissions account for 90% of the uncontrolled cupola furnace PM emissions; it also indicates that PM_{10} emissions account for 90% of the uncontrolled EAF PM emissions. Table 12.10.9 of the Gray Iron Foundry section (12.10) of AP-42 indicates that $PM_{2.5}$ is 84.0 percent for uncontrolled cupolas and 61.6 percent (interpolated between 2.0 µm and 5.0 µm size distribution) for uncontrolled EAF. Therefore, the average distribution was determined to be 90% for PM_{10} emissions and 70% for $PM_{2.5}$. This proportional distribution was applied to all types of melting furnaces and all cycles of the melting cycle, including charging/tapping and melting emissions.

Development of PM Condensable Emission Factors for Melting Furnaces

For each melt furnace, use an emission factor of 0.05 lb/ton for PM-CON. The emission factor 0.05 was derived from PM condensable data collected from the Foundry Information Collection Request. **Table B-5** summarizes the available PM-CON data used to develop the PM-CON emission factor for melting furnaces in the protocol document. The cupola baghouse operated by WI-35 was a special low-temperature, high efficiency, horizontal baghouse that set the new source "MACT floor" for cupolas and is not expected to be indicative of typical emissions from cupolas. Excluding this data point, the average PM-CON emission factor for cupola would be 0.04 lb/ton. Given the variability in the emissions for different units and the limited data set for some types of units, a single emission factor of 0.05 lb/ton averaged across all of the data is recommended for all melting furnaces.

Table B-5. Summary of PM Condensable Data for Melting Furnaces

Docket Item*	ICR Return ID	Test	Control Type	Average PM-CON lb/ton
Cupola				
II-D-82	WI-35	Avg of 3 tests	Baghouse	0.00343
II-D-46	IA-19	Feb-98	Baghouse	0.0614
II-D-65	NC-05	Feb-00	Baghouse	0.0184
		AVG	Baghouse	0.028
Electric Induction Furnace				
II-D-56	MN-07	Aug-96	Baghouse	0.053
II-D-57	MN-12	Mar-95	Baghouse	0.0633
II-D-57	MN-12	May-96	Baghouse	0.0203
II-D-75	TX-11	Oct-93	Baghouse	0.086
		AVG	Baghouse	0.056
Electric Arc Furnace				
II-D-44	IA-09	Aug-96	Baghouse	0.044
II-D-76	TX-19	Jan-95	Baghouse	0.14
II-D-55	MN-03	May-93	Baghouse	0.019
		AVG	Baghouse	0.067
Average Emission Factor for Melting Furnaces				0.05

*Docket No.: EPA-HQ-OAR-2002-0034

For emissions from charging and tapping use the emission factor of 0.01 lb/ton for PM-CON. The emission factor 0.01 was derived considering the average proportion of PM filterable emissions for charging/tapping versus melting as developed for EAF and EIF furnaces.

Development of Metal HAP Emission Factors for Melting Furnaces

Default metal HAP concentrations for emitted PM were determined based on data collected during the foundries ICR. For facilities that performed a multi-metals emission determination concurrent with a PM emissions determination, the metals mass emission rate was divided by the PM mass emissions rate to determine a metals concentration for the emitted PM. **Table B-6** provides a summary of the metal HAP emissions as a percent of filterable PM emissions determined from the ICR source tests. These average concentrations were used as the primary source for the filterable PM metal HAP concentrations.

Tables B-7 and B-8 provides a summary of the PM emission source test conducted by the EPA. During these tests, metal concentration and PM emissions were determined before and after the control device. These data were used to assess the concentration of non-PM associated HAP emissions. Metal fumes that remain gaseous are expected to pass through the PM control device (particularly high-temperature baghouses) as are condensable PM. The additional uncondensed metal HAP emissions needed to yield the measured outlet pollutant emissions were determined and used to determine a metal HAP content for condensable PM. For example, in the GM source test, the outlet emission rate for manganese was 0.13 lb/hr greater than would be predicted based on the PM-FIL control efficiency. The PM-CON emission rate is estimated to be 2.1 lbs/hr (using the default PM-CON factor of 0.05 and the site specific melting rate). Therefore, for this test, it appears that manganese comprises approximately 6 percent (0.13/2.1) of the PM-CON. Although there are very limited data by which to assess the metal HAP content of PM-CON emissions, it is important to consider these emissions, particularly for mercury and other volatile metals.

Table B-6. Summary of Metal HAP Emissions as a Percent of Filterable PM Emissions

Docket Item*	Furnace Type	% Pb	% Mn	% Cd	% Cr	%Ni	%Hg	% Other
II-I-27	Cupola - BH	1.99%	1.73%	0.12%				
II-I-20	EAF		8.64%			0.69%		
Charlotte Pipe	Cupola BH	0.26%	1.08%		0.06%	0.01%		0.004%
II-I-49	Cupola BH	2.04%		0.06%	0.06%	0.09%	0.57%	
II-I-24	Cupola BH	2.35%						
II-I-30	Cupola	0.12%	6.20%	0.001%	0.02%	0.01%		0.03%
II-D-114	EAF		0.22%		0.07%			
II-D-100	Cupola Gray Iron	0.36%		0.01%	0.13%	0.51%		0.19%
II-D-100	Cupola Nodular	0.19%		0.01%	0.11%	0.26%		0.12%
II-D-50	Cupola	0.21%	1.76%					0.01%
II-A-32	Cupola WS	1.10%	7.28%	0.001%	0.08%	0.01%	0.04%	0.01%
II-A-30	Cupola BH	1.03%	0.59%	0.14%	0.09%	0.06%	1.49%	0.10%
II-D-60	Cupola	3.98%		0.12%	0.02%		0.08%	
II-D-80	Cupola 1991		1.28%		0.03%	0.004%		
II-D-80	Cupola 1994	0.06%	2.08%		0.02%	0.03%		
AL-11	EAF	0.11%	2.68%	0.02%	0.29%	0.74%	0.14%	0.01%
MI-13	Cupola WS	0.29%	2.18%					
IN-12	Cupola WS	1.62%	3.33%	0.93%	0.03%	0.01%		0.01%
IN-12	Preheater cyclone	0.70%	1.35%		0.20%	0.51%		
IN-12	EIF	0.25%	0.74%					
OH-11	Cupola WS	2.20%						
II-I-63	Pouring	0.42%	2.01%	0.01%	0.01%		0.28%	1.78%
	Average	1.01%	2.70%	0.13%	0.08%	0.23%	0.43%	0.23%

*Docket No.: EPA-HQ-OAR-2002-0034

Table B-7. Summary of Metal HAP Emissions Measured during EPA Source Test: Cupola Baghouse Waupaca, IN (U.S. EPA, 1999a)

Pollutant	Emission Rate (lbs/hr)				% of PM
	Run 1	Run 2	Run 3	Average	
Emissions prior to Baghouse Control					
PM	143	471	353	322	N/A
Antimony	0.0377	0.0611	0.0555	0.0515	0.02
Arsenic	0.0083	0.0109	0.0135	0.0109	0.003
Barium	0.0625	0.1254	0.1076	0.0985	0.03
Beryllium	0.0001	0.0007	0.0004	0.0004	0.0001
Cadmium	0.0608	0.1656	0.1295	0.1186	0.04
Chromium	0.0548	0.1071	0.0878	0.0833	0.03
Cobalt	0.0015	0.0019	0.0020	0.0018	0.001
Lead	3.5108	8.7429	6.3628	6.2055	1.92
Manganese	3.6702	9.1579	7.1378	6.6553	2.06
Mercury	0.0021	0.0082	0.0026	0.0043	0.001
Nickel	0.0137	0.0197	0.0215	0.0183	0.01
Phosphorus	0.0804	0.1204	2.6324	0.9444	0.29
Selenium	0.0032	0.0056	0.0050	0.0046	0.001
Silver	0.0006	0.0024	0.0009	0.0013	0.0004
Thallium	0.0031	0.0073	0.0057	0.0054	0.002
Zinc	16.9502	48.8963	33.3442	33.0636	10.25
Emissions after Baghouse Control					
PM	0.71	ME	0.45	0.58	N/A
Antimony	0.0003	0.0003	0.0003	0.0003	0.05
Arsenic	0.00004	0.0001	0.0001	0.0001	0.01
Barium	0.0030	0.0031	0.0033	0.0033	0.56
Beryllium	ND	ND	ND	ND	ND
Cadmium	0.0017	0.0001	0.0005	0.0010	0.17
Chromium	0.0005	0.0005	0.0006	0.0006	0.10
Cobalt	ND	ND	ND	ND	ND
Lead	0.0096	0.0028	0.0056	0.0068	1.17
Manganese	0.0020	0.0029	0.0053	0.0033	0.57
Mercury	0.0121	0.0086	0.0054	0.0096	1.65
Nickel	0.0004	0.0003	0.0004	0.0004	0.06
Phosphorus	0.0048	0.0046	0.0041	0.0047	0.81
Selenium	0.0002	0.0003	0.0003	0.0003	0.05
Silver	0.00002	0.00002	0.0001	0.00004	0.01
Thallium	ND	ND	ND	ND	ND
Zinc	0.0083	0.0135	0.0368	0.0187	3.20

Table B-8. Summary of Metal HAP Emissions Measured during EPA Source Test: Cupola Wet Scrubber at General Motors Corporation (U.S. EPA, 1999b)

Pollutant	Emission Rate (lbs/hr)					% of PM
	Run 1	Run 2	Run 3	Run 4	Average	
Emissions prior to Wet Scrubber Control						
PM	139	169	186	215	177	N/A
Antimony	0.008	0.003	0.015	0.018	0.011	0.01
Arsenic	0.004	0.005	0.005	0.006	0.005	0.00
Barium	0.041	0.070	0.052	0.070	0.058	0.03
Beryllium	ND	0.00015	ND	ND	0.0002	0.00
Cadmium	0.011	0.015	0.016	0.013	0.014	0.01
Chromium	0.063	0.065	0.054	0.051	0.058	0.03
Cobalt	0.003	0.003	0.002	0.002	0.003	0.001
Lead	1.281	0.840	1.740	1.800	1.415	0.80
Manganese	8.210	9.160	7.550	8.090	8.253	4.66
Mercury	0.001	0.001	0.007	0.001	0.003	0.001
Nickel	0.004	0.003	0.003	0.002	0.003	0.002
Phosphorus	0.055	0.355	0.234	0.230	0.218	0.12
Selenium	0.003	0.004	0.003	0.003	0.003	0.002
Silver	0.001	0.002	0.002	0.001	0.002	0.001
Thallium	0.004	0.004	0.003	0.004	0.004	0.002
Zinc	10.340	10.470	13.570	17.500	12.970	7.32
Emissions after Wet Scrubber Control						
PM	8.08	7.61	1.71	1.71	4.78	N/A
Antimony	1.2E-03	7.2E-04	6.1E-04	5.6E-04	7.8E-04	0.02
Arsenic	6.4E-04	3.3E-04	ND	ND	4.9E-04	0.01
Barium	5.8E-03	5.0E-03	2.4E-03	1.6E-03	3.7E-03	0.08
Beryllium	3.7E-05	3.0E-05	ND	ND	3.3E-05	0.00
Cadmium	9.3E-04	1.1E-03	2.6E-04	1.4E-04	6.1E-04	0.01
Chromium	6.9E-03	4.9E-03	1.8E-03	1.3E-03	3.7E-03	0.08
Cobalt	ND	2.8E-04	1.4E-04	ND	2.1E-04	0.004
Lead	9.0E-02	7.6E-02	3.0E-02	1.5E-02	5.3E-02	1.10
Manganese	7.0E-01	5.2E-01	1.0E-01	7.0E-02	3.5E-01	7.28
Mercury	1.1E-03	1.0E-03	3.6E-03	1.2E-03	1.7E-03	0.04
Nickel	1.1E-03	5.8E-04	4.2E-04	ND	6.9E-04	0.01
Phosphorus	3.4E-02	3.1E-03	6.4E-03	4.0E-03	1.2E-02	0.25
Selenium	6.8E-04	4.4E-04	3.3E-04	3.4E-04	4.5E-04	0.01
Silver	5.5E-04	3.8E-04	1.4E-04	1.2E-04	3.0E-04	0.01
Thallium	4.7E-04	2.5E-04	8.1E-05	1.0E-04	2.2E-04	0.005
Zinc	7.3E-01	6.1E-01	1.8E-01	1.7E-01	4.2E-01	8.82

Development of Chromium Hexavalent Distribution of Total Chromium

To determine the distribution of chromium hexavalent emissions the values reported in Exhibit D-1 of "An Overview of Methods for EPA's National-Scale Air Toxics Assessment" for Standard Classification Codes from Iron and Steel melting operations were used (U.S. EPA, 2011). For melting furnaces from iron foundries the percent chromium hexavalent emissions of total chromium emissions was reported as 3 percent. For steel foundries the percent chromium hexavalent emissions of total chromium emissions was reported as 12 percent. For all other operations at iron and steel foundries the percent of chromium hexavalent emissions of total chromium emissions was reported as 3 percent. **Table B-9** summarizes the percent chromium hexavalent of total chromium emissions for the applicable SCC codes for iron and steel foundries from Exhibit D-1.

Table B-9. Percent Cr (VI) of Total Chromium Emissions for Iron and Steel Foundry SCC

Type of Foundry	Source	SCC	% Cr (VI)
Iron	Cupola	3-04-003-01	3
Iron	Reverberatory	3-04-003-02	not in table
Iron	EIF	3-04-003-03	3
Iron	EAF	3-04-003-04	3
Iron	Scrap and Charge handling, heating	3-04-003-15	3
Iron	Pouring, Cooling	3-04-003-18	3
Iron	core making baking	3-04-003-19	not in table
Iron	Magnesium treatment	3-04-003-21	not in table
Iron	Refining	3-04-003-22	3
Iron	Shakeout	3-04-003-31	3
Iron	Cleaning and finishing	3-04-003-40	3
Iron	sand handling	3-04-003-50	3
Steel	EIF	3-04-007-05	12
Steel	EAF	3-04-007-01	12
Steel	Pouring and casting	3-04-007-08	3
Steel	Sand grinding/handling in mold and core making	3-04-007-06	3
Steel	Core ovens	3-04-007-07	not in table
Steel	Casting cleaning	3-04-007-11	3
Steel	Charge handling	3-04-007-12	3
Steel	Casting cooling	3-04-007-13	3
Steel	Open hearth	3-04-007-02	not in table
Steel	Open hearth oxygen lanced	3-04-007-03	not in table

Development of Mercury Emission Factors

Automobile scrap has more potential for mercury emissions because of the mercury switches contained in old cars. There are other sources of mercury in scrap metals, but mercury from switches found in automobile scrap has the most potential for mercury emissions. If a facility is using automobile scrap, they should use the upper emission factor for mercury found in Table 3-6 of the Protocol document. Facilities not using automobile scrap should use the lower emission factor value for mercury from Table 3-6 of the Protocol document.

Development of SO_2 Emission Factors

Source test data for SO_2 emissions from cupola melting furnaces were compiled as part of the impact analyses conducted to support MACT standards for iron and steel foundries. **Table B-10** summarizes the available source test data for SO_2 emissions from cupola melting furnaces. While the SO_2 emissions are expected to vary based on the quantity and sulfur content of the coke used, these data were not generally known for these tests. Nonetheless, the test data presented in Table B-10 are more recent and are better documented than the emission factors reported in AP-42 (U.S. EPA, 2003). Therefore, the average emission factors from these source tests are recommended for use (as presented in Table 3-5 of the Protocol document) rather than the emission factors (dependent on sulfur content) presented in AP-42 (U.S. EPA, 2003).

Table B-10. Summary of SO2 Emissions for Cupola Melting Furnaces (SCC 30400301)

Plant - cupolas with baghouses[a]	SO_2 (lb/ton)
US Pipe (NJ-03) 1991 - [II-D-58]	0.059
US Pipe (NJ-03) 1997 [II-D-58]	0.072
Waupaca Tell City (IN-34) 1997 [II-D-41]	0.11
Waupaca Plant 1 (WI-01)1998 [G. Mosher e-mail]	0.115
Grede Reedsburg (WI-35) 1998 [II-D-117]	0.18
Charlotte Pipe (NC-05) 2000 [II-I-70]	0.23
Grede Reedsburg (WI-35) 2000 [II-I-73]	0.32
Average	**0.155**
Standard Deviation	**0.094**

Plant - cupolas with wet scrubbers[a]	SO_2 (lb/ton)
Atlantic States (NJ-04) [II-D-59]	0.0006
CMI Cast Parts (MI-13) 1997 [II-D-49]	<0.0015
Briggs & Stratton (WI-24) [II-D-80]	0.0015
Griffin Pipe (NJ-05) 1997 [II-D-60]	0.002
Waupaca Plant 2/3 (WI-42) 1995 [II-D-83]	0.0023
Waupaca Plant 1 (WI-01) 1998 [G. Mosher e-mail]	0.006
Waupaca Plant 2/3 (WI-42) 1997 [II-D-83]	0.0097
Great Lakes Casting (MI-17) 1996 [II-D-50]	<0.011
Waupaca Plant 2/3 (WI-42) 1994 [II-D-83]	0.011
Charlotte Pipe (NC-05) 1994 [II-D-61]	0.015
Waupaca (WI-01) 1994 [II-D-78]	<0.02
LaGrange Foundry (MO-05) 1993 [II-D-100]	0.026
Wrightsville (PA-34) 1995 [Survey response for No. 688]	0.061
GM Saginaw (MI-33) 1995 [II-D-54]	0.12
Average	**0.019**
Standard Deviation	**0.033**

[a] Items available in Docket No. EPA-HQ-OAR-2002-0034

References

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U.S. EPA (1999a). *Iron and steel foundries manual emissions testing of cupola baghouse at Waupaca Foundry in Tell City, Indiana.* Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA-454/R-99-017A and EPA-454/R-99-017B. June.

U.S. EPA (1999b). *Iron and steel foundries manual emissions testing of cupola wet scrubber at General Motors Corp., Saginaw, Michigan.* Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA-454/R-99-025A and EPA-454/R-99-025B. July.

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U.S. EPA (2003). *Compilation of air pollutant emission factors. Volume 1: Stationary point and area sources. Section 12.10 Gray iron foundries*. AP-42, Fifth Edition. Office of Air Quality Planning and Standards, Research Triangle Park, NC.

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Appendix C:
Development of Emission Factors for Section 4 Mold and Core Making

Table 4-2 of this Protocol document provides emission factors for specific chemicals contained within specific binder system components. Table 4-3 provides typical composition of these binder system components, as well as typical chemical use rates per ton of sand. Together, these data provide a means to determine default emission factors for each binder system. The general equation to calculate the default emission factor is as follows:

$$\mathrm{EmF_i} = \sum_{c=1}^{N} \left(\mathrm{Q_c} \times \mathrm{C_{i,c}} \times \frac{\%\mathrm{emitted_{i,c}}}{100\%} \right)$$

where:

$\mathrm{EmF_i}$ = Emission factor for pollutant “i” in a given binder system (lb/ton sand)
$\mathrm{Q_c}$ = Chemical use rate for component “c” of the binder system from **Table C-1** (lbs/ton sand)
$\mathrm{C_{i,c}}$ = Concentration of pollutant “i” in component “c” of the binder system from Table 4-3 (weight fraction)
$\%\mathrm{emitted_{i,c}}$ = percent of pollutant “i” in component “c” of the binder system emitted to the atmosphere (see Table 4-2).

Typical chemical use rates were summarized in Appendix B of the Iron and Steel Foundries BID (U.S. EPA, 2002). The binder use rates used in the development of the default emission factors are provided in **Table C-1**, along with the typical concentration and percent emitted as presented in Section 3 of the Foundries Protocol. Table C-1 shows the calculated chemical and component specific emission factors. For most chemicals, the emission factors calculated in Table C-1 were rounded and presented directly in Table 4-4 of the Protocol. For a few binder systems, a given pollutant is present in more than one binder component. For example, methanol is used in both the resin and catalyst for furan nobake binder systems. The overall emission factor for methanol for furan nobake is the emission factor for the resin (0.252 lb/ton sand) plus the emission factor for the catalyst (0.972 lb/ton sand) or 0.252 + 0.972 = 1.224 lb/ton sand. Therefore, the default emission factor for methanol from furan nobake is provided as 1.22 lb/ton sand in Table 4-4 of the Protocol.

Table C-1. Calculation of Default Emission Factors

Binder system	Component	(A) Component Use Rate (lb/ton sand)	HAP	(B) Typical Concen-tration (wt%)	(C) Percent emitted (wt%)	D=A×B×C Emission Factor (lb/ton sand)
Alkyd oil	Co-reactant	13.5	Methylene phenylene isocyanate	80	0.001	0.000108
	Resin	16.5	Cobalt	ND	0	0
	Resin	16.5	Lead	ND	0	0
Acrylic/Epoxy/ SO_2	Resin	34	Cumene hydroperoxide	ND	0.3	0
	Resin	34	Cumene	5	1.5	0.0255
Furan hotbox	Resin	40	Formaldehyde	3	5	0.06
Furan nobake	Resin	16.8	Phenol	1	0.2	0.000336

Binder system	Component	(A) Component Use Rate (lb/ton sand)	HAP	(B) Typical Concentration (wt%)	(C) Percent emitted (wt%)	D=A×B×C Emission Factor (lb/ton sand)
	Resin	16.8	Formaldehyde	0.1	2	0.000336
	Resin	16.8	Methanol	3	50	0.252
	Catalyst	7.2	Methanol	27	50	0.972
	Catalyst	7.2	Sulfuric acid	ND	0	0
Furan/SO_2	Resin	16.5	Formaldehyde	2	2	0.0066
	Resin	16.5	Methanol	2	50	0.165
	Oxidizer	13.5	Dimethyl phthalate	45	50	3.0375
	Oxidizer	13.5	Methyl ethyl ketone	2	50	0.135
Furan warmbox	Resin	25.6	Formaldehyde	0.5	5	0.0064
	Catalyst	6.4	Methanol	50	100	3.2
Phenolic baking	Part I	30	Phenol	8	0.5	0.012
	Part I	30	Formaldehyde	1	5	0.015
Phenolic ester nobake	Resin	33	Formaldehyde	0.5	2	0.0033
	Resin	33	Phenol	4	0.2	0.00264
Phenolic ester coldbox	Resin	32	Formaldehyde	0.5	2	0.0032
	Resin	32	Phenol	4	0.2	0.00256
	Resin	32	Glycol ethers	0.1	50	0.016
	Co-reactant	3	Methanol	27	50	0.405
Phenolic CO_2 cure	Resin	30	Diethylene glycol butyl ether (112-34-5)	1	0.5	0.0015
	Resin	30	Ethylene glycol monophenyl ether (122-99-6)	1	0.5	0.0015
Phenolic hotbox	Resin	30	Formaldehyde,	2	5	0.03
	Resin	30	Phenol	5	0.5	0.0075
Phenolic nobake (acid catalyzed)	Resin	18.4	Phenol	12	0.2	0.004416
	Resin	18.4	Formaldehyde	0.5	2	0.00184
	Resin	18.4	Methanol	3	50	0.276
	Acid	8.6	Methanol	27	50	1.161
	Acid	8.6	Sulfuric acid	ND	0	0
Phenolic Novolac flake (hot coating operations)	Resin	50	Phenol	5.5	0.5	0.01375
Phenolic Novolac liquid (warm-coating operations)	Part I	50	Phenol	2	20	0.2
	Part I	50	Formaldehyde	0.5	5	0.0125
	Part I	50	Methanol	5	100	2.5
Phenolic Novolac flake (resin-coated	Resin	50	Phenol	5.5	0.1	0.00275
	Catalyst	10	Ammonia, catalyst (*Assume ammonia =	40*	50	2

Binder system	Component	(A) Component Use Rate (lb/ton sand)	HAP	(B) Typical Concen-tration (wt%)	(C) Percent emitted (wt%)	D=A×B×C Emission Factor (lb/ton sand)
sand)			40% of hexamethylenetetramine)			
Phenolic urethane nobake	Part I	13.75	Formaldehyde	0.1	2	0.000275
	Part I	13.75	Phenol	6	0.2	0.00165
	Part I	13.75	Xylene I	0.1	16	0.0022
	Part I	13.75	Cumene	0.5	16	0.011
	Part I	13.75	Naphthalene	1	16	0.022
	Part I	13.75	1,2,4-Trimethylbenzene		16	0
	Part II	11.25	Methylene phenylene isocyanate	80	0.001	0.00009
	Part II	11.25	Xylene	0.1	16	0.0018
	Part II	11.25	Cumene	0.1	16	0.0018
	Part II	11.25	Naphthalene	1	16	0.018
	Part II	11.25	1,2,4-Trimethylbenzene	0	16	0
Phenolic urethane coldbox	Part I	16.5	Formaldehyde	0.1	2	0.00033
	Part I	16.5	Phenol	6	0.2	0.00198
	Part I	16.5	Xylene	0.1	9	0.001485
	Part I	16.5	Naphthalene	1	9	0.01485
	Part I	16.5	Cumene	0.5	9	0.007425
	Part I	16.5	1,2,4-Trimethylbenzene	0	9	0
	Part II	13.5	Methylene phenylene isocyanate	80	0.001	0.000108
	Part II	13.5	Xylene	0.1	9	0.001215
	Part II	13.5	Naphthalene	1	9	0.01215
	Part II	13.5	Cumene	0.1	9	0.001215
	Part II	13.5	Biphenyl	0.1	9	0.001215
	Catalyst	3	Triethyl amine or diethyl amine (uncontrolled)	100	100	3.0
Urea formaldehyde	Part I	30	Formaldehyde	1	2	0.006

References

U.S. EPA (2002). *National Emission Standards for Hazardous Air Pollutants for iron and steel foundries—Background information for proposed standards*. Office of Air Quality Planning and Standards, Research Triangle Park, NC.

Appendix D: Development of Emission Factors for Pouring, Cooling, and Shakeout

Development of Organic Emission Factors for PCS Operations

The organic emission factors for pouring, cooling and shakeout (PCS) were developed primarily based on data developed for the Casting Emission Reduction Program (CERP); most of these reports were prepared by Technikon LLC. Initial testing results for the pre-production foundry are summarized in **Table D-1**.

Table D-1. Summary of Baseline Emission Results from Pre-production Foundry[a]

Analyte	Emission Factor (lb/ton metal)			
	Background Baseline	Greensand Baseline	Core Baseline	Greensand / Core Baseline
Sum of VOCs	0.0312	0.4722	0.4708	0.8324
Sum of HAPs	0.0249	0.3160	0.3161	0.5424
Benzene	0.0061	0.1244	0.1389	0.2202
Toluene	0.0031	0.0836	0.0324	0.1059
Xylene (Total)	0.0026	0.0620	0.0163	0.0790
Ethylbenzene	0.0005	0.0099	0.0015	0.0115
Naphthalene	0.0011	0.0153	0.0226	0.0113
1-Methylnaphthalene	0.0002	0.0029	0.0052	0.0036
2-Methylnaphthalene	0.0005	0.0055	0.0115	0.0075
Acetaldehyde	0.0087	0.0077	0.0060	0.0096
Formaldehyde	0.0017	0.0015	0.0008	0.0027
Phenol	BDL	0.0046	0.0137	0.0026
o -Cresol	BDL	0.0022	0.0052	0.0047
Aniline	NT	NT	0.0917	0.0533
Hexane	0.0005	0.0210	0.0011	0.0181
Styrene	BDL	0.0024	0.0016	0.0053

[a] As reported in by CERP (1999b).

Note that "Sum of VOCs" were the sum of individual analytes and, depending on the analytes tested, may or may not be a complete measure of all VOC. CERP also performed "baseline" emission testing at their production foundry and at a foundry in Mexico. These facilities were greensand foundries with chemically-bonded cores. The Mexico study (CERP, 1999a) used primarily phenolic hot box cores, while the CERP production foundry used phenolic urethane cold box cores. **Table D-2** summarizes the test data from these three studies. The Mexico study focused on HAPs and did not analyze for or report data for as many non-HAP VOCs as compared to the CERP production foundry test. It is unclear exactly why the HAP emissions from the Mexico study are lower than the CERP production foundry; it is expected to be a combination of casting size and complexity, poorer capture in the real-world foundry, and differences in emission potential for the different core systems. Nevertheless, the benzene and total HAP emissions from the CERP production foundry agrees well with the benzene and total HAP emissions from the CERP pre-production foundry, indicating that the pre-production foundry results provide a reasonable assessment of the emissions resulting during full foundry production.

Table D-2. Summary of Baseline Emission Results from Production Foundry

Analyte	**Emission Factor (lb/ton metal)**		
	CERP, 1999b	**CERP, 2000**	**Technikon, 2001a**
Sum of VOCs	NR	0.6768	0.735
Sum of HAPs	0.318	0.4882	0.643
Benzene	0.0639	0.2255	0.251
Toluene	0.0421	0.0715	0.065
Xylene (Total)	0.0298	0.0460	0.035
Ethylbenzene	0.0049	0.0097	0.0064
Naphthalene	0.0110	0.0365	0.021
1-Methylnaphthalene	0.0044	0.0161	0.0095
2-Methylnaphthalene	0.0063	0.0253	0.0189
Acetaldehyde	0.0613	0.0051	0.0052
Formaldehyde	0.0276	0.0018	0.0029
Phenol	0.0338	0.0554	0.060
o –Cresol	0.0149	0.0114	0.026
Aniline	BDL	NT	0.073
N,N-Dimethylaniline	NT	NT	0.042
Hexane	NT	0.0120	0.016
Styrene	0.0053	0.0079	0.0034

NR – not reported
NT – not tested
BDL – below detection limit

CERP evaluated various chemically bonded cores systems in their pre-production foundry. These cores were made using mold sand without any organic additives (similar to the core baseline tests). **Table D-3** summarizes the results of these studies.

Table D-3. Summary of Core Binder System Studies in the Pre-production Foundry

Analyte	**Emission Factor (lb/ton metal)**	
	FB-FC 1409-125-117public.pdf (Technikon 2000)	**CM 1256 11 GSA 3 Ashland Core Binder Repalcement.pdf (Technikon, 2003)**
Sum of VOCs	0.4274	0.3962
Total HAPs	0.386	0.368
Benzene	0.142	0.0955
Toluene	0.039	0.0201
Xylene (Total)	0.021	0.0063
Ethylbenzene	0.0030	0.0011
Naphthalene	0.0142	0.0068
1-Methylnaphthalene	0.0071	0.0023
2-Methylnaphthalene	0.0124	0.0041

Analyte	Emission Factor (lb/ton metal)	
	FB-FC 1409-125-117public.pdf (Technikon 2000)	CM 1256 11 GSA 3 Ashland Core Binder Repalcement.pdf (Technikon, 2003)
Acetaldehyde	0.0027	0.0065
Formaldehyde	0.0006	0.0015
Phenol	0.097	0.1022
o,m,p-Cresol	0.0223	0.0348
Aniline	0.0273	0.0521
N,N-Dimethylaniline	BDL	0.0121
Hexane	0.004	0.0066
Styrene	0.0053	0.0010

NR – not reported
NT – not tested
BDL – below detection limit

CERP also evaluated various chemically bonded mold systems in their pre-production foundry. These castings did not have cores. **Table D-4** summarizes the results of these studies.

Table D-4. Summary of Chemically Bonded Mold Sand Studies in the Pre-production Foundry

Analyte	Emission Factor (lb/ton metal)				
	DG1211- Phenolic Urethane No-Bake (Technikon, 2001b)	FP 1410 -113 Phenolic Urethane No-Bake (Technikon, 2004)	DP 1256-112 Phenolic Urethane No-Bake (Technikon, 2001d)	DX 1256-1115 Furan No Bake (Technikon, 2001f)	DZ 1256-1116 Ester-Cured Phenolic No Bake (Technikon, 2001g)
Sum of VOCs	4.06	1.852	1.73	1.1	0.901
Total HAP	1.797	1.470	1.123	1.059	0.807
Benzene	0.299	0.2487	0.229	0.818	0.318
Toluene	0.056	0.0519	0.045	0.106	0.054
Xylene (Total)	0.031	0.035	0.0285	0.0078	0.032
Ethylbenzene	0.0061	0.0035	0.0045	0.0017	0.0019
Naphthalene	BDL	0.0138	BDL	0.0035	0.015
1-Methylnaphthalene	0.0065	0.0030	0.0035	BDL	0.046
2-Methylnaphthalene	0.012	0.0058	0.0061	0.0027	0.004
Acetaldehyde	0.0041	0.0062	0.0069	0.066	0.069
Formaldehyde	0.0205	0.0221	0.0187	0.025	0.084
Propionaldehyde	0.0007	0.0046	0.0027	0.0012	0.017
Phenol	0.942	0.4965	0.718	0.044	0.121
o,m,p-Cresol	0.500	0.6154	0.058	BDL	0.047
Aniline	0.0185	BDL	0.011	BDL	NT
N,N-Dimethylaniline	Invalid	BDL	BDL	BDL	NT
Hexane	0.0003	0.0004	0.0026	BDL	BDL
Styrene	0.0143	0.0106	0.0122	BDL	0.0008

BDL – below detection limit
NT – not tested
Invalid – data rejected due to validation considerations

Looking at the baseline pre-production foundry results, it appears that the greensand plus core system emissions are approximately equal to the baseline greensand emissions and the baseline core emissions. This observation led to a simple additive correlation considering mold and core emissions separately. In a summary report (CERP/Technikon, 2006), strong correlations were identified for greensand mold systems between the emissions of benzene and the casting weight (at constant surface area to volume ratios), casting surface area at constant pour weights, and combustible level (loss on ignition equating to seacoal level). As the emission factors are provided on a per mass of metal basis, the variability with casting weight is already incorporated in the emission estimation methodology. There was inadequate information by which to develop a correction factor for surface area; however, the benzene emissions appeared to be directly related to the percent loss on ignition (%LOI). The baseline greensand studies used molds with a %LOI of 5.1%, so a simple correction factor "greensand correction factor" was incorporated into the calculation methodology based on baseline emissions factors. Consequently, the following equation is recommended for estimating organic emissions from PCS operations.

$$E_i = Q_{MS}\left[\left(MS_{VOC} \times C_{i,MS}\right) \times GSCF + \left(CS_{VOC} \times C_{i,CS}\right)\right]/2{,}000$$

Eqn D-1

where:

E_i = Emission of pollutant "i" (tons/yr).
Q_{MS} = Quantity of metal poured into a given type of mold system, tons/yr.
MS_{VOC} = VOC emission factor for the mold system used, lb VOC/ton metal poured (from Table 5-2).
CS_{VOC} = VOC emission factor for the cores used, lb VOC/ton metal poured (from Table 5-2).
$C_{i,MS}$ = Concentration profile of pollutant "i" in emissions from mold system used, lb pollutant/lb VOC (from Table 5-3).
$C_{i,CS}$ = Concentration profile of pollutant "i" in emissions for core system used, lb pollutant/lb VOC (from Table 5-3).
GSCF = Green sand correction factor, unitless; for green sand systems, GSCF = percent LOI/5.1 percent; for all other types of mold systems, GSCF = 1.
%LOI = Percent of green sand lost on ignition, weight percent using ASTM D7348 or similar methods .
2,000 = Conversion factor, lbs/ton.

For foundries that operate several different types of mold systems, Equation D-1 should be applied separately for each type of mold system. The total PCS emissions for the facility would then be the sum of the emissions for each type of mold system. The default emissions factors for Equation D-1 were developed from the data presented in Tables D-1 through D-4. The greensand baseline results in Table D-1 were used directly for the greensand mold system VOC emission factor. The median value for the phenolic urethane no-bake mold systems was selected for phenolic urethane bonded mold sand (FP Test in Table D-4) and the average VOC emission factor from the furan no-bake and ester-cured phenolic no-bake (Tests DX and DZ in Table D-4) were used for the "other chemically bonded mold sand" VOC emission factor. The VOC emission factor for chemically bonded cores was selected based on the data presented in Table D-3 with consideration that the sum of MS_{VOC} and CS_{VOC} would approximately equal the baseline emissions for greensand with chemically bonded cores in the baseline pre-production foundry (in Table D-1). The background baseline (Table D-1) was used as the default VOC emission factor for permanent mold, centrifugal, and investment casting systems. Finally, the HAP emission factors for PCS from expendable pattern casting (EPC) of iron as presented by Twarog (1991) suggest a total HAP emission factor of approximately 1.0 lb/ton. Based on the ratio of VOC to HAP emissions for the PCS emissions presented in Tables D-1 through D-4, a default VOC emission factor of 1.2 lb/ton was determined. The summary of recommended VOC emission factors for Equation D-1 is presented in **Table D-5**.

Table D-5. VOC Emission Factors by Casting Type for PCS Operations[a,b]

Type of Mold/Core System	Factor Designation	VOC Emission Factor, (lb/ton metal poured)
Green Sand	MS_{VOC}	0.47[a]
Phenolic Urethane Bonded Mold Sand	MS_{VOC}	1.85[b]
Other Chemically Bonded Mold Sand	MS_{VOC}	1.0[b]
Chemically Bonded Cores (all)	CS_{VOC}	0.4[a]
Mold systems without cores	CS_{VOC}	0
Expendable Pattern Casting (Lost Foam)	MS_{VOC}	1.2[c]
Permanent, Centrifugal, or Investment Casting	MS_{VOC}	0.03[d]

[a] Developed from CERP baseline testing (CERP, 1999b and 2000; Technikon 2000, 2001a, 2003).
[b] Developed from CERP testing of chemically bonded mold systems (Technikon, 2001b, 2001d, 2001f, 2001g, 2004).
[c] Based on data reported by Twarog (1991).
[d] Developed from CERP “background baseline” (CERP, 1999b).

In a similar fashion, default chemical composition of the emitted VOC was determined for each of these mold systems. For each test presented in Tables D-1 through D-4, a ratio of the specific analyte’s emission factor to the VOC emission factor was calculated. The greensand baseline results in Table D-1 were used directly for the greensand mold system composition profile. The compositional profile for the “other chemically bonded mold sand” systems was significantly different for the composition profile for phenolic urethane no-bake systems. An average composition profile was developed for the phenolic urethane no-bake molds (based on Tests DG, FP, and DP) and a separate composition profile was developed for other chemically bonded molds (using Tests DX and DZ).

The composition profile for cores was determined by taking the average composition for the test summarized in Table D-2 and the composition for the baseline core test in Table D-1. The emission factors predicted using these profiles and the default VOC factors were then compared to the emission factors for greensand/core baseline emissions from Table D-1 and D-2 (excluding the Mexico data). Application of the default VOC emission factors and composition profiles yielded combined greensand/core emissions that were in excellent agreement for nearly all compounds. Based on this comparison, the average proportion of phenol from core systems was adjusted down to 0.10 (rather than 0.14) to improve the overall prediction when applying Equation D-1 to estimate emissions from greensand/core systems.

The background baseline (Table D-1) was again used as the default composition profile for permanent mold, centrifugal, and investment casting systems. Finally, the compositional profile for iron EPC was determined based on the data presented by Twarog (1991). The iron casting emission factors were only provided for a limited number of compounds (6 analytes, with measurable emissions for styrene, benzene, and toluene). The concentrations of these compounds was selected so that the concentration times the VOC emission factor yield the emission factor reported by Twarog for these three compounds. Other data reported by Twarog indicate that naphthalene and other polycyclic organic matter (POM) is likely to be emitted, but no direct study of POM emissions was conducted for iron castings (only aluminum castings). As naphthalene and other POM tend to be ubiquitous pyrolysis products, 1 percent of the VOC emissions from EPC was projected to be naphthalene and 1 percent was projected to be “other POM.” The summary of recommended compositional profiles are provided in **Table D-6**.

Table D-6. Default HAP Composition Profiles for PCS Operations

	Concentration Ratio, lb HAP per lb VOC					
HAP Compound	**Green Sand Molds**[a]	**Phenolic Urethane Bonded Molds**[b]	**Other Chemically Bonded Molds**[b]	**Cores**[a]	**Expendable Pattern Casting**[c]	**Permanent, Centrifugal, or Investment**[d]
Acetaldehyde	0.02	0.003	0.07	0.01		0.28
Aniline	0.03	0.005		0.14		
Benzene	0.26	0.11	0.55	0.29	0.28	0.20
Cresols (total)	0.006	0.16	0.05	0.04		
N,N-Dimethylaniline	0.01			0.03		
Ethylbenzene	0.02	0.002	0.002	0.004		0.02
Formaldehyde	0.003	0.01	0.06	0.002		0.05
Hexane	0.04			0.008		
Naphthalene	0.03	0.007	0.01	0.03	0.01	0.04
Other POM[e]	0.04	0.01	0.05	0.06	0.01	0.02
Phenol	0.03	0.31	0.09	0.10		0.01
Propianaldehyde		0.001	0.01			
Styrene	0.005	0.005	0.001	0.005	0.48	
Toluene	0.18	0.02	0.08	0.07	0.09	0.1
Xylenes (total)	0.13	0.01	0.02	0.03		0.08

[a] Developed from CERP baseline testing (CERP, 1999b, 2000; Technikon, 2000, 2001a, 2003).

[b] Developed from CERP testing of chemically bonded mold systems (Technikon, 2001b, 2001d, 2001f, 2001g, 2004).

[c] Based on data reported by Twarog (1991).

[d] Developed from CERP “background baseline” (CERP, 1999b).

[e] POM other than naphthalene, predominately methylnaphthalenes and dimethylnaphthalenes.

Development of PM Emission Factors for PCS Operations

For the captured, uncontrolled PM-FIL emission factors for pouring, cooling, and shakeout operations from Table 5-4 in the Protocol document, the emission factors were adapted from the Uncontrolled component PM emission factor, lb/ton metal melted from Table 5-6 of the Iron and Steel Foundry BID (U.S. EPA, 2002). **Table D-7** summarizes the Uncontrolled PM emission factors from Table 5-6 of the Iron and Steel Foundry BID.

Table D-7. PM Emission Factors for PCS Lines

PCS Component	Uncontrolled component PM emission factor, lb/ton metal melted
Pouring	0.0873
Cooling	0.29
Shakeout	79.3

For the captured, uncontrolled PM_{10}-FIL and $PM_{2.5}$-FIL emission factors for pouring, cooling, and shakeout operations from Table 5-4 in the Protocol document, the size distributions presented in Section 12.13 Steel Foundries: Casting Shakeout of Appendix B.1 Particle Size Distribution Data and Sized Emission Factors for Selected Sources of AP-42 were used to calculate the emission factors (U.S. EPA, 1986). **Table D-8** summarizes the size distributions for PCS operations from the AP-42 Appendix B.1. The captured, uncontrolled PM_{10}-FIL emission factor was calculated by multiplying the captured, uncontrolled PM-FIL emission factor for each operation by the size distribution for PM_{10}, 82.0%. The captured, uncontrolled $PM_{2.5}$-FIL emission factor was calculated by multiplying the captured, uncontrolled PM-FIL emission factor for each operation by the size distribution for $PM_{2.5}$, 72.2%.

Table D-8. Size Distributions for PCS Operations

Aerodynamic particle, diameter, µm	Cumulative wt. % < stated size, Uncontrolled
2.5	72.2
6.0	76.3
10.0	82.0

For the captured, uncontrolled PM-CON emission factors for pouring, cooling, and shakeout operations from Table 5-4 in the Protocol document, several tests conducted by Technikon for the Casting Emission Reduction Program (CERP) were used. The available PM-CON lb/ton values reported in the test reports were compiled. The average of the PM-CON lb/ton values from all the tests was calculated. **Table D-9** summarized the PM-CON lb/ton values reported from the Technikon test reports used in calculating the PM-CON emission factor.

Table D-9. Size Distributions for PCS Operations

Technikon Source	2001c	2001e	2001a	2001b	2001d	2001f	2001g
PCS Combined PM-CON lb/ton	0.2324	1.17	1.47	0.8	0.916	2.28	0.448
Average PM-CON lb/ton	1.0						

To determine the distribution of PM-CON emissions between pouring and cooling used the same distribution as in PM-FIL emission factors for PM-CON emission factors, 23 percent for pouring and 77 percent for cooling. For Shakeout PM-CON emissions, assumed that PM-CON emissions would be zero.

Development of HAP Content of PM for PCS Operations

For the metal HAP percent of PM-FIL from Table 5-5 of the Protocol document, the metal HAP and PM data were used from a Casting Emission Reduction Program (CERP) testing program of a foundry in Mexico (CERP, 1999a). **Table D-10** summarizes the metal HAP and PM emission factors reported in the test report. Calculated the percent metal HAP of PM for each of the reported metal HAPs.

Table D-10 HAP Metal and PM Emission Factors from CERP Foundry Mexico Baseline Testing

Analyte	Pouring (lb/ ton metal poured)	Cooling (lb/ton metal poured)	Shakeout (lb/ton metal poured)	Totals (lb/ton metal poured)
Antimony	Non-detect	1.03E-05	2.53E-06	1.29E-05
Arsenic	1.91E-06	Non-detect	Non-detect	1.91E-06
Cadmium	4.55E-06	2.03E-05	1.67E-05	4.16E-05
Chromium	4.85E-05	2.31E-04	1.71E-04	4.51E-04
Cobalt	7.39E-04	5.33E-05	8.62E-05	8.78E-04
Lead	1.79E-04	2.22E-04	7.29E-04	4.74E-04
Manganese	8.37E-04	5.21E-04	3.39E-04	1.70E-03
Nickel	1.16E-04	1.92E-04	3.13E-04	6.20E-04
Selenium	Non-detect	4.10E-06	Non-detect	4.10E-06
Total PM	0.042	0.11	0.12	0.26

To determine the distribution of chromium hexavalent emissions the values reported in Exhibit D-1 of “An Overview of Methods for EPA’s National-Scale Air Toxics Assessment” for Standard Classification Codes from Iron and Steel pouring, cooling, and shakeout operations were used, 3 percent (U.S. EPA, 2011). **Table D-11** summarizes the percent chromium hexavalent of total chromium emissions for the applicable SCC codes for iron and steel foundries from Exhibit D-1.

Exhibit D-11. Chromium Speciation Table Used for the 2005 NATA

Type of Foundry	Source	SCC	% Cr (VI)
Iron	Cupola	3-04-003-01	3
Iron	Reverberatory	3-04-003-02	not in table
Iron	EIF	3-04-003-03	3
Iron	EAF	3-04-003-04	3
Iron	Scrap and Charge handling, heating	3-04-003-15	3
Iron	Pouring, Cooling	3-04-003-18	3
Iron	core making baking	3-04-003-19	not in table
Iron	Magnesium treatment	3-04-003-21	not in table
Iron	Refining	3-04-003-22	3
Iron	Shakeout	3-04-003-31	3

Type of Foundry	Source	SCC	% Cr (VI)
Iron	Cleaning and finishing	3-04-003-40	3
Iron	sand handling	3-04-003-50	3
Steel	EIF	3-04-007-05	12
Steel	EAF	3-04-007-01	12
Steel	Pouring and casting	3-04-007-08	3
Steel	Sand grinding/handling in mold and core making	3-04-007-06	3
Steel	Core ovens	3-04-007-07	not in table
Steel	Casting cleaning	3-04-007-11	3
Steel	Charge handling	3-04-007-12	3
Steel	Casting cooling	3-04-007-13	3
Steel	Open hearth	3-04-007-02	not in table
Steel	Open hearth oxygen lanced	3-04-007-03	not in table

Development of CO Emission Factor for PCS Operations Table 5-6

To determine the carbon monoxide emission factor for PCS operations in Table 5-6 of the Protocol document used several tests conducted by Technikon for CERP. The reported CO lb/ton values were compiled. The average of the compiled lb/ton values was calculated. The majority of the CO emissions reported were from chemically bonded molds, there was a lack of CO data from the other mold types. **Table D-12** summarizes the Technikon carbon monoxide data used to develop the CO emission factor.

Table D-12. Summary of CO Emission Factors for PCS Operations[a]

Technikon Source	2001b	2004	2001d	2001f	2001g
PCS Total CO lb/ton	4.18	0.0796	4.11	5.99	4.32
Average CO lb/ton	3.7				

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Appendix E:
Development of Emission Factors for Finishing Operations

Development of PM-FIL Captured, Uncontrolled Emission Factors for Finishing Operations

In the development of the PM-FIL emission factors for Cutting, Grinding, and Shotblasting, captured and uncontrolled found in Table 6-2 of the Protocol document (designated with footnote a), PM data that was collected from the Foundry Information Collection Request (ICR) was used. The PM lb/ton data for cutoff, grinding, and shotblasting process units that were tested separately were used. Data that came from more than one process unit ducted together was not used. The data that had a collection period of less than twenty hours of testing was not used in the calculations. The median emission factor for each operation was calculated, and rounded to the nearest whole number. **Table E-1** summarizes the data from the Foundry ICR used to calculate emission factors.

Table E-1. PM Data from Foundry ICR

Facility ID	Operation	Collection period, hours	Emission factor, lb/ton
358	Cutoff	5,814	3.53
358	Cutoff	5,814	3.53
159	Cutoff	2,080	5.08
227	Cutoff	64	5.47
358	Cutoff	5,814	6.67
358	Cutoff	5800	8.60
358	Cutoff	4,845	9.00
619	Cutoff	3,840	20.3
462	Grinding	2,838	1.02
519	Grinding	2,670	3.82
230	Grinding	40	4.44
389	Grinding	6,000	4.67
14	Grinding	2,000	6.15
818	Grinding	8,760	12.6
818	Grinding	8,760	12.6
529	Grinding	120	14.3
159	Grinding	2,080	15.6
140	Grinding	2,080	16.8
365	Grinding	1,353	21.0
72	Grinding	5,000	21.9
385	Grinding	5,856	23.8
363	Grinding	40	28.6
760	Grinding	80	30.8
262	Grinding	150	45.0

Facility ID	Operation	Collection period, hours	Emission factor, lb/ton
270	Grinding	1,200	72.7
110	Grinding	40	250
232	Shotblast	22	57.1
184	Shotblast	24	13.6
213	Shotblast	434	32.8
16	Shotblast	24	2.14
16	Shotblast	24	15.6
16	Shotblast	24	4.66
542	Shotblast	2,000	1.95
567	Shotblast	1,920	9.26
413	Shotblast	20	15.3
760	Shotblast	40	15.4
76	Shotblast	120	22.5
23	Shotblast	2,652	25.4
363	Shotblast	40	28.6
818	Shotblast	8,760	33.7
682	Shotblast	80	62.5
389	Shotblast	6,000	82.3
433	Shotblast	160	1.56
433	Shotblast	320	1.67
519	Shotblast	2,670	2.52
608	Shotblast	4,500	6.92
519	Shotblast	2,670	9.21
818	Shotblast	8,760	16.9
14	Shotblast	30	26.7
140	Shotblast	2,080	39.4
645	Shotblast	80	42.9
110	Shotblast	40	62.5
534	Shotblast	40	83.9
262	Shotblast	150	2.50
207	Shotblast	24	5.00
257	Shotblast	80	41.8
184	Shotblast	24	133
72	Shotblast	5,000	4.48
72	Shotblast	5,000	8.38
Cutoff Median Emission Factor Value			6.0
Grinding Median Emission Factor Value			16.0
Shotblast Median Emission Factor Value			16.0

Development of PM_{10}-FIL and $PM_{2.5}$-FIL Captured, Uncontrolled Emission Factors for Finishing Operations

Table 12.10-9 of Section 12.10 of AP-42 (U.S. EPA, 2003) lists the particle size distributions for $PM_{2.5}$ and PM_{10} for different foundry operations. The table does not include particle size distributions for finishing operations. The particle size distributions for pouring, cooling operations at foundries were as a starting point in estimating particle size distributions for finishing operations. **Table E-2** summarizes the size distribution values from Table 12.10-9 and the values used to calculate the PM_{10}-FIL and $PM_{2.5}$-FIL emission factors in Table 6-2 of the Protocol document. The size distribution ratio for PM_{10} and $PM_{2.5}$ was applied to each PM-FIL captured, uncontrolled value for Cutting, Grinding, and Shot blasting to calculate the PM_{10}-FIL and $PM_{2.5}$-FIL emission factors for each emission source.

Table E-2. Size Distribution of PM10-FIL and PM2.5-FIL for PCS Operations

Source	Particle Size (µm)	Table 12.10-9. Particle Size Distribution Data and Emission Factors for Gray Iron Foundries from Section 12.10 of AP-42 Cumulative Mass % ≤ Stated Size	Size Distribution Ratio Used
Pouring, cooling Uncontrolled	2.5	24.0	20
	10.0	49.0	50

Development of PM Uncaptured, Uncontrolled Emission Factors for Finishing Operations

Table 12.10-7 of Section 12.10 of AP-42 (U.S. EPA, 2003) shows that 0.1 PM lb/ton is emitted to the atmosphere from 17 PM lb/ton emissions from uncontrolled finishing operations at a foundry. Thus, approximately 99 percent of the finishing emissions are expected to remain (redeposit) within the foundry building and approximately 1 percent of the emission are projected to be released to the atmosphere. The uncaptured and uncontrolled PM-FIL values for each emission source in Table 6-2 of the Protocol document were calculated by multiplying the captured and uncontrolled PM-FIL value for each emission source by 1 percent.

For the PM_{10}-FIL and $PM_{2.5}$-FIL emission factors, it was assumed that 90 percent of the uncaptured PM-FIL is PM_{10}-FIL and 80 percent of the uncaptured PM-FIL is $PM_{2.5}$-FIL as smaller particles are more likely to escape to the atmosphere than be captured by a control device. The uncaptured and uncontrolled PM_{10}-FIL values for each emission source in Table 6-2 of the Protocol document were calculated by multiplying the uncaptured and uncontrolled PM-FIL value by 90 percent. The uncaptured and uncontrolled $PM_{2.5}$-FIL values for each emission source in Table 6-2 of the Protocol document were calculated by multiplying the uncaptured and uncontrolled PM-FIL value by 80 percent.

References

U.S. EPA (2003). *Compilation of air pollutant emission factors. Volume 1: Stationary point and area sources. Section 12.10: Gray iron foundries*. AP-42, Fifth Edition. Office of Air Quality Planning and Standards, Research Triangle Park, NC.

Appendix F:
Control Efficiency and Particulate Matter Size Distribution

To simplify the protocol document, the collection efficiencies for filterable particles size 2.5-6 and 6-10 µm were condensed down to be presented as the collection efficiencies for filterable particle size 2.5-10 µm. **Table F-1** provides the collection efficiency values as reported in AP-42. In general, the average collection efficiency for PM in the 2.5-10 µm range was determined as the arithmetic average of the collection efficiencies for the 2.5- 6 µm PM size range and the 6-10 µm PM size range.

Table F-1. Typical Collection Efficiencies of Various Particulate Control Devices[a] (%)

AIRS Code[b]	Type of Collector	Collection Efficiency			Average Collection Efficiency for PM 2.5–10 µm
		Filterable Particle Size (µm)			
		0–2.5	2.5–6	6–10	
001	Wet scrubber – hi-efficiency	90	95	99	97
002	Wet scrubber – med-efficiency	25	85	95	90
003	Wet scrubber – low-efficiency	20	80	90	85
004	Gravity collector – hi-efficiency	3.6	5	6	5
005	Gravity collector – med-efficiency	2.9	4	4.8	4
006	Gravity collector – low-efficiency	1.5	3.2	3.7	3.4
007	Centrifugal collector – hi-efficiency	80	95	95	95
008	Centrifugal collector – med-efficiency	50	75	85	80
009	Centrifugal collector – low-efficiency	10	35	50	42
010	Electrostatic precipitator – hi-efficiency	95	99	99.5	99
011	Electrostatic precipitator – med-efficiency	80	90	97	93
012	Electrostatic precipitator – low-efficiency	70	80	90	85
014	Mist eliminator – high velocity >250 FPM	10	75	90	92
015	Mist eliminator – low velocity <250 FPM	5	40	75	57
016	Fabric filter – high temperature (>250 °F)	99	99.5	99.5	99.5
017	Fabric filter – med temperature (180 °F ≤T≤250 °F)	99	99.5	99.5	99.5
018	Fabric filter – low temperature (<180 °F)	99	99.5	99.5	99.5
049	Liquid filtration system	50	75	85	80
050	Packed-gas absorption column	90	95	99	97
051	Tray-type gas absorption column	25	85	95	90
052	Spray tower	20	80	90	85
053	Venturi scrubber (ΔP > 30 inches of water)	95	98	99	98
053	Venturi scrubber (ΔP ≤ 30 inches of water)	88	94	99	96
054	Process enclosed	1.5	3.2	3.7	3.4
055	Impingement plate scrubber	25	95	99	97
056	Dynamic separator (dry)	90	95	99	97
057	Dynamic separator (wet)	50	75	85	80
058	Mat or panel filter – mist collector	92	94	97	95
059	Metal fabric filter screen	10	15	20	17
061	Dust suppression by water sprays	40	65	90	77

AIRS Code[b]	Type of Collector	Collection Efficiency Filterable Particle Size (µm) 0–2.5	2.5–6	6–10	Average Collection Efficiency for PM 2.5–10 µm
062	Dust suppression by chemical stabilizer or wetting agents	40	65	90	77
063	Gravel bed filter	0	5	80	42
064	Annular ring filter	80	90	97	93
071	Fluid bed dry scrubber	10	20	90	55
075	Single cyclone	10	35	50	42
076	Multiple cyclone w/o fly ash reinjection	80	95	95	95
077	Multiple cyclone w/fly ash reinjection	50	75	85	80
085	Wet cyclonic separator	50	75	85	80
086	Water curtain	10	45	90	67

[a] Data represent an average of actual efficiencies. Efficiencies are representative of well designed and well operated control equipment. Site-specific factors (e. g., type of particulate being collected, varying pressure drops across scrubbers, maintenance of equipment) will affect collection efficiencies. Efficiencies shown are intended to provide guidance for estimating control equipment performance when source-specific data are not available. Table derived from Table B.2-3 Typical Collection efficiencies of various particulate control devices of Appendix B.2 of AP-42, Volume I, Fifth Edition (U.S. EPA, 1996)

[b] Control codes in Aerometric Information Retrieval System (AIRS), formerly National Emissions Data Systems.

References

U.S. EPA (1996). *Compilation of air pollutant emission factors. Volume 1: Stationary point and area sources. Appendix B.2: Generalized Particle Size Distributions.* AP-42, Fifth Edition. Office of Air Quality Planning and Standards, Research Triangle Park, NC. September.

Appendix G:
List of Suggested SCC for Iron and Steel Foundry Operations

Table G-1. Iron and Steel Foundry SCC

Source Classification Code	SCC Level One	SCC Level Two	SCC Level Three	SCC Level Four
Suggested SCC for Iron Foundry Operations				
30400301	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Cupola
30400302	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Reverberatory Furnace
30400303	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Electric Induction Furnace
30400304	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Electric Arc Furnace
30400310	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Inoculation
30400314	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Scrap Metal Preheating
30400315	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Charge Handling
30400316	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Tapping
30400319	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Core Making, Baking
30400320	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Pouring/Casting
30400321	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Magnesium Treatment
30400322	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Refining
30400325	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Castings Cooling
30400331	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Casting Shakeout
30400340	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Grinding/Cleaning
30400350	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Sand Grinding/Handling
30400360	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Castings Finishing
30400370	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Shell Core Machine
30400371	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Core Machines/Other
2294000000	Mobile Sources	Paved Roads	All Paved Roads	Total: Fugitives
2296000000	Mobile Sources	Unpaved Roads	All Unpaved Roads	Total: Fugitives

Source Classification Code	SCC Level One	SCC Level Two	SCC Level Three	SCC Level Four
Other SCC for Iron Foundry Operations				
30400305	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Annealing Operation
30400317	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Pouring Ladle
30400318	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Pouring, Cooling
30400330	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Miscellaneous Casting-Fabricating **
30400332	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Casting Knock Out
30400333	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Shakeout Machine
30400341	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Casting Cleaning/Tumblers
30400342	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Casting Cleaning/Chippers
30400351	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Core Ovens
30400352	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Sand Grinding/Handling
30400353	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Core Ovens
30400354	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Core Ovens
30400355	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Sand Dryer
30400356	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Sand Silo
30400357	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Conveyors/Elevators
30400358	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Sand Screens
30400398	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Other Not Classified
30400399	Industrial Processes	Secondary Metal Production	Grey Iron Foundries	Other Not Classified
Suggested SCC for Steel Foundry Operations				
30400701	Industrial Processes	Secondary Metal Production	Steel Foundries	Electric Arc Furnace
30400705	Industrial Processes	Secondary Metal Production	Steel Foundries	Electric Induction Furnace
30400708	Industrial Processes	Secondary Metal Production	Steel Foundries	Pouring/Casting
30400709	Industrial Processes	Secondary Metal Production	Steel Foundries	Casting Shakeout
30400711	Industrial Processes	Secondary Metal Production	Steel Foundries	Cleaning
30400712	Industrial Processes	Secondary Metal Production	Steel Foundries	Charge Handling

Source Classification Code	SCC Level One	SCC Level Two	SCC Level Three	SCC Level Four
30400713	Industrial Processes	Secondary Metal Production	Steel Foundries	Castings Cooling
30400715	Industrial Processes	Secondary Metal Production	Steel Foundries	Finishing
30400716	Industrial Processes	Secondary Metal Production	Steel Foundries	Sand Grinding/Handling
30400730	Industrial Processes	Secondary Metal Production	Steel Foundries	Shell Core Machine
30400731	Industrial Processes	Secondary Metal Production	Steel Foundries	Core Machines/Other
30400741	Industrial Processes	Secondary Metal Production	Steel Foundries	Scrap Heating
30400765	Industrial Processes	Secondary Metal Production	Steel Foundries	Billet Cutting
30400768	Industrial Processes	Secondary Metal Production	Steel Foundries	Scrap Handling
30400770	Industrial Processes	Secondary Metal Production	Steel Foundries	Slag Storage Pile
2294000000	Mobile Sources	Paved Roads	All Paved Roads	Total: Fugitives
2296000000	Mobile Sources	Unpaved Roads	All Unpaved Roads	Total: Fugitives
Other SCC for Steel Foundry Operations				
30400702	Industrial Processes	Secondary Metal Production	Steel Foundries	Open Hearth Furnace
30400703	Industrial Processes	Secondary Metal Production	Steel Foundries	Open Hearth Furnace with Oxygen Lance
30400704	Industrial Processes	Secondary Metal Production	Steel Foundries	Heat Treating Furnace
30400706	Industrial Processes	Secondary Metal Production	Steel Foundries	Sand Grinding/Handling
30400707	Industrial Processes	Secondary Metal Production	Steel Foundries	Core Ovens
30400710	Industrial Processes	Secondary Metal Production	Steel Foundries	Casting Knock Out
30400714	Industrial Processes	Secondary Metal Production	Steel Foundries	Shakeout Machine
30400717	Industrial Processes	Secondary Metal Production	Steel Foundries	Core Ovens
30400718	Industrial Processes	Secondary Metal Production	Steel Foundries	Core Ovens
30400720	Industrial Processes	Secondary Metal Production	Steel Foundries	Sand Dryer
30400721	Industrial Processes	Secondary Metal Production	Steel Foundries	Sand Silo
30400722	Industrial Processes	Secondary Metal Production	Steel Foundries	Muller
30400723	Industrial Processes	Secondary Metal Production	Steel Foundries	Conveyors/Elevators
30400724	Industrial Processes	Secondary Metal Production	Steel Foundries	Sand Screens

Source Classification Code	SCC Level One	SCC Level Two	SCC Level Three	SCC Level Four
30400725	Industrial Processes	Secondary Metal Production	Steel Foundries	Casting Cleaning/Tumblers
30400726	Industrial Processes	Secondary Metal Production	Steel Foundries	Casting Cleaning/Chippers
30400732	Industrial Processes	Secondary Metal Production	Steel Foundries	Electric Arc Furnace: Baghouse
30400733	Industrial Processes	Secondary Metal Production	Steel Foundries	Electric Arc Furnace: Baghouse Dust Handling
30400735	Industrial Processes	Secondary Metal Production	Steel Foundries	Raw Material Unloading
30400736	Industrial Processes	Secondary Metal Production	Steel Foundries	Conveyors/Elevators: Raw Material
30400737	Industrial Processes	Secondary Metal Production	Steel Foundries	Raw Material Silo
30400739	Industrial Processes	Secondary Metal Production	Steel Foundries	Scrap Centrifugation
30400740	Industrial Processes	Secondary Metal Production	Steel Foundries	Reheating Furnace: Natural Gas
30400742	Industrial Processes	Secondary Metal Production	Steel Foundries	Crucible
30400743	Industrial Processes	Secondary Metal Production	Steel Foundries	Pneumatic Converter Furnace
30400744	Industrial Processes	Secondary Metal Production	Steel Foundries	Ladle
30400745	Industrial Processes	Secondary Metal Production	Steel Foundries	Fugitive Emissions: Furnace
30400760	Industrial Processes	Secondary Metal Production	Steel Foundries	Alloy Feeding
30400775	Industrial Processes	Secondary Metal Production	Steel Foundries	Slag Crushing
30400780	Industrial Processes	Secondary Metal Production	Steel Foundries	Limerock Handling
30400785	Industrial Processes	Secondary Metal Production	Steel Foundries	Roof Monitors - Hot Metal Transfer
30400799	Industrial Processes	Secondary Metal Production	Steel Foundries	Other Not Classified