

# Environmental, Health, and Safety Guidelines for Foundries

## Introduction

The Environmental, Health, and Safety (EHS) Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP)<sup>1</sup>. When one or more members of the World Bank Group are involved in a project, these EHS Guidelines are applied as required by their respective policies and standards. These industry sector EHS guidelines are designed to be used together with the **General EHS Guidelines** document, which provides guidance to users on common EHS issues potentially applicable to all industry sectors. For complex projects, use of multiple industry-sector guidelines may be necessary. A complete list of industry-sector guidelines can be found at: [www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines](http://www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines)

The EHS Guidelines contain the performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets, with an appropriate timetable for achieving them. The applicability of the EHS Guidelines should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-specific variables, such as host country context, assimilative capacity of the environment, and other project factors, are taken into account.

<sup>1</sup> Defined as the exercise of professional skill, diligence, prudence and foresight that would be reasonably expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally. The circumstances that skilled and experienced professionals may find when evaluating the range of pollution prevention and control techniques available to a project may include, but are not limited to, varying levels of environmental degradation and environmental assimilative capacity as well as varying levels of financial and technical feasibility.

The applicability of specific technical recommendations should be based on the professional opinion of qualified and experienced persons. When host country regulations differ from the levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent. If less stringent levels or measures than those provided in these EHS Guidelines are appropriate, in view of specific project circumstances, a full and detailed justification for any proposed alternatives is needed as part of the site-specific environmental assessment. This justification should demonstrate that the choice for any alternate performance levels is protective of human health and the environment.

## Applicability

The EHS Guidelines for Foundries include information relevant to foundry projects and facilities casting ferrous (iron and steel) and nonferrous (primarily aluminum, copper, zinc, lead, tin, nickel, magnesium, and titanium) metals. Nonferrous metals are cast in combinations with each other or in combination with more than forty other elements to make a wide range of nonferrous alloys. These guidelines address sand casting, including the preparation and regeneration of molding sand, and the high- and low-pressure die casting of aluminum, zinc, and magnesium. In addition to these processes, this document includes consideration of Disamatic (DISA) technology. It does not cover further processing of the semifinished products. This document is organized according to the following sections:

Section 1.0 — Industry-Specific Impacts and Management  
Section 2.0 — Performance Indicators and Monitoring  
Section 3.0 — References  
Annex A — General Description of Industry Activities

## 1.0 Industry-Specific Impacts and Management

The following section provides a summary of EHS issues associated with foundries, which occur during the operational phase, along with recommendations for their management. Recommendations for the management of EHS issues common to most large industrial facilities during the construction and decommissioning phases are provided in the **General EHS Guidelines**.

### 1.1 Environmental

Environmental issues associated with this sector primarily include the following:

- Air emissions
- Solid waste
- Wastewater
- Noise

#### Air Emissions

##### *Dust and Particulate Matter*

Dust and particulate matter are generated in each of the process steps with varying levels of mineral oxides, metals (mainly manganese and lead), and metal oxides. Dust emissions arise from thermal (e.g. melting furnaces) and chemical / physical processes (e.g. molding and core production), and mechanical actions (e.g. handling of raw materials, mainly sand, and shaking out and finishing processes).

Recommended prevention and control to reduce fugitive emissions of dust include the following:

- Use of pneumatic conveying systems, particularly for transferring and feeding additives into the process area;

- Use of enclosed conveyers with dust-controlled transfer points, especially when transferring sand into the molding shop;
- Clean return belts in the conveyor belt systems to remove loose dust;
- Use indoor or covered stockpiles or, when open-air stockpiles are unavoidable, use water spray system, dust suppressants, windbreaks, and other stockpile management techniques;
- Use of enclosed silos to store bulk powder materials;
- Implement routine plant maintenance and good housekeeping to keep small leaks and spills to a minimum.

In the melting process, particulate matter (PM) emissions in the form of dust, metallic materials, and metal oxide fumes, vary according to furnace type, fuel, metal to be melted and melting characteristics. Cupola furnaces produce the most significant amount of particulate matter (e.g. coke, fly ash, silica, rust and limestone). Electric arc furnaces (EAFs) are another significant source of PM during charging, at the beginning of melting, during oxygen injection, and during the decarburizing phases. Lower emission rates are associated with other melting furnaces types, particularly induction furnaces. Load-based emissions for metal melting range from insignificant values for certain nonferrous metals up to above 10 kilograms per ton (kg/ton) for melting of cast iron using a cupola furnace.<sup>2</sup>

Recommended pollution prevention techniques include the following:

- Use of induction furnaces, where possible;
- Use of open hearth furnaces is no longer considered good practice for steel smelting and should be avoided;

<sup>2</sup> European Commission. 2005. Integrated Pollution Prevention and Control (IPPC). BAT Techniques Reference (BREF) Document on the Smelting and Foundries Industry

- Avoid use of traditional cupola furnace technology. If cupola furnaces are used, enhanced technologies should be adopted to increase furnace energy efficiency and reduce the coke charge, including:
  - Use of oxygen injection or enrichment of blast air
  - Superheating of blast air in hot blast cupolas
  - Use of cokeless cupola where the metal charge is heated by the combustion of natural gas
- Implement technologies in melting furnaces which allow reduction of energy consumption (e.g. installation of oxyfuel burners, slag foaming practice in the EAFs, or oxygen injection when applicable);
- Installation of off-gas collection hoods for cupolas, canopy hood enclosures for electric arc furnaces (EAFs), and cover extraction for induction furnaces to reduce fugitive emissions. Installation of an appropriate furnace hooding system may facilitate the capture of up to 98 percent of the furnace dust;<sup>3</sup>
- Use of dust control technologies, typically including installation of bag filters and cyclones to control emissions from melting processes. Wet scrubbers may be used to capture water-soluble compounds (such as sulfur dioxide (SO<sub>2</sub>) and chlorides). The adoption of cyclones as pretreatments and use of bag filters typically enables emission levels of 10 mg/Nm<sup>3</sup> or less.<sup>4</sup>

The large amount of sand used in lost mold casting generates dust emissions during the various molding stages, and produces non-metallic particulates, metallic oxide particulates, and metallic iron. Non-metallic particulates are emitted from casting, shakeout and finishing processes.

Recommended prevention and control techniques for particulate matter arising from casting and molding include the following:

<sup>3</sup> EC BREF (2005)

<sup>4</sup> Ibid.

- Use dry dust collection technologies (e.g. bag filters and cyclones) instead of wet scrubbers, especially in green sand preparation plants. The dry techniques allow dust to be easily collected, transported, and recirculated into the sand mixing process, thus avoiding the creation of effluent from wet scrubbers;
- Use of filters on exhausts, especially in casting and finishing shops;
- Use of vacuum cleaning in moulding and casting shop;
- Install closed dedusting units in working areas.

### *Nitrogen Oxides*

Nitrogen oxides (NO<sub>x</sub>) emissions are caused by high furnace temperature and the oxidation of nitrogen. Techniques to prevent and control the generation of NO<sub>x</sub> are addressed in the **General EHS Guidelines**. Emission reduction can be achieved through primary process modification measures and secondary end-of-pipe abatement techniques. Pollution prevention and control techniques include the following:

- Minimize the air / fuel ratio in the combustion process;
- Use oxygen enrichment in the combustion process;
- Use low NO<sub>x</sub> burners in fuel firing furnaces, when possible;
- Install secondary controls (mainly for cupola furnaces, EAFs, and rotary furnaces) such as a catalytic incinerator, as necessary.<sup>5</sup>

### *Sulfur Oxides*

The presence of sulfur oxides (SO<sub>x</sub>) in waste gases from melting furnaces depends on the sulfur content of fuel and process coke. Sulfur dioxide (SO<sub>2</sub>) emissions are emitted from waste gases in cupola and rotary furnaces. Other emission sources include gas hardening processes in mold- and core-

<sup>5</sup> Ibid.

making with chemically bonded sand, and in magnesium (Mg) melting.

Recommended pollution prevention and control techniques to reduce SO<sub>2</sub> emissions include the following:

- Select feedstocks and scrap with low sulfur content;
- Use fuel with low sulfur content, such as natural gas;
- Install gas wet scrubbing systems before dry scrubbers as part of dedicated collecting and dedusting system.

### *Carbon Monoxide*

The most significant sources of carbon monoxide (CO) are off-gases from cupola furnaces and EAFs. The presence of CO in off-gases from cupola furnaces is due to the cupola process itself. In EAFs, CO is generated from the oxidation of the graphite electrodes and the carbon from the metal bath during the melting and refining phases. Carbon monoxide is also emitted when sand molds and cores come into contact with the molten metal during metal pouring activities.

The recommended pollution prevention and control techniques to reduce CO emissions include the following:

- Use of induction furnaces;
- Improve thermal efficiency of the process (e.g. adoption of oxygen injection or oxyfuel burners in cupola furnaces);
- Adopt foamy slag practice in EAF process;
- Install post combustion chamber in dedusting units of cupola and EAF off-gases;
- Encapsulate the metal pouring lines with fitted extractors.

### *Chlorides and Fluorides*

Chlorides and fluorides exist in small quantities in waste gases from melting furnaces and are generated from flux. Prevention and control of chloride and fluoride emissions should be

undertaken as part of dry dedusting or wet scrubbing techniques installed to control particulate matter and sulfur oxide emissions.

### *Volatile Organic Compounds (VOCs) and other hazardous air pollutants*

Emissions of VOCs, mainly consisting of solvents (e.g. BTEX – benzene, toluene, ethyl benzene, and xylenes) and other organics (e.g. phenols and formaldehyde) are primarily generated by the use of resins, organic solvents, or organic-based coatings in molding and core making. Organic hazardous air pollutant (HAP) emissions may also be released during the pouring, cooling, and shakeout of either green sand or no bake molds, resulting from the thermal decomposition of the organic compounds (carbonaceous additives contained in green sand molds and different core binders) during metal pouring.<sup>6</sup>

Cold-box systems using organic solvents may generate emissions of VOCs during core production and storage. Amines are the most significant emissions, and may pose a potential hazard due to their low odor detection thresholds and relatively low exposure value limit. Potential hazardous air pollutants are emitted when chemical binding systems are used during hardening, coating and drying, including formaldehyde, methylene diphenyl diisocyanate (MDI), isopropyl alcohol, phenol, amines (e.g. triethylamine), methanol, benzene, toluene, cresol / cresylic acid, naphthalene and other polycyclic organics, and cyanide compounds.

Recommended pollution prevention and control techniques for VOC and other hazardous air pollutant emissions include<sup>7</sup>:

- Minimize binder and resin use through optimization of process control and material handling in mixer operations and through temperature control;
- Optimize temperature control during core making;

<sup>6</sup> EC BREF (2005)

<sup>7</sup> Ibid.

- Replace alcohol-based coating (e.g. isopropyl alcohol) with water-based coating;
- Use non-aromatic solvents (e.g. vegetable oil methyl esters or silicate esters) in core box production;
- Minimize curing gas used for 'cold box binders'.
- Enclose molding or coring machines as well as temporary core storage areas;
- Use cold box systems (e.g. activated carbon adsorption, incineration, chemical scrubbing or biofiltration) to treat spent amines;
- Use of collection systems (e.g. canopy hoods) to capture VOC resulting from chemically-bonded sand preparation, in addition to pouring, cooling and shakeout. Use of adsorption to activated carbon, catalytic oxidation, or biofiltration treatment, as necessary.

#### *Dioxins and Furans*<sup>8</sup>

- Polychlorinated dibenzodioxin and dibenzofuran (dioxins and furans, or PCDD/F) emissions may be emitted during melting processes. In ferrous metal foundries, dioxins may be generated in cupola furnaces, EAFs, and rotary furnaces. PCDD/F may be produced if chloride ions, chlorinated compounds, organic carbon, catalysts, oxygen, and certain temperature levels exist simultaneously in the metallurgical process. The risk of dioxin formation in non-ferrous metal foundries is very low.

The primary techniques to prevent dioxin emissions in the melting phase is the post combustion of the furnace off-gas at a temperature above 1200°C, and maximizing the residence time at this temperature. The process is completed with a rapid quenching to minimize time in the dioxin reformation temperature window. Other recommended measures include:

- Use clean scrap for melting;

- Inject additive powders (e.g. activated carbons) into the gas stream to adsorb dioxins and remove dust by filtration in fabric filters;
- Install fabric filters with catalytic oxidation system incorporated.

#### *Metals*

Metal emissions should be controlled during the melting and casting processes. Metal emissions may be emitted through volatilization and condensation of metals during molten metal pouring into molds. Particulates in ferrous foundries may contain heavy metals, such as zinc (mainly if galvanized steel scrap is used), cadmium, lead (e.g. from painted scrap), nickel, and chromium (these last two in alloy steel casting production) depending on the steel grade being produced and scrap used.

Particulates associated with nonferrous metal production may contain copper, aluminum, lead, tin, and zinc. The presence of metal in particulate emissions can be especially significant during alloying activities and during the introduction of additives. For example, the addition of magnesium to molten metal to produce ductile iron may result in a reaction releasing magnesium oxides and metallic fumes.

High-efficiency dust abatement techniques (as discussed in the 'Dust and Particulate Matter' section of this Guideline) should be used for control of metal particulate emissions. Gaseous metal emissions should be controlled through the installation of dry and semi-dry scrubbers, in combination with dust abatement techniques.

#### *Greenhouse Gases (GHGs)*

The foundry process is energy intensive and a significant emitter of carbon dioxide (CO<sub>2</sub>), primarily associated with fuel combustion. Most energy use can be attributed to the melting process (40-60 percent of the total energy input). The melting energy input ranges from 500 to 1200 kilowatt hours per ton

<sup>8</sup> EC BREF (2005)

(kWh/t) metal charge for ferrous metals and from 400 to 1200 kWh/t metal charge for aluminum.

Recommended carbon dioxide (CO<sub>2</sub>) emission prevention and control techniques include the following<sup>9</sup>:

- Replace conventional cupola furnaces with induction, cokeless cupola, or oxygen injection cupola type furnaces. Use medium frequency power in induction furnaces;
- Limit energy consumption and increase energy efficiency through primary measures including, but not limited to:
  - Adequate surface insulation to limit heat dispersion;
  - Control of the correct air/fuel ratio reducing excess O<sub>2</sub>;
  - Implementation of heat recovery systems;
  - Use of waste gas thermal properties, through an appropriate heat exchanger, to produce hot water, hot air, and/or steam.
- Implement best available combustion technologies (e.g. oxygen enrichment of blast air, preheating the charge, and automatic control of combustion parameters);
- Implement equipment operation and maintenance practices, and avoid partial-loading of equipment;
- Preheat the scraps prior to use;
- Reduce fuel consumption in heating of ladles and molten metal thermal treatment by adopting recovery gas and / or combustion controls;
- Select fuel with a lower ratio of carbon content to calorific value (e.g. natural gas [CH<sub>4</sub>]). CO<sub>2</sub> emissions from the combustion of CH<sub>4</sub> are approximately 60 percent less than the emissions from coal or pet-coke.
- Additional information on the management of greenhouse gases is discussed in the **General EHS Guidelines**.

<sup>9</sup> Ibid.

## Solid Waste

Solid waste streams include sand waste, slag from desulfurization and from melting, dust collected within emissions control systems, refractory waste, and scrubber liquors and sludges (see 'Wastewater' section of this Guideline).

General techniques to manage the waste generated by foundries include the selection, design and construction of storage areas for metals, dust waste from filters, refractory waste, slag, and sand waste, with due consideration of site geological and hydrogeological conditions to prevent potential contamination from potential heavy metal leaching. Transfer points and chemical storage areas (e.g. for resins and binders) should be designed in order to minimize spill risks. Additional guidance on the management of solid and hazardous waste, and hazardous materials, is provided in the **General EHS Guidelines**.

### *Sand Waste*

Sand waste from foundries using sand molds is a significant waste by volume. Molding and core sand make up 65 to 80 percent of the total waste from ferrous foundries.<sup>10</sup> Sand that is chemically bound to make cores or shell molds is more difficult to reuse effectively and may be removed as waste after a single use. Sand wastes from brass and bronze foundries are often hazardous and should be disposed of accordingly.

Recommended prevention and control of sand waste includes the following<sup>11</sup>:

- Maximization of sand reuse within the facility;
  - External re-use of sand waste should be considered, (e.g. as concrete and paving materials, and for brick manufacturing, concrete backfill, and construction fill)

<sup>10</sup> US EPA Office of Compliance. 1998. Sector Note Book Project: Profile of the Metal Casting Industry

<sup>11</sup> Ibid.

- Green foundry sand should be reused once it is removed from the metal piece and regenerated. Sand recovery methods consist of primary (e.g. vibration, rotating drum or shot blasting) and secondary regeneration (e.g. processing of the sand to remove residual binders, as well as cold mechanical and thermal treatments, or wet scrubbing. Thermal treatment units are used to reclaim chemically bonded sand.)

### *Dust from Abatement Equipment*

Dust from emission control equipment may contain zinc, lead, nickel, cadmium, copper, aluminum, tin, chromium, and other metals, and may be classified as hazardous waste. Dust from emissions control equipment in non-ferrous foundries often contains sufficient levels of metals to make metal recovery economically feasible. Filter dust should be recirculated in the furnaces, to the extent possible. This allows metal recovery through dust reprocessing, and therefore minimizing waste to landfills.

### *Slag Wastes*

Slag waste often has a complex chemical composition and contains a variety of contaminants from the scrap metals. It may constitute about 25 percent of the solid waste stream from a foundry. Common slag components include metal oxides, melted refractories, sand, and coke ash (if coke is used). Fluxes may also be added to help remove the slag from the furnace. Slag may be hazardous if it contains lead, cadmium, or chromium from steel or nonferrous metals melting.<sup>12</sup>

Recommended prevention and control of slag waste includes the following:

- Slag production should be minimized through process optimization measures including:
  - Sorting of scrap improves metal quality and reduces the potential for emissions and generation of contaminated slag. Scrap from electronic products, painted scrap, and scrap from used vehicles are potential sources of contamination and should be carefully screened and sorted
  - Lower metal melting temperatures
  - Optimizing use of fluxes and refractory lining
- Slag should be reused, and valuable metals should be extracted. Reuse options may, depending on slag characteristics, include block making, road-base construction, and as coarse aggregate.

### *Sludge Treatment*

Sludge from wastewater treatment may contain heavy metals (e.g. chromium, lead, zinc, and nickel) and oil and grease. A small part of the sludge from wastewater treatment can be internally recycled, however the vast majority of it is landfilled. Metal leaching potential is significant and should be evaluated in relation to establishing reuse potential, and with regard to use of landfill linings and controls. Sludge reuse may require a pre-treatment stage, which typically consists of pressing, drying, and granulation activities. Recommended management of hazardous sludge is provided in the **General EHS Guidelines**.

### *Decommissioning Waste*

Industry-specific environmental issues generated during decommissioning include handling and disposal of insulation materials containing asbestos and soil / groundwater contamination from areas such as the coal and raw materials storage stockpiles. Impacts should be prevented through application of sound environmental practices as described in these Guidelines. For guidance on management of legacy

<sup>12</sup> US EPA Office of Compliance. 1998. Sector Note Book Project: Profile of the Metal Casting Industry

issues which may have resulted in surface and groundwater contamination, refer to the **General EHS Guidelines**.

## Wastewater

### *Industrial process wastewater*

The most significant use of water in foundries is in the cooling systems of electric furnaces (induction or arc), cupola furnaces, and in wet dedusting systems. In most foundries, water management involves an internal recirculation of water resulting in a minimal effluent volume. Use of wet dedusting techniques may increase water use and consequent disposal management. In core making, where scrubbers are used, the scrubbing solutions from cold-box and hot-box core-making contain biodegradable amines and phenols. In high-pressure die-casting, a wastewater stream is formed, which needs treatment to remove organic (e.g. phenol, oil) compounds before discharge. Wastewater containing metals and suspended solids may be generated if the mold is cooled with water. Wastewater with suspended and dissolved solids and low pH may also be generated if soluble salt cores are used. Wastewater may be generated by certain finishing operations such as quenching and deburring, and may contain high levels of oil and suspended solids.<sup>13</sup>

Recommended prevention techniques for effluent streams from foundries include the following:

- Install closed loops for cooling water to reduce water consumption and discharge;
- Recycle tumbling water by sedimentation or centrifuging followed by filtering;
- Store scrap and other materials (e.g. coal and coke) under cover and / or in bunded area to limit contamination of stormwater and facilitate drainage collection.

### *Process Wastewater Treatment*

Techniques for treating industrial process wastewater in this sector include source segregation and pretreatment of wastewater streams for reduction in heavy metals using chemical precipitation, coagulation and flocculation, etc. Typical wastewater treatment steps include: grease traps, skimmers or oil water separators for separation of oils and floatable solids; filtration for separation of filterable solids; flow and load equalization; sedimentation for suspended solids reduction using clarifiers; dewatering and disposal of residuals in designated hazardous waste landfills. Additional engineering controls may be required for (i) advanced metals removal using membrane filtration or other physical/chemical treatment technologies, (ii) removal of recalcitrant organics using activated carbon or advanced chemical oxidation, (iii) chemical or biological nutrient removal for reduction in nitrogen; and (iv) reduction in effluent toxicity using appropriate technology (such as reverse osmosis, ion exchange, activated carbon, etc.).

Management of industrial wastewater and examples of treatment approaches are discussed in the **General EHS Guidelines**. Through use of these technologies and good practice techniques for wastewater management, facilities should meet the Guideline Values for wastewater discharge as indicated in the relevant table of Section 2 of this industry sector document.

### *Other Wastewater Streams & Water Consumption*

Guidance on the management of non-contaminated wastewater from utility operations, non-contaminated stormwater, and sanitary sewage is provided in the **General EHS Guidelines**. Contaminated streams should be routed to the treatment system for industrial process wastewater. Recommendations to reduce water consumption, especially where it may be a limited natural resource, are provided in the **General EHS Guidelines**.

<sup>13</sup> US EPA Office of Compliance. 1998. Sector Note Book Project: Profile of the Metal Casting Industry

Stormwater from outdoor coal storage areas may become contaminated by highly acidic leachate containing polycyclic aromatic hydrocarbons (PAHs) and heavy metals. Industry-specific recommendations include:

- Pave process areas, segregate contaminated and non-contaminated stormwater, and implement spill control plans. Route stormwater from process areas into the wastewater treatment unit;
- Design leachate collection system and location of coal storage facilities to prevent impacts to soil and water resources. Coal stockpile areas should be paved to segregate potentially contaminated stormwater for pretreatment and treatment in the wastewater treatment unit.

## Noise

The foundry process generates noise from various sources, including scrap handling, furnace charging and EAF melting, fuel burners, shakeout and mould / core shooting, and transportation and ventilation systems. Recommended noise management techniques include the following:

- Enclose the process buildings and / or insulate them;
- Cover and enclose scrap storage and handling areas, as well as shake out and fettling processes;
- Enclose fans, insulate ventilation pipes and use dampers;
- Implement management controls, including limitation of scrap handling and transport during nighttime.

Noise abatement measures should achieve the ambient noise levels described in the **General EHS Guidelines**.

## 1.2 Occupational Health and Safety

Occupational health and safety issues during the construction, operation, maintenance, and decommissioning of foundry

facilities are common to those of large industrial facilities, and their prevention and control is discussed in the **General EHS Guidelines**.

In addition, the following occupational health and safety issues may be encountered during foundry activities:

- Physical hazards
- Radiation
- Respiratory hazards
- Electrical hazards
- Noise
- Burial hazards
- Fire and explosions

### Physical Hazards

Recommendations for the prevention and control of physical hazards are presented in the **General EHS Guidelines**.

Industry specific physical hazards are discussed below.

Physical hazards in foundry operations may be related to handling of large, heavy, and hot raw materials and product (e.g. charging of furnaces); accidents related to heavy mechanical transport (e.g. trains, trucks and forklifts); injuries from grinding and cutting activities (e.g. contact with scrap material ejected by machine-tools); and injuries due to falls from elevation (e.g. high platforms, ladders, and stairs).

### *Lifting / Movement of Heavy Loads*

Lifting and moving heavy loads at elevated heights using hydraulic platforms and cranes presents a significant occupational safety hazard in foundries. Recommended measures to prevent and control potential worker injury include the following:

- Clear signage in all transport corridors and working areas;

- Appropriate design and layout of facilities to avoid crossover of different activities and flow of processes;
- Implementation of specific load handling and lifting procedures, including:
- Description of load to be lifted (dimensions, weight, position of center of gravity);
- Sling scheme and strength parameters;
- Train staff in the handling of lifting equipment and driving mechanical transport devices.
- The area of operation of fixed handling equipment (e.g. cranes, elevated platforms) should not cross above worker and pre-assembly areas;
- Proper handling and shielding of moving hot liquids, as well as solid metal parts;
- Material and product handling should remain within restricted zones under supervision, with particular attention paid to proximity of electrical cables / equipment;
- Regular maintenance and repair of lifting, electrical, and transport equipment should be conducted.

### *Product Handling*

Prevention and control of injuries related to handling, grinding and cutting activities, and use of scrap, include the following:

- Locate machine-tools at a safe distance from other work areas and from walkways. Individual, enclosed workplaces should be provided to prevent accidents resulting from fettling or the use of grinders;
- Conduct regular inspection and repair of machine-tools, in particular protective shields and safety devices / equipments;
- Provide rails along the transfer plate with interlocked gates that open only when machine is not in use;
- Train staff to properly use machines-tools, and to use appropriate personal protection equipment (PPE).

### *Heat and Hot Liquid Splashes*

High temperatures and direct infrared (IR) radiation are common hazards in foundries. High temperatures can cause fatigue and dehydration. Direct IR radiation also poses a risk to sight. Contact with hot metal or hot water may result in severe burns. Recommended measures for prevention and control of exposure to heat and hot liquids / materials include the following:

- Shield surfaces where close contact with hot equipment or splashing from hot materials is expected (e.g. in cupola furnaces, EAF, induction melting ladles, and casting);
- Implement safety buffer zones to separate areas where hot materials and items are handled or temporarily stored. Rail guards around those areas should be provided, with interlocked gates to control access to areas during operations;
- Use appropriate PPE (e.g. insulated gloves and shoes, goggles to protect against IR and ultraviolet radiation, and clothing to protect against heat radiation);
- Implement shorter shift durations for work in high air temperature environments. Provide regular work breaks and access to drinking water for workers in hot areas;
- Install cooling ventilation to control extreme temperatures.

### **Exposure to Radiation**

Workers may be exposed to gamma rays and related ionizing radiation exposure risks. The following techniques may be used to limit the worker exposure risk:

- Gamma ray testing should be carried out in a controlled, restricted area using a shielded collimator. No other activities should be undertaken in the testing area;
- All incoming scrap should be tested for radioactivity prior to use as feedstock material;

- If the testing area is near the plant boundary, ultrasonic testing (UT) should be considered as an alternative to gamma ray techniques;
- Regular maintenance and repair should be conducted on testing equipment, including protective shields.

## Exposure to Respiratory Hazards

### *Insulation Materials*

The use of insulation material is widespread in foundries and handling of this material during construction and maintenance may release fibers and present an occupational health hazard. Asbestos and other mineral fibers widely used in older plants may expose people to inhalation risks of cancer-causing substances. In order to limit releases, appropriate and material specific work practices should be applied.

### *Dust and Gases*

Dust generated in foundries includes iron and metallic dusts, which are present in melting, casting and finishing shops; and wooden and sand dusts, which are present in the molding shop. In the former, workers are exposed to iron oxide, and silica dust that may be contaminated with heavy metals such as chromium (Cr), nickel (Ni), lead (Pb), and manganese (Mn). The dust present in the melting and casting shops is generated by high temperature operations, and the fine particle size, and potential metallurgical fumes, creates a serious occupational inhalation risk. In the molding shop, workers are exposed to sand dust, which may contain heavy metals, and wood dust, which may have carcinogenic properties, particularly if hard wood is used.

Recommendations to prevent exposure to gas and dust include the following:

- Sources of dust and gases should be separated and enclosed;

- Design facility ventilation to maximize air circulation. Outlet air should be filtered before discharge to the atmosphere;
- Exhaust ventilation should be installed at the significant point sources of dust and gas emissions, particularly the melting shop;
- Use automated equipment, especially in the fettling process;
- Provide a sealed cabin with filtered air conditioning if an operator is needed;
- Provide separated eating facilities that allow for washing before eating;
- Provide facilities that allow work clothes to be separated from personal clothes and for showering / washing after work and before eating;
- Implement a policy for periodic personnel health checks.
- Respiratory hazard control technologies should be used when exposure cannot be avoided with other means, such as operations for creating sand moulds; manual operations such as grinding or use of non-enclosed machine-tools; and during specific maintenance and repair operations.
- Recommendations for respiratory protection include the following:
- Use of filter respirators when exposed to heavy dust (e.g. fettling works);
- For light, metallic dust and gases, fresh-air supplied respirators should be used. Alternatively, a complete facial gas mask (or an "overpressure" helmet) can be used, equipped with electrical ventilation;
- For carbon monoxide (CO) exposure, detection equipment should be installed to alert control rooms and local personnel. In case of emergency intervention in areas with high levels of CO, workers should be provided with portable CO detectors, and fresh-air supplied respirators.

## Noise

Raw and product material handling (e.g. waste metals, plates, bars), sand compacting, wood-model manufacturing, fettling and finishing may generate noise. Recommended measures to prevent and control noise emissions are discussed in the **General EHS Guidelines**.

## Electrical Hazards

Workers may be exposed to electrical hazards due to the presence of heavy-duty electrical equipment throughout foundries. Recommendations to prevent and control exposure to electrical hazards are provided in the **General EHS Guidelines**.

## Entrapment

Workers creating sand molds are exposed to risk of entrapment due to sand collapse in storage areas and during maintenance operations. Measures to prevent sand burials include the application of material storage criteria as described in the **General EHS Guidelines**.

## Explosion and Fire Hazards

Handling of liquid metal may generate a risk of explosion, melt runoff, and burns, especially if humidity is trapped in enclosed spaces and exposed to molten metal. Other hazards include fires caused by melted metal, and the presence of liquid fuel and other flammable chemicals. In addition, iron foundry slag may be highly reactive if calcium carbide is used to desulfurize the iron.

Recommended techniques to prevent and control explosion and fire hazards include the following:

- Design facility layout to ensure adequate separation of flammable gas and oxygen pipelines, and storage tanks, away from heat sources;
- Separate combustible materials and liquids from hot areas and sources of ignition (e.g. electrical panels);

- Protect flammable gas and oxygen pipelines and tanks during “hot work” maintenance activities;
- Guidance on emergency preparedness and response is provided in the **General EHS Guidelines**.

## 1.3 Community Health and Safety

Community health and safety impacts during the construction, operation, and decommissioning of foundries are common to those of most industrial facilities, and are discussed, along with recommended management actions for prevention and control, in the **General EHS Guidelines**.

## 2.0 Performance Indicators and Monitoring

### 2.1 Environment

#### Emissions and Effluent Guidelines

Tables 1 and 2 present effluent and emission guidelines for this sector. Guideline values for process emissions and effluents in this sector are indicative of good international industry practice as reflected in relevant standards of countries with recognized regulatory frameworks. These guidelines are achievable under normal operating conditions in appropriately designed and operated facilities through the application of pollution prevention and control techniques discussed in the preceding sections of this document. Emissions guidelines are applicable to process emissions. Combustion source emissions guidelines associated with steam and power generation activities from sources with a capacity equal to or lower than 50 megawatts thermal input (MWth) are addressed in the **General EHS Guidelines** with larger power source emissions addressed in the **EHS Guidelines for Thermal Power**. Guidance on ambient considerations based on the total load of emissions is provided in the **General EHS Guidelines**.

Effluent guidelines are applicable for direct discharges of treated effluents to surface waters for general use. Site-specific discharge levels may be established based on the availability and conditions in the use of publicly operated sewage collection and treatment systems or, if discharged directly to surface waters, on the receiving water use classification as described in the **General EHS Guidelines**. These levels should be achieved, without dilution, at least 95 percent of the time that the plant or unit is operating, to be calculated as a proportion of annual operating hours. Deviation from these levels in consideration of specific, local project conditions should be justified in the environmental assessment.

**Table 1 - Effluents Levels for Foundries**

Pollutants	Units	Guideline Value
pH	-	6-9
Total suspended solids	mg/L	35
Oil and grease	mg/L	10
Temperature increase	°C	3 <sup>a</sup>
COD	mg/L	125
Phenol	mg/L	1
Cadmium	mg/L	0.01
Chromium (total)	mg/L	0.5
Copper	mg/L	0.5
Lead	mg/L	0.2
Nickel	mg/L	0.5
Zinc	mg/L	0.5
Tin	mg/L	2
Ammonia	mg/L (as N)	5
Fluoride	mg/L (as F)	5
Iron	mg/L	5
Aluminum	kg/t	0.02 <sup>b</sup>

**NOTES:**

<sup>a</sup> At the edge of a scientifically established mixing zone which takes into account ambient water quality, receiving water use, potential receptors and assimilative capacity

<sup>b</sup> Aluminum smelting and casting

**Table 2. Air Emission Levels for Foundries<sup>(1)</sup>**

Pollutant	Units	Guideline Value
Particulate Matter	mg/Nm <sup>3</sup>	20 <sup>(2)</sup>
		50 <sup>(3)</sup>
Oil Aerosol / Mist	mg/Nm <sup>3</sup>	5
NO <sub>x</sub>	mg/Nm <sup>3</sup>	400 <sup>(4)</sup>
		120 <sup>(5)</sup>
		150 <sup>(6)</sup>
SO <sub>2</sub>	mg/Nm <sup>3</sup>	400 <sup>(8)</sup>
		50 <sup>(9)</sup>
		120 <sup>(7)</sup>
VOC	mg/Nm <sup>3</sup>	20 <sup>(10)</sup>
		30
		150 <sup>(11)</sup>
PCDD/F	ng TEQ/ Nm <sup>3</sup>	0.1
CO	mg/Nm <sup>3</sup>	200 <sup>(12)</sup>
		150 <sup>(13)</sup>
Amines	mg/Nm <sup>3</sup>	5 <sup>(14)</sup>
Chlorine	mg/Nm <sup>3</sup>	5 <sup>(15)</sup>
Pb, Cd and their compounds	mg/Nm <sup>3</sup>	1-2 <sup>(16)</sup>
Ni, Co, Cr, Sn and their compounds	mg/Nm <sup>3</sup>	5
Cu and their compounds	mg/Nm <sup>3</sup>	5-20 <sup>(17)</sup>
Chloride	mg/Nm <sup>3</sup>	5 <sup>(18)</sup>
Fluoride	mg/Nm <sup>3</sup>	5 <sup>(19)</sup>
H <sub>2</sub> S	ppm v/v	5

**NOTES:**

- References conditions for limits. For combustion gases: dry, temperature 273K (0°C), pressure 101.3 kPa (1 atmosphere), oxygen content 3% dry for liquid and gaseous fuels, 6% dry for solid fuels. For non-combustion gases: no correction for water vapor or oxygen content, temperature 273K (0°C), pressure 101.3 kPa (1 atmosphere).
- Particulate matter emissions where toxic metals are present
- Particulate matter emissions where toxic metals are not present
- Ferrous metal melting. Maximum emissions level considered on BAT base and based on cokeless cupola furnaces
- Non-ferrous metal melting (shaft furnaces)
- From thermal sand reclamation systems/regeneration units
- Maximum emissions level considered on BAT base and based on cold blast cupola furnaces
- Non-ferrous metal melting (shaft furnaces)
- Ferrous metal melting (cupola furnaces)
- Non-ferrous metal melting (shaft furnaces)
- Ferrous metal melting (EAFs). Cupola furnaces may have higher emission levels (up to 1,000 mg/N<sub>3</sub>)
- Non-ferrous metal melting (shaft furnaces)
- Cold box molding and core making shop
- Non-ferrous metal melting (aluminum)
- Thermal sand reclamation systems and solvent based investment foundry coating, shelling, and setting operation
- Higher value applicable to non-ferrous metal foundries from scrap
- Higher value applicable to copper and its alloy producing processes
- Furnace emissions where chloride flux is used
- Furnace emissions where fluoride flux is used

## Environmental Monitoring

Environmental monitoring programs for this sector should be implemented to address all activities that have been identified to have potentially significant impacts on the environment, during normal operations and upset conditions. Environmental monitoring activities should be based on direct or indirect indicators of emissions, effluents, and resource use applicable to the particular project.

Monitoring frequency should be sufficient to provide representative data for the parameter being monitored. Monitoring should be conducted by trained individuals following monitoring and record-keeping procedures and using properly calibrated and maintained equipment. Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Additional guidance on applicable sampling and analytical methods for emissions and effluents is provided in the **General EHS Guidelines**.

## 2.2 Occupational Health and Safety

### Occupational Health and Safety Guidelines

Occupational health and safety performance should be evaluated against internationally published exposure guidelines, of which examples include the Threshold Limit Value (TLV®) occupational exposure guidelines and Biological Exposure Indices (BEIs®) published by American Conference of Governmental Industrial Hygienists (ACGIH),<sup>14</sup> the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety (NIOSH),<sup>15</sup> Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United

States (OSHA),<sup>16</sup> Indicative Occupational Exposure Limit Values published by European Union member states,<sup>17</sup> or other similar sources.

### Accident and Fatality Rates

Projects should try to reduce the number of accidents among project workers (whether directly employed or subcontracted) to a rate of zero, especially accidents that could result in lost work time, different levels of disability, or even fatalities. Facility rates may be benchmarked against the performance of facilities in this sector in developed countries through consultation with published sources (e.g. US Bureau of Labor Statistics and UK Health and Safety Executive)<sup>18</sup>.

### Occupational Health and Safety Monitoring

The working environment should be monitored for occupational hazards relevant to the specific project. Monitoring should be designed and implemented by accredited professionals<sup>19</sup> as part of an occupational health and safety monitoring program. Facilities should also maintain a record of occupational accidents and diseases and dangerous occurrences and accidents. Additional guidance on occupational health and safety monitoring programs is provided in the **General EHS Guidelines**.

<sup>14</sup> Available at: <http://www.acgih.org/TLV/> and <http://www.acgih.org/store/>

<sup>15</sup> Available at: <http://www.cdc.gov/niosh/hpg/>

<sup>16</sup> Available at: [http://www.osha.gov/pls/oshaweb/owadisp.show\\_document?p\\_table=STANDARDS&p\\_id=9992](http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992)

<sup>17</sup> Available at: [http://europe.osha.eu.int/good\\_practice/risks/ds/oe/](http://europe.osha.eu.int/good_practice/risks/ds/oe/)

<sup>18</sup> Available at: <http://www.bls.gov/iif/> and <http://www.hse.gov.uk/statistics/index.htm>

<sup>19</sup> Accredited professionals may include Certified Industrial Hygienists, Registered Occupational Hygienists, or Certified Safety Professionals or their equivalent.

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## Annex A: General Description of Industry Activities

Foundries produce ferrous and non-ferrous metal castings.

Ferrous castings are comprised of iron and steel, while non-ferrous castings primarily include aluminum, copper, zinc, lead, tin, nickel, magnesium, and titanium. Castings are produced by melting, pouring, and casting the ferrous and non-ferrous metals. Many foundries cast both types of materials.

Ferrous castings typically include:

- Grey cast iron, with good damping and machinability characteristics, but lower durability;
- Malleable cast iron, containing small amounts of carbon, silicon, manganese, phosphorus, sulfur and metal alloys;
- Spheroidal graphite cast iron (SG), obtained by removing the sulfur from the melt of cast iron;
- Cast carbon steel (low-medium-high), with superior strength, ductility, heat resistance, and weldability compared to iron casting.

Non-ferrous metals are produced to meet product specifications such as mechanical properties, corrosion resistance, machinability, lightness, and thermal and electrical conductivity.

Non-ferrous casting includes many non-ferrous compounds, such as: aluminum and aluminum alloys; copper and copper alloys; zinc and zinc alloys; magnesium and magnesium alloys; cobalt-base alloys; nickel and nickel alloys; titanium and titanium alloys; zirconium and zirconium alloys; and cast metal-matrix composites.

Common non-ferrous alloys include: copper – zinc alloy (Brass); copper – tin alloy (Bronze); nickel-copper alloys (monel / cupronickel); nickel-chromium-iron alloys (stainless steel); aluminum-copper alloys; aluminum-silicon alloys; aluminum-magnesium-alloys; and titanium alloys.

### The Foundry Process

Many different casting techniques are available. All involve the construction of a container (mold) into which molten metal is poured.

Two basic casting process subgroups are based on expendable and non-expendable mold casting. Expendable mold casting, typical to ferrous foundries although also used in non-ferrous casting, uses lost molds (e.g. sand molding). Non-expendable mold casting, adopted mainly in non-ferrous foundries, uses permanent molds (e.g. die-casting). Lost molds are separated from the casting and destroyed during the shakeout phase, while permanent molds are reused. A variety of techniques are used within these two mold casting processes depending on the melting, molding and core-making systems, the casting system, and finishing techniques applied.

A typical foundry process, outlined in Figure A.1, includes the following major activities: Melting and metal treatment in the melting shop; preparation of molds and cores in the molding shop; casting of molten metal into the mold, cooling for solidification, and removing the casting from the mold in the casting shop; and finishing of raw casting in the finishing shop.

#### *Melting Shop*

Different types of melting furnaces and metal treatments are used to produce ferrous and non-ferrous materials depending on the type of metal involved.

*Cast iron* is typically melted in cupola furnaces, induction furnaces (IF), electric arc furnaces (EAF), or rotary furnaces. Use of induction furnaces (coreless induction-type furnace for melting and channel induction-type for holding) is preferred over cupola furnaces due to their superior environmental performance. EAFs are employed less commonly.

Cast steel is typically melted in electric arc furnaces or coreless induction furnaces. Cast steel metal treatment consists of refining (e.g. removal of carbon, silicon, sulfur and/or phosphorous) and deoxidization depending on the charge metal and required quality of the casting product.

Melted metal may require treatments such as desulfurization, and deslagging. To remove impurities in the melt, metal flux is added to the furnace charge or to the molten metal. Flux unites with impurities to form dross or slag which is removed before pouring.

### *Cupola Furnaces*

The cupola furnace is the common furnace used for cast iron melting and the oldest type of furnace used in foundries. It is a cylindrical shaft type furnace lined with refractory material. The furnace uses coke as a fuel and combustion air. Molten iron flows down the cupola furnace while combustion gases move upward leaving the furnace through its stack. As melting proceeds, new material is added at the top of the shaft through a charging door. Added flux combines with non-metallic impurities in the iron to form slag, which is lighter than molten iron and floats on the top of the molten metal protecting it from oxidation. The liquid metal is tapped through a tap-hole at the level of the sand bed and collected into a ladle and / or a holding furnace. The slag is removed through a hole at higher level. Coke accounts for 8–16 percent of the total charge to provide the heat needed to melt the metal. Melting capacities of cupola furnaces generally range from 3 to 25 metric tons per hour.

Cupola furnaces require a reducing atmosphere to prevent oxidation of the iron as it is melted. Oxidization is minimized by assuring the presence of carbon monoxide (CO) in the combustion gas (about 11-14 percent CO content). This results in inefficient use of the available energy in the coke, and significant CO emissions to the environment. Alternative technologies can be used to increase the efficiency of the

cupola furnace and reduce CO emissions. These include preheating combustion air up to 600°C as performed in the Hot Blast Cupola<sup>20</sup>; oxygen enrichment; or supersonic direct injection of pure oxygen.

The cupola process also produces a significant amount of particulate emissions. Emission control systems typically require use of high energy wet scrubbers or dry baghouse (fabric filter) systems.

### *Electric Arc Furnaces (EAF)*

The EAF is a batching furnace often used in large steel foundries. Its use for cast iron production is less common. The EAF is shaped as a ladle. Heat required to melt the metal is produced with an electric arc from electrodes, initially positioned above the charge. The furnace is tapped by tilting it and forcing the molten metal to flow out through the tapping spout. Opposite the tapping spout is an operating door that allows deslagging and sampling operations.

### *Induction Furnaces*

Induction furnaces (IF) are used for melting ferrous and non-ferrous metals. Melting is achieved through a strong magnetic field created by passing an alternating electric current through a coil wrapped around the furnace and consequently creating an electric current through the metal. The electric resistance of the metal produces heat, which melts the metal itself. These furnaces provide excellent metallurgical control and are relatively pollution free.

The most significant air emissions released by IFs relate to the charge cleanliness resulting in the emission of dust and fumes (organic or metallic). Other emissions result from chemical

<sup>20</sup> EC BREF (2001) on the Smelteries and Foundries Industry

reactions during holding or adjusting the metal composition, which originate metallurgical fumes.<sup>21</sup>

### *Reverberatory or Hearth Furnaces*

Reverberatory or hearth furnaces are used for batch melting of non-ferrous metals. It is a static furnace with direct heating and consists of a refractory-lined, rectangular or circular bath furnace that is fired by wall or roof mounted burners. Hot air and combustion gases from the burners are blown over the metal charge and exhausted out of the furnace. In addition to the oil or gas fuel burners, oxy-fuel burners may also be used to increase the melting rate. These furnaces are typically used for small-scale production as emissions control is difficult.

### *Crucible Furnaces*

Crucible furnaces are used primarily to melt smaller amounts of non-ferrous metals. The crucible or refractory container is heated in a furnace fired with natural gas, liquid fuel (e.g. propane) or by electricity. The crucible is either tilted manually, with a crane, or automatically, to pour the molten metal into the mold.<sup>22</sup>

### *Rotary Furnaces*

The rotary furnace consists of a horizontal cylindrical vessel in which the metallic charge is heated by a burner located at one side of the furnace. The flue gases leave the oven through the opposite side. Once the metal is melted, and after a composition check and adjustment, a tap-hole in front of the furnace is opened and the melt in the furnace is discharged into ladles. Rotary furnaces are used for melting volumes of 2 to 20 tonnes, with typical production capacities of 1 to 16 tonnes per hour. Emissions control is often difficult.

Rotary furnaces have been used in non-ferrous melting for many years. In this type of furnace, traditional oil-air burners can provide relatively low melting temperatures. The development of oxygen-air burners has enabled their use in cast iron production, using a higher amount of steel scrap and applying graphite for carburization.

### *Shaft Furnaces*

Shaft furnaces are only used for non-ferrous metal melting, mainly for aluminum. It is a simple vertical furnace with a collecting hearth (inside or outside the furnace) and burner system at the lower end, and a material charging system at the top. The burners are usually gas-fired. Combustion gases are usually extracted and cleaned. An afterburner is sometimes used to treat any carbon monoxide, oil, volatile organic compounds (VOC), or dioxins produced.

### *Radiant Roof Furnaces*

Radiant roof furnaces are mainly used in non-ferrous (aluminum) pressure die-casting shops with centralized melting facilities. The radiant-roof furnace is a low-energy holding furnace with a heavily insulated box design with banks of resistance elements in a hinged, insulated roof. Typical units have capacities of 250 – 1000 kilograms (kg).<sup>23</sup>

## **Molding Shop**

Before metal casting can take place, a mold is created into which the molten metal is poured and cooled. The mold normally consists of a top and bottom form, containing the cavity into which molten metal is poured to produce a casting. To obtain tunnels or holes in the finished mold (or to shape the interior of the casting or that part of the casting that cannot be shaped by the pattern) a sand or metal insert called a "core" is placed inside. The materials used to make the molds depend on the type of metal being cast, the desired shape of the final

<sup>21</sup> EC BREF (2001) on the Smitheries and Foundries Industry and US EPA Office of Compliance. 1998. Sector Note Book Project: Profile of the Metal Casting Industry

<sup>22</sup> EC BREF (2001) on the Smitheries and Foundries Industry

<sup>23</sup> EC BREF (2001) on the Smitheries and Foundries Industry

product, and the casting technique. Molds can be classified in two broad types<sup>24</sup>:

- *Lost molds (single use molds)*: These are specially made for each casting and are destroyed in the shake-out process. These molds are generally made of sand and are clay-bonded, chemically bonded, or sometimes unbonded. Investment casting (lost wax) can also be included in this family;
- *Permanent molds (multi-use molds)*: These are used for gravity and low-pressure casting, high pressure die-casting, and centrifugal casting. Typically, permanent molds are metallic.

Sand is the most common molding material used. Sand grains are bonded together to form the desired shape. The choice of binder technology used depends on factors such as the casting size, the type of sand used, the production rate, the metal poured, and the shakeout properties. In general, the various binding systems can be classified as either clay-bonded sand (green sand) or chemically-bonded sand. The differences in binding systems can have an impact on the amount and toxicity of wastes generated and potential environmental emissions.<sup>25</sup> Green sand, which is a mixture of sand, clay, carbonaceous material, and water, is used as a mold in 85 percent of foundries. The sand provides the structure for the mold, the clay binds the sand together, and the carbonaceous materials prevent rust. Water is used to activate the clay. The mold must be dry otherwise it may present a risk of explosion. Green sand is not used to form cores, which require different physical characteristic than mold. Cores should be strong enough to withstand the molten metal and collapsible so they can be removed from the metal piece after cooling. Cores are typically obtained from silica sand and strong chemical binders placed in

a core box. The hardening or curing of the chemical binding system is obtained through chemical or catalytic reactions, or by heat. Sand cores and chemically-bonded sand molds are often treated with water-based or spirit-based blacking to improve surface characteristics. The advantages to using chemically-bonded molds over green sand molds include a longer storage life for the molds; a potentially lower metal pouring temperature; and better dimensional stability, and surface finish to the molds. Disadvantages include higher costs of chemical binders and energy used in the process; added complexity to reclaim used sand; and environmental and worker safety concerns related to air emissions associated with binding chemicals during curing and metal pouring.<sup>26</sup>

Sand molding involves the use of large volumes of sand, with sand-to-liquid metal weight ratios generally ranging from 1:1 to 20:1. After the solidification process, the mold is broken away from the metal piece in a process called "shake-out" whereby the sand mold is shaken from the metal parts. Most of the used sand from green sand molds is reused to make future molds. Reused sand mixtures are also often used to create cores. However, a portion of sand becomes spent after a number of uses and needs to be disposed of. For this reason, mold and core making are a large source of foundry waste.

Investment casting, also known as the lost wax process, is one of oldest manufacturing processes. It is used to make parts with complex shapes or for high-precision metal castings. An investment mold is obtained by pouring, around (investing) a wax or thermoplastic pattern, a slurry which conforms to the pattern shape and subsequently sets to form the investment mold. After the mold has dried, the pattern is burned or melted out of the mold cavity and the mold is ready to be utilized.

<sup>24</sup> Ibid.

<sup>25</sup> US EPA Office of Compliance. 1998. Sector Note Book Project: Profile of the Metal Casting Industry

<sup>26</sup> US EPA Office of Compliance. 1998. Sector Note Book Project: Profile of the Metal Casting Industry

Permanent metal molds are typically used in foundries producing large quantities of the same piece. They can be used for casting both ferrous and non-ferrous metals as long as the mold metal has a higher melting point than the casting metal. Metal molds are used for gravitational casting, low and high pressure die-casting, and centrifugal casting. Cores for permanent molds can be made of sand, plaster, collapsible metal, or soluble salts.

### **Casting Shop**

Pouring the melted metal is the most significant activity in the casting process. Different pouring systems are used depending on the mold and metal type used for casting. The mold can be filled with the liquid metal by gravity (lost mold) or by injection under low or high pressure (die-cast) or by centrifugal forces. A pouring furnace is often utilized in automatic casting lines.<sup>27</sup> This casting furnace automatically feeds the molds in the casting lines and is refilled with liquid metal at fixed time intervals. Correct introduction and distribution of poured metal into the mold are provided by a set of columns and channels inside the mold (a "runner system" or "gating system"). The shrinkage (the difference in volume between liquid and solid metal) is compensated by the presence of an adequate feeder reservoir (a "riser"). After pouring, the casting is cooled to allow for solidification (first cooling) and it is then removed from the mold for further controlled cooling (second cooling). In sand casting foundries, sand castings enter the shakeout process to remove the mold after solidification. During shake-out, dust and smoke are collected by dust-control equipment. Investment molds and shell molds are destroyed during removal, creating solid waste. When the permanent mold technique is used, the mold (die) is opened and the casting extracted without destroying the mold after solidification.<sup>28</sup> Some foundries treat mold and core sand

thermally to remove binders and organic impurities before recycling to the mold-making facility.

Since various additives are used in the manufacture of the molds and cores to bind the sand during metal pouring activities, reaction and decomposition products are generated. These include organic and inorganic compounds (amines and VOC). The generation of decomposition products (mainly VOC) continues during the casting, cooling, and removing operations. Since these products may cause health and odor hazards, they should be extracted and the gas cleaned prior to release.

### **Finishing Shop**

All remaining operations necessary to yield a finished product are conducted in the finishing shop. Depending on the process used, different steps may be required such as removal of the running and gating system, removal of residual molding sand from the surface and core remains in the casting cavities, removal of pouring burrs, repair of casting errors, and preparation of the casting for mechanical post-treatment, assembly, thermal treatment, and coating.<sup>29</sup>

The metal piece is cleaned using steel shot, grit, or other mechanical cleaners to remove any remaining casting sand, metal flash, or oxide. Flame cut-off devices and air-carbon arc devices may also be used for this purpose. Small items are usually ground by tumbling, which is carried out in a rotating or vibrating drum. This usually involves the addition of water, which may contain surfactants. Residual refractory material and oxides are typically removed by sand blasting or steel shot blasting, which can also be used to provide the casting with a uniform and improved surface appearance. Welding may be required to join castings, as well as to repair casting flaws. Chemical cleaning of castings may be carried out before coating operations to ensure that the coating will adhere to the metal.

<sup>27</sup> EC BREF (2001) on the Smitheries and Foundries Industry

<sup>28</sup> Ibid.

<sup>29</sup> Ibid.

## **DISA Technology**

Disamatic (DISA) technology is a green sand molding process designed to automatically build molds and inject the metal. The DISA molds are produced with the help of a hydraulic press, improving the production and quality of compacted sand. DISA allows for various molding configurations, including vertical molding, horizontal molding, and matchplate molding technology. The vertical molding configuration is the most popular configuration since it provides very close tolerance castings. In this process, the molding chamber is movable and achieved by two opposite patterns (ram pattern and swing pattern). This allows the sand blown in the molding chamber to be compressed and then extracted from the chamber.

DISA technology allows an efficient means of creating a string of flask-less molds (without rigid metal or wood frame). It is typically the choice for mass production of close-tolerance iron castings or aluminum. Environmental aspects related to the DISA technology are similar to those experienced by other foundries casting ferrous products in sand molds, but are normally contained and handled as part of the automated system.

