Environmental, Health, and Safety Guidelines Base Metal Smelting and Refining

Introduction

The Environmental, Health, and Safety (EHS) Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP)[1]. 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

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. 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 Smelting & Refining cover information relevant to base metal smelting and refining of lead, zinc, copper, nickel, and aluminum. It does not include the mining and concentration of the raw materials, which is covered in the EHS Guidelines for Mining. Annex A contains a description of industry sector activities.

This document is organized according to the following sections:

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[1] 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.

1.0 Industry-Specific Impacts and Management

The following section provides a summary of EHS issues associated with base metal smelting and refining, which generally 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, operation and decommissioning phases are provided in the **General EHS Guidelines**.

1.1 Environment

Significant environment aspects of smelting and refining during the operational phase relate to:

- Air Emissions
- Wastewater
- Hazardous materials
- Residues and waste
- Noise

Air Emissions

Particulate Matter [2]

Emissions of particulate matter (which may contain metals) may result from fugitive and point sources, including receiving, conditioning, handling, transport (e.g. conveyors, vehicular traffic), and storage (e.g. outdoor piles) of ores, concentrates, and secondary raw materials; from hot gases during pyro-processing (e.g. sintering, smelting, roasting, and converting); during leach processing (e.g. dry material handling, filtering, storage of leach residues); during pyro-refining (e.g. furnace processing and transfer of the hot materials); during collection and transport of contents of abatement systems (e.g. baghouse filters); and during melting and casting (e.g. molten metal and dross handling). Fugitive emissions can be greater than those that are collected and abated; therefore, control of fugitive emissions is particularly important.

Measures to prevent and control particulate matter emissions include the following:

- Characterize all feed materials with regard to risk reduction potential;
- Store dust-forming materials in enclosed buildings or containers and transfer using pneumatic or enclosed conveyor systems. Cover all transport vehicles;
- Reduce the quantity of materials transported, and transport distances, through efficient plant layout and design;
- Reduce off-gas volumes where possible (e.g. by employing oxygen-smelting processes);
- Design for continuous operation where possible, and ensure environmental control systems are adequate to optimize smooth, consistent operation.[3]
- Use sealed furnaces and reactors with reduced pressure, or retrofit existing furnaces with maximum sealing (e.g. use of a "fourth hole" in the roof of an electric arc furnace to extract the process gases as efficiently as possible);
- Enclose, contain, or use hoods to collect emissions from process vessels, feed and discharge points, and conveyor systems;
- Use systems that maintain the sealing or hood deployment during transfer of materials, such as through electrode additions of material; additions via tuyeres or lances; and the use of robust rotary valves on feed systems;

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[2] Particulate matter (dust) is classified as total particulate matter with an upper size limit of 100 µm (TPM), particulate matter less than µ10 m (PM10), and particulate matter less than 2.5 µm (PM2.5). The impact of particulate matter depends on the size and nature of the particles (e.g. $PM_{2.5}$ are more respirable), their relative solubility, and the concentration and toxicity of the substances contained within the particulate matter.

[3] For example, the converter stages that are used in the continuous Mitsubishi and Outokumpu/Kennecott flash smelting/flash converting processes do not require ladle transfer and therefore remove this source of secondary fume.

- Use damper controls that change the extraction points automatically during different stages of the process in order to target the extraction effort to the fume source and thereby minimize energy consumption. Extraction of fumes at the roof ventilator should generally only be used as a last resort because of the high energy use and reduced collection efficiency;
- Control particulate matter emissions using electrostatic precipitators, bagfilters, scrubbers, or cyclones that are appropriate for the exhaust stream characteristics (e.g. considering temperature, size fraction of particulate matter).[4]
- Maintain the collector hood, ducts, and filter system to ensure that collection or extraction rates remain at the designed level;
- Cover all transport vehicles and enclose storage and process equipment.
- Employ a watering program to minimize airborne particulate matter emissions from on-site roadways, storage piles, and other sources;
- Diligent housekeeping and providing vehicle wash facilities to prevent the migration of materials within the facility and offsite.

Metals

In addition to the primary base metals, feed materials may contain trace amounts of other metals (e.g. aluminum, arsenic, antimony, bismuth, cadmium, chromium, copper, germanium, gold, indium, lead, mercury, nickel, selenium, silver, thallium, tin and zinc).

Emissions of metals in various forms and compounds, which may be mobilized as contaminants in particulate matter, mists, fumes or in liquids, may be generated throughout all of the production stages including pyro-processing (e.g. large volumes of hot gas are generated containing particulate matter and metal fumes during sintering, smelting, roasting, and converting); pyro-refining (e.g. fine particulate matter and metal fume are generated during the furnace processing and transfer of the hot materials); electro-refining (e.g. acid mist emissions from electrolyte solutions); and melting and casting (e.g. metal fume emissions from molten metal and dross handling, and baghouse particles). The degree to which these metals may impact the environment depends on their form, toxicity and concentration[5].

Emissions of metals are controlled through the application of measures to control particulate matter.

<u>Mercury</u>: A special note is made for metal emissions that are generated from smelting and refining processes that have the potential to release mercury. While most exhaust streams that contain metals are effectively controlled using the same

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[4] The following is adapted from information contained in the European Commission (2001). Reference document on best available techniques (BREF) for the non-ferrous metals industries: Fabric filter systems are employed extensively within this industry sector, due to their high efficiency in controlling the fine particulate matter encountered in melting operations. Due to their tendency to blind and their sensitivity to fire, they are not suitable for all applications / situations. Settling and cooling chambers and also waste heat recovery boilers are used before bag-houses to reduce the likelihood of fires, to condition the particles, and to recover the heat content of the off-gas before de-dusting. The electrostatic precipitator (EP) is also used extensively in the industry and is capable of operating over a wide range of conditions of temperature, pressure and dust burden. It is not particularly sensitive to particle size, and collects dust in both wet and dry conditions. Corrosion and abrasion resistance is built into the design. However, the EP usually does not achieve final dust concentrations as low as those achieved by a fabric filter. Wet electrostatic precipitators are necessary when humid, saturated gases with a high particulate content have to be cleaned (e.g., off-gas from the production of primary zinc and copper, which contains dust and sulphur dioxide, is cleaned by using a scrubber and a wet electrostatic precipitator). Wet precipitators are also used to collect the tar mist in the waste gases from an electrode-baking furnace. Cascade wet scrubbers are often used for the de-dusting of CO-rich off-gases from sealed electric arc furnaces; the gas is used as high calorific-value gas. It is also used to treat gases from a steel belt sintering machine, where the dust is very abrasive but easily wetted, and the use of scrubber allows gas cooling to be achieved at the same time as dust removal. Cyclones are not generally suitable for controlling emissions directly from the processes in this industry sector. The efficiency in collecting fine dust is too low to deal effectively with furnace releases. Operational experience has shown that they are not capable of meeting modern release standards. However, cyclones are used effectively as a primary collector in conjunction with another technique, particularly on larger processes where throughput can vary.

[5] European Commission (2001). Reference document on best available techniques (BREF) for the non-ferrous metals industries.

abatement controls as particulate matter, mercury will remain as a vapor at ambient temperatures and pass through some control equipment. It is important to significantly cool the inlet gas to the particulate matter control system to ensure mercury capture is sufficient or to use an activated charcoal media to adsorb the mercury.[6]

Sulphur Dioxide

Sulphur dioxide (SO_2) is produced from the combustion of fossil fuels and when metal sulphide concentrates are roasted, sintered, smelted, converted or refined. The concentration of SO_2 in the off-gas streams is an important characteristic for managing SO_2 emissions. Above concentrations of 5 – 7 percent in the raw gas stream, SO_2 can be processed into sulphuric acid. Lower concentrations in gas streams require the use of raw materials containing lower amounts of sulphur, or some form of scrubbing to fix the sulphur and minimize SO_2 emissions to the atmosphere and achieve appropriate ambient air concentrations. Oxygen smelting processes reduce the volume of off-gases and increase the concentration of SO_2, which results in greater conversion efficiency and reduced contaminant emissions with the lower volume.

Measures to prevent and control sulphur dioxide emissions include the following:

- Process (fix) the sulphur for safe storage and / or use as a product (e.g. sulphuric acid, liquid sulphur dioxide, fertilizer, and elemental sulphur);
- Consider technology choices to reduce gas volumes and increase SO2 concentration;[7]
- Implement process control systems to ensure consistent operation;
- Install gas scrubbing processes that remove SO_2 from low concentration streams;
- Enclose process equipment and vessels to prevent fugitive emissions;
- Use pre-treatment (e.g. flotation) to remove unwanted sulphide and reduce sulphur in feeds;
- Use low-sulphur fuels (e.g. natural gas instead of heavy fuel oil or coke) and raw materials (e.g. lower sulphur raw materials).

Nitrogen Oxides

NO_x emissions are primarily related to the combustion of fuels (e.g. coal in smelting and natural gas in pyro-refining). NO_X may be formed from nitrogen components that are present in the fuel or the concentrates, or as thermal NO_X. In aluminum production, NO_X is also produced during electrolysis due to the presence of nitrogen in the anode.

- Minimize NO_x generation by using low NO_x gas burners and staged combustion air in pyro-refining furnaces and other combustion facilities.
- Treat roasting gases to remove NO_x (e.g. using oxidizing scrubber) if high levels of NO_X are present to enhance the quality and usability of sulfuric acid produced from off-gasses containing SO_2;
- Use of oxy fuel burners can result in reduced NO_X formation. When using oxygen enrichment, consider introducing oxygen downstream of the burner if the higher temperatures caused by using pure oxygen at the burner result in additional NO_X formation.

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[6] Further detailed information on technologies and methods to control mercury emissions, in addition to management of residual substances (e.g. mercuric chloride or calomel from the Boliden / Norzink and Outukumpu mercury control systems) is provided in European Commission (2001). Reference document on best available techniques (BREF) for the non-ferrous metals industries , pg 135.

[7] There are two basic smelting processes in use, bath smelting and flash smelting. The flash smelting process uses oxygen enrichment to produce auto-thermal (autogenic) or nearly autothermal operation. Bath smelting processes generally use a lower degree of oxygen enrichment. The use of oxygen also gives higher sulphur dioxide concentrations that make the collection of the gas more effective using one of the sulphur recovery systems (usually the production of sulphuric acid or production of liquid sulphur dioxide). European Commission (2001). Reference document on best available techniques (BREF) for the non-ferrous metals industries.

Dioxins and Furans

Polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs) may be generated during the production of metals (e.g. pyro-processing), particularly with respect to production from secondary raw materials or in processes that require chlorination. Impurities in the scrap material may result in PCDD/F formation during incomplete combustion or de-novo synthesis.[8]

Measures to prevent and control dioxins and furans include the following:

- Cull metal scrap to eliminate or minimize the presence of organic materials (e.g. plastics and wood) prior to any combustion and / or heating involving metal scrap;
- Implement procedures for the operation and maintenance of combustion equipment to ensure efficient combustion at the designed temperatures and residence times to ensure destruction of dioxins, and avoid reformation as gases cool;
- Consider use of activated carbon in a fixed bed or moving bed reactor or by injection into the gas stream, and subsequent removal as filter dust.

Volatile Organic Compounds

Volatile Organic Compounds (VOCs) are produced by poor combustion and during operations such as degreasing of components, solvent extraction processes, and from the venting of tanks used to store solvents and fuel. VOCs can also be released during smelting and refining of secondary metals if the feed includes organic materials.

Recommended measures to prevent, minimize, and control releases of VOCs include:

- Use water-based solvents were possible, or use the least toxic solvent suitable for the application;
- Contain emissions (e.g. by use of sealed equipment or hoods);
- Use mixer / settlers that minimize contact with air to minimize evaporation of VOCs;
- Control VOC emissions using afterburners, scrubbers, biofilters or bioreactors, activated carbon traps, or chiller / condenser systems, depending on, for example, the composition of the gas stream;
- Use back venting of displaced gases to the delivery vehicle when filling solvent or fuel tanks, and use of automatic resealing of delivery connections to prevent spillage.

Acid Mist and Arsine

Electro winning and other processes such as pressure leaching and production of sulfuric acid may produce acid mist containing soluble metals. Acid mists can also be generated during of breaking lead-acid batteries. Arsine gas may be produced when certain trace metals and acid are mixed (e.g. during the leaching process). Acid mist is produced by the reactions in the electro winning cells, as well as by any aeration or aggressive mixing and / or chemical reactions in subsidiary processes and / or at open drop points handling liquid flows.

Measures to prevent and control acid mist and arsine emissions include the following:

- Monitor process control parameters to reduce and / or eliminate upset conditions;
- Install hoods on tanks, maintaining an adequate foam layer on the surface of the electrolyte solution, and treatment of

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[8] The presence of oils and other organic materials on scrap or other sources of carbon (partially burnt fuels and reductants, such as coke), can produce fine carbon particles which react with inorganic chlorides or organically bound chlorine in the temperature range of 250 to 500 °C to produce dioxins. This process is known as de-novo synthesis and is catalyzed by the presence of metals such as copper or iron. European Commission (2001). Reference document on best available techniques (BREF) for the non-ferrous metals industries.

the exhaust gases and mists using control equipment (e.g. scrubbers).

- Use stack and candle filters to control acid mist emissions at sulfuric acid plants;
- Collect and treat acid mist (e.g. using wet scrubbers or mist filters) generated in the milling stages of battery breaking.

Carbon Monoxide

Some pyrometallurgical processes (i.e. the carbo-thermic production of ferro-alloys in closed submerged electric arc furnaces) produce a carbon monoxide rich off-gas as a by-product. The amount of CO varies largely depending on the metal and the production process. Measures to control and minimize CO emissions include collecting and cleaning the CO-rich gas (e.g. using a cascade wet scrubber), and use or sale of the gas as fuel. CO may also be produced by incomplete combustion and from smelting and refining of secondary feedstocks containing organic material. Control of CO from these sources is similar to control of VOCs, described above.

Greenhouse Gases

Carbon dioxide (CO_2): Carbon dioxide is produced in significant quantities during smelting and refining operations.[9] The main sources include the smelting of concentrates, the direct combustion of fossil fuels for power and heat generation, and the indirect emissions resulting from fossil fuels used to generate electrical energy for facility operations (e.g. for electrolysis in aluminum smelting). Further indirect contributions to greenhouse gases in this sector are associated with the use of chemical reagents that release a significant quantity of greenhouse gases during offsite manufacturing. Opportunities to reduce greenhouse gas generation are closely linked to measures to increase energy efficiency and reduce energy consumption, both of which are addressed in the 'Energy Consumption and Efficiency' section below. Additional recommendations for the management of greenhouse gases are discussed in the **General EHS Guidelines**.

Perfluorocarbons (Aluminum Only)[10,11]: Two perfluorocarbons (PFCs), tetra-fluoromethane (CF_4) and hexa fluoroethane (C_2F_6), are formed during the anode effects (temporary imbalance of raw material feed-in rate and the aluminum production rate) stage of aluminum manufacturing and, once formed, they cannot be removed from the gas stream with existing technology.

Anode effects occur when the alumina content of the electrolyte falls below 1 - 2 percent which results in the formation of a gas film on the electrode. The formation of the film on the anode results in stoppage of metal production and increases cell voltage from the 4 – 5 volt range to 8 - 50 volts. The generation of PFCs is dependent upon the frequency and duration of the anode effects.[12]

Measures to control perfluorocarbons (and reduce overall GHG emissions) include the following[13]:

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[9] Carbon dioxide is also formed in aluminum production during electrolysis by the reaction of the carbon anode with the oxygen formed by electrolysis and by a secondary reaction with air. This emission is, however, far less than the emission of CO_2 by combustion of fossil fuels when used for the generation of the electric power required for electrolysis.

[10] Among the six GHGs to be abated under the Kyoto Protocol, two Perfluorocarbons (PFCs), namely tetra-fluoromethane (CF_4) and hexa fluoroethane (C_2F_6) are a by-product of aluminum smelting. The Global Warming Potential (GWP) is a measurement technique to define the relative contribution of each GHG to atmospheric warming. A GWP can be calculated for specified time horizons (e.g. 20 to 500 years) and for given GHG concentration levels (e.g. current). Both direct and indirect effects are considered. Indirect effects include changes in atmospheric chemistry such as ozone formation and changes in stratospheric water vapor. CO2 has been assigned a GWP of 1, against which all other GHGs are compared. The GWP of tetra-fluoromethane (CF_4) is 6500 times that of CO2 (100 year time horizon), and hexa fluoroethane (C_2F_6) is 9200 times that of CO2 (100 year time horizon). United Nations Framework Convention on Climate Change (UNFCCC).

[11] International Aluminum Institute. Greenhouse Gas Protocol: Greenhouse gas emission monitoring and reporting by the aluminum industry, October, 2006. Available at www.world-aluminium.org/environment/climate/ghg_protocol.pdf

[12] European Commission (2001). Reference document on best available techniques (BREF) for the non-ferrous metals industries.

[13] International Aluminum Institute. "PFC Emissions: A Decade of Progress".http://www.world-aluminium.org/environment/climate/index.html

- Increase the use of recycled aluminum (use of recycled aluminum requires significantly less energy than is required for primary production);
- Increase the electrical conversion efficiency;
- Reduce anode effects that produce PFS:
    - Control anode effects by adjustment of cell voltage and alumina additions
    - Use of semi-continuous point feeding of the alumina combined with process control
- Change the reduction technology to minimize use of fossil carbon[14].

Energy Consumption and Efficiency: Smelting and refining facilities require large amounts of energy, notably the fuel energy used for drying, heating, smelting, fuming, melting and transportation, and the electrical energy used in electrolysis and for powering utilities / equipment. The **General EHS Guidelines** contains guidance to improve energy efficiency performance. The following recommendations are specific to this sector:

- Assess alternative smelting and processing technologies that optimize energy use (e.g. flash smelting requires about half the energy of conventional blast furnace smelting, and use of recycled aluminum typically requires significantly less energy than needed for primary production);
- Employ heat and energy recovery techniques to maximize energy utility (e.g. waste heat boilers, heat exchangers, steam-driven drives)[15], for example from gases generated by pyrometallurgical processes. Heat recovery techniques will vary between facilities but may include use of oxygen rich air to reduce energy consumption; use of steam raising boilers to capture hot gases generated by smelting or roasting; and use of heat generated by smelting and refining processes to melt secondary material.

Nickel Carbonyl (Nickel Only)

Production of nickel carbonyl is an intermediate step in the production of purified nickel. Depending on the process, other carbonyls such as cobalt and iron carbonyl can also be formed. Carbonyl laden gas streams should be incinerated to convert the metal carbonyl to the base metal oxide and carbon dioxide. Control technologies should be used to capture base metal oxide and carbon dioxide arising from the incineration of carbonyl laden gas streams.

Fluorides (Aluminum Only)

The main source of gaseous fluorides is the pots during electrolysis. The majority of the gaseous fluorides produced are in the form of hydrogen fluoride, which results from the reaction of aluminum fluoride and cryolite with hydrogen. Control of fluoride emissions can be achieved through fume capture. Captured fumes (typically greater than 98 percent of total fumes) can be cleaned using alumina injection in the off gas for the absorption of the fluoride, followed by use of bag filters (the dust is returned to the pots) or wet scrubbers (typically greater than 99.5 to 99.9 percent efficient).

Tar and Polycyclic Aromatic Hydrocarbons (Aluminum Only)

Tar and polycyclic aromatic hydrocarbons (PAHs) may be released (mainly from the anode baking plants). Measures to prevent and control these emissions include the following:

- Improve combustion efficiency;
- Switch to another type of anode;
- Removal of tar and PAHs utilizing alumina scrubbers and fabric filters;

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[14] Reduction technologies that do not use carbon are currently at a pilot stage of development.

[15] Detailed guidance on energy efficiency for smelting is available in the European Commission (2001). Reference document on best available techniques (BREF) for the non-ferrous metals industries.

- Use of dry anode paste and maintenance of anode tops at cold temperatures to reduce PAH emissions.

Anode preparation (Aluminum only)

The electrolysis of alumina into aluminum results in the consumption of the anode, during which the released oxygen will burn away the carbon. These anodes are normally prepared onsite in an anode baking facility where the carbon containing materials (including petroleum pitch) are attached to a metal core and baked to increase the strength. The baking will release volatile hydrocarbons and also other contaminants such as sulfur from the raw materials. If feasible, the heating value from VOC emissions could be used by combusting these substances within the baking furnace. The off-gas from the baking house should be treated by scrubbing or by absorption followed by filtering in plants integrated with a primary aluminum smelter, where hydrocarbons are returned to the production process; alternatively afterburners and wet ESPs can be used depending on the site and scale of production.

Wastewater

Industrial process wastewater

The main sources of wastewater in the smelting and refining sector include process water from hydro-metallurgical processes (e.g. roasting gas cleaning, leaching, purification, and electrolysis); wet off-gas cleaning; slag granulation; cooling water; and surface runoff / stormwater. Wastewaters typically contain soluble and non-soluble metal compounds, oil and organic material. Direct contact cooling water (e.g. for some casting operations) may contain elevated levels of metals and suspended solids, and should be routed through the facility wastewater treatment system.

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 oil water separators or dissolved air floatation 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, electrolysis or other physical / chemical treatment technologies, (ii) removal of recalcitrant organics using activated carbon or advanced chemical oxidation, and (iii) 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**. Non-contact cooling water systems in the smelting and refining sector may be a direct once-through design, or a recirculation route involving the use of evaporative cooling towers. Water from a once through, system is typically discharged to surface waters after appropriate consideration / reduction of temperature effects on the receiving water body. Stormwater may become contaminated through contact with material stockpiles and surface deposition of airborne contaminants. Guidance for the management of stormwater 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**.

Hazardous Materials

The smelting and refining sector utilizes a number of acids, alkalis, and chemical reagents (in leaching and precipitation of metals, and for pollution control systems); and process gases (e.g. oxygen, carbon dioxide, argon, nitrogen, chlorine, hydrogen, among others). Guidance on the safe storage, transport, and use of hazardous materials is addressed in the **General EHS Guidelines**.

Residues and Waste

Sources of hazardous and non-hazardous residues and waste in the smelting and refining sector include slag, drosses, mattes, and skimmings from pyrometallurgical processes; spent linings and refractories from furnaces; waste from abatement systems (e.g. flue gas dust, sludge, and spent filter material); sludge from wastewater treatment (e.g., from wet scrubber systems and process water treatment, which may contain gypsum [CaSO4] and metal hydroxides and sulphides); and sludge from leaching, purification, and electrolysis activities.

Opportunities to recycle the by-products and waste from smelting and refining activities[16] back to the process (e.g. drosses, mattes, and skimmings, pot and furnace linings, cleanouts) should be maximized. Large quantities of slag produced at the smelting stage may be processed (e.g., fuming to recover residual metals) to produce an inert granular material that can be sold for industrial use, such as cement manufacturing and insulation products. Waste from abatement systems, and sludge from leaching and wastewater treatment may be recycled into pyro-processing stages depending on the level of process integration available at the facility. Anode and tank bottom sludge may be recycled for residual metals recovery. Guidance for management and safe disposal of hazardous and non-hazardous industrial waste is addressed in the **General EHS Guidelines**. Generation and management of selected wastes specific to the non-ferrous metals smelting and refining sector are described below.

Spent Cathodes (Aluminum only)

Spent cathodes, also known as spent potlinings, are the major source of waste in primary aluminum manufacturing. A spent cathode consists of a carbon portion which was formerly the cathode from the electrolysis cell, and the refractory material which consists of various types of insulating material. The spent potlinings contain soluble fluoride and cyanide, and can produce an alkaline leachate if the material is rendered wet. Spent potlinings should be treated and reused (e.g. in pyrometallurgical furnaces, in cryolite production, in the cement industry, or as a fuel source) where possible, or disposed of according to the hazardous waste management guidance in the **General EHS Guidelines**.

Red Mud (Aluminum only)

Red mud is generated from the extraction of aluminum from bauxite and is an alkaline substance which requires controlled storage, typically in sealed (lined) ponds, to minimize potential for contamination of surface and ground water. Excess water from the mud is returned to the process.

Noise

Smelting and refining operations are inherently noisy due to the large amount of mechanical equipment, transport vehicles, physical activities, and energy usage, notably furnaces and steam. The significant sources are transport and handling of raw

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[16] Detailed guidance on waste minimization, reuse, and recycling opportunities is available in the European Commission (2001) Reference document on best available techniques (BREF) for the non-ferrous metals industries.

materials and products; the production processes involving pyro-metallurgy, grinding and milling operations; the use of pumps and fans; the venting of steam and the existence of unattended alarm systems. Guidance for noise management is provided in the **General EHS Guidelines**.

1.2 Occupational Health and Safety

Occupational health and safety issues should be considered as part of a comprehensive hazard or risk assessment, including, for example, a hazard identification study [HAZID], hazard and operability study [HAZOP], or other risk assessment studies. The results should be used for health and safety management planning, in the design of the facility and safe working systems, and in the preparation and communication of safe working procedures.

General facility design, operation, and monitoring measures to manage principal risks to occupational health and safety are provided in the **General EHS Guidelines**. General guidance specific to construction and decommissioning activities is also provided along with guidance on health and safety training, personal protective equipment and the management of physical, chemical, biological and radiological hazards common to all industries.

Occupational health and safety issues for further consideration in smelting and refining operations include:

- Chemical exposure
- Physical hazards
- Noise
- Radiation
- Confined space entry

Chemical exposure

The smelting and refining sector utilizes a number of hazardous materials including acids, alkalis, and chemical reagents (e.g., in leaching and precipitation of metals, and for pollution control systems); and process gases (e.g., oxygen, carbon dioxide, argon, nitrogen, chlorine, hydrogen, among others). Workers may be exposed to hazardous materials in organic and inorganic dusts, vapors, gases, mists and fumes released as part of operations and / or human activities in all stages of production and maintenance.

Inorganic hazardous materials typically include soluble and insoluble base metals (e.g. nickel, copper, and trace contaminants such as arsenic, antimony, thallium, mercury, and cadmium, among others). Trace contaminants and their metals depend on the nature of the ore being processed and the specific process being used. Exposure to acid mists may occur during leaching and / or electro-refining. Exposure to organic materials may include dioxins and furans, residual organic solvents used as reagents, and polycyclic aromatics associated with pitch fume and dust (in carbon electrode plants and aluminum reduction cell processes). Exposure to gases may include sulphur dioxide, ammonia, carbon monoxide, oxygen, arsine, chlorine, and fluoride, among others. Some gases may be metallic in nature such as cobalt, iron, and nickel carbonyls.

Guidance on managing exposure to chemicals and other hazardous materials, including the use of personal protection equipment (PPE), is addressed in the **General EHS Guidelines**. In addition, the following measures are recommended to prevent, minimize, and control potential chemical exposures:

- Enclose and isolate potential sources of air emissions to the extent practical;

- Provide continuous monitoring in areas where sudden and unexpected hazards may occur (e.g. where arsine or hydrogen cyanide releases might be possible);
- Monitor worker exposure using personal occupational hygiene sampling devices;
- Provide training and encourage good personal hygiene, and prohibit smoking and eating at the worksite;
- Automate processes and material handling to the extent practical and provide enclosures for operators;
- Provide local exhaust ventilation to limit exposure to, for example, sulfur dioxide, carbon monoxide, and sulfuric acid mists.

Physical hazards

Physical hazards, including exposure to heat from furnaces and molten metal and ergonomic stress, may result in bodily injury related to equipment operation, burns, and explosions associated with work involving hot metals (e.g. during pyro-processing activities), acids, caustics, solvents, leach solutions, and solutions used in electro-refining. Guidance on the management of physical hazards is provided in the **General EHS Guidelines**. In addition, the following measures are recommended to prevent, minimize, and control potential heat illnesses:

- Use water screens or air curtains in front of furnaces;
- Provide spot cooling where necessary;
- Install enclosed air-conditioned booths for operators;
- Proved heat-protective clothing and air-cooled suits;
- Allow sufficient time for acclimatization to hot environments, provide work breaks in cool areas, and provide an adequate supply of beverages for frequent drinking.

Noise

Smelting and refining personnel may be potentially exposed to high levels of noise from heavy equipment operation and furnaces. As most of these noise sources cannot be prevented, control measures should include the use of personal hearing protection by exposed personnel and implementation of work rotation programs to reduce cumulative exposure. Additional recommendations on the management of occupational noise are provided in the **General EHS Guidelines.**

Radiation

Occupational exposure to radiation may occur as a result of radioactive sources in certain process equipment (e.g. load cells and particulate monitors) and laboratory equipment. Recommendations on the management of radiation exposure are provided in the **General EHS Guidelines.**

Confined spaces

A smelting and refining facility has equipment and situations that require entry into confined spaces. Facilities should develop and implement confined space entry procedures as described in the **General EHS Guidelines**.

Electric and Magnetic Fields

Electric and magnetic fields (EMF) are invisible lines of force emitted by and surrounding any electrical device. Electric fields are produced by voltage and increase in strength as the voltage increases. Magnetic fields result from the flow of electric current and increase in strength as the current increases. Electric fields are shielded by materials that conduct electricity and other materials, such as trees and building materials. Magnetic fields pass through most materials and are difficult to shield. Both electric and magnetic fields decrease rapidly with distance. The power supplied to electrolytic reduction cells is direct current, and the electromagnetic fields generated in the potrooms are mainly of the static or standing field type. Such fields, in contrast to low frequency electromagnetic fields, are even less readily shown to exert consistent or reproducible biological effects. The flux levels of the magnetic fields measured cell rooms are commonly found to be within threshold limit values for static magnetic, sub-radio frequency and static electric fields. Exposure to ultra-low frequency electromagnetic fields may occur in reduction plants, especially adjacent to rectifier rooms. The flux levels found in the potrooms are minimal and below present standards.[17] EMF exposure may also be associated with electric arc furnaces and other electrical equipment.[18]

1.3 Community Health

Smelting and refining facilities are significant emitters of pollutants, which may result in health and safety hazards for nearby communities. A significant risk involves the accumulative contamination of land and dwellings in the community with fine metal particulate, and the consequential exposure and health risk to residents and the surrounding ecosystem. Deposition of metals (e.g., cadmium, copper, lead, zinc, and manganese) and other pollutants can also potentially affect crop and livestock production and the quality of agricultural products from nearby land. Emission controls described in Section 1.1 can minimize such impacts.

Smelting and refining facilities should develop and maintain a comprehensive environmental, health, and safety program through a cooperative process involving all interested parties, including community residents. The program should include the following components:

- Education and awareness raising among communities with regarding health risks related to smelter operations
- Baseline health assessment, as necessary
- Investigation of legacy issues for contaminated sites, including evaluation and remediation strategies
- Development of an emergency preparedness and response plan, with participation of affected communities and relevant regulatory agencies.
- The **General EHS Guidelines** provides further guidance for these and other community health and safety issues.

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[17] International Labour Organization, Encyclopedia of Occupational Health and Safety, Fourth Edition, Volume 3, Part XIII, Chapter 82. Available at http://www.ilo.org/encyclopedia/ .

[18] Individuals using cardiac pacemakers should be excluded from reduction operations because of the risk of magnetic field induced dysrhythmias.

2.0 Performance Indicators and Monitoring

2.1 Environment

Emissions and Effluent Guidelines

Tables 1 and 2 present the emission and effluent concentration guidelines for smelting and refining projects. 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 assumed to be 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. 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.

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 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 Guideline.** 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.

Resource Use

Table 3 provides an example of energy and water use from selected processes in the smelting and refining sector, which can be considered as an indicator of the efficiency of the sector and may be used to track performance changes over time.

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**.

Table 1. Air Emissions for Nickel, Copper, Lead, Zinc, and Aluminum Smelting & Refining*

Pollutant	Emission Source (by metal type / smelting process)	Units	Guideline Value
SO_2	**Copper**: Primary smelting and converting **Lead and Zinc**: Primary smelting, roasting and sintering **Nickel**: Roasting and smelting of sulphide concentrates and intermediates	>99.1% conversion efficiency (for ~ 1 – 4 percent SO_2 off gas) >99.7 % conversion efficiency (for >5 percent SO_2 off gas)	
	Copper: Secondary smelting and converting, primary and secondary fire refining, electric slag cleaning and melting **Aluminum**: Holding and de-gassing of molten metal from primary and secondary aluminum **Lead and Zinc**: Materials pre-treatment, secondary smelting, thermal refining, melting, slag fuming, and Waelz kiln operation	mg/Nm^3	<50 – 200[1,2,3]
NO_x	**Copper**: Secondary smelting and converting, primary and secondary fire refining, electric slag cleaning and melting **Aluminum**: Holding and de-gassing of molten metal from primary and secondary aluminum, materials pre-treatment, and from melting and smelting of secondary aluminum **Lead and Zinc**: Melting of clean material, alloying, and zinc dust production; From materials pre-treatment, secondary smelting, thermal refining, melting, slag fuming, and Waelz kiln operation **Nickel**: Leaching, chemical extraction and refining, electro-winning and solvent extraction; From materials pre-treatment incineration or after-burning, roasting, smelting thermal refining, and melting.	mg/Nm^3	100 – 300[4,5,6]
Acid Mists / Gases	**Copper**: Hydrometallurgical and electro-winning processes **Lead and Zinc**: Chemical refining, electro-winning, and solvent extraction **Nickel**: Leaching, chemical extraction and refining, electro-winning and solvent extraction	mg/Nm^3	50[1,7]
VOC / solvents (as C)	**Copper**: Hydrometallurgical and electro-winning processes **Lead and Zinc**: Chemical refining, electro-winning, and solvent extraction **Nickel**: Leaching, chemical extraction and refining, electro-winning and solvent extraction	mg/Nm^3	5 – 15[9]
Dust[22]	**Copper**: Secondary smelting and converting, primary and secondary fire refining, electric slag cleaning and melting, secondary fume collection systems, and drying. **Aluminum**: Primary aluminum electrolysis, from holding and de-gassing of molten metal from primary and secondary aluminum, materials pre-treatment, and from melting and smelting of secondary aluminum **Lead and Zinc**: Melting of clean material, alloying, and zinc dust production; From materials pre-treatment, secondary smelting, thermal refining, melting, slag fuming, and Waelz kiln operation **Nickel**: Materials pre-treatment incineration or after-burning, roasting, smelting thermal refining, and melting.	mg/Nm^3	1 – 5[3,10,11]
TOC (as C)	**Copper**: Secondary smelting and converting, primary and secondary fire refining, electric slag cleaning and melting **Aluminum**: Materials pre-treatment, and from melting and smelting of secondary aluminum **Lead and Zinc**: Melting of clean material, alloying, and zinc dust production; From materials pre-treatment, secondary smelting, thermal refining, melting, slag fuming, and Waelz kiln operation **Nickel**: Materials pre-treatment incineration or after-burning, roasting, smelting thermal refining, and melting.	mg/Nm^3	5 – 50[12,13]
Dioxins	**Copper**: Secondary smelting and converting, primary and secondary fire refining, electric slag cleaning and melting, secondary fume collection systems, and drying. **Aluminum**: Materials pre-treatment, and from melting and smelting of secondary aluminum **Lead and Zinc**: Melting of clean material, alloying, and zinc dust production; From materials pre-treatment, secondary smelting, thermal refining, melting, slag fuming, and Waelz kiln operation **Nickel**: Materials pre-treatment incineration or after-burning, roasting, smelting thermal refining, and melting.	ngTEQ/m^3	0.1 – 0.5[3,10,14,15,16]

Table 1. Air Emissions for Nickel, Copper, Lead, Zinc, and Aluminum Smelting & Refining (con't)*			
Pollutant	**Emission Source (by metal type / smelting process)**	**Units**	**Guideline Value**
Ammonia	**Nickel**: Leaching, chemical extraction and refining, electro-winning and solvent extraction	mg/Nm^3	5[17]
Chlorine		mg/Nm^3	0.5[2,18]
CO and carbonyls		mg/Nm^3	5[19]
Arsine	**Lead and Zinc**: Chemical refining, electro-winning, and solvent extraction	mg/Nm^3	0.5[6]
Mercury	All types of metals / smelting processes	mg/Nm^3	0.02
Hydrogen Chloride	**Aluminum:** Holding and de-gassing of molten metal from primary & secondary aluminum, materials pre-treatment, melting and smelting of secondary aluminum	mg/Nm^3	5[1]
Hydrogen Fluoride	**Aluminum**: Primary aluminum electrolysis, materials pre-treatment, and from melting and smelting of secondary aluminum	mg/Nm^3	0.5[10,20]
Total Fluoride	**Aluminum**: Primary aluminum electrolysis	mg/Nm^3	0.8[10,22]
Polyfluorinated hydrocarbons		0.1 (anode effects / cell / day)	

1. Alkali scrubber (semi-dry and fabric filter, wet scrubber or double alkali using lime, magnesium hydroxide, sodium hydroxide).
2. Combinations of sodium or alumina/aluminum sulphate in combination with lime.
3. For copper smelting, an SO_2 emission concentration of 500 mg/m^3 can be achieved through use of a fabric filter with lime injection.
4. Low NOx burner
5. Oxy-fuel burner
6. Oxidizing scrubber
7. De-mister
8. Excluding Aluminum smelting.
9. Containment, condenser, carbon and bio-filter
10. Fabric filter
11. Temperature control
12. Afterburner
13. Optimized combustion
14. Afterburner followed by quenching
15. Adsorption by activated carbon
16. Oxidation catalyst
17. Acidic scrubber
18. Collection and re-use
19. Process control and sealed reactor
20. Alumina scrubber
21. Excluding Aluminum smelting
22. Emissions of metals are dependent on the composition of the dust produced by the processes. The composition varies and is influenced by the process source of dust and by the raw materials that are being processed.

Source: Based in part on EU BREF in the Non-Ferrous Metals Industries (2001) *Associated emissions to air are given as daily averages based on continuous monitoring and standard conditions of 273 K, 101.3 kPa, measured oxygen content and dry gas without dilution of the gases with air. In cases where continuous monitoring is not practicable the value should be the average over the sampling period. If thermal cleaning and pyrolysis systems (e.g. swarf drying and de-coating) are used to destroy combustion products (e.g. VOCs and dioxins) oxygen content 6 percent dry.

Table 2. Effluent Levels for Nickel, Copper, Lead, Zinc, and Aluminum Smelting & Refining

Pollutant	Smelting type	Units	Guideline Value
pH	All	S.U.	6 - 9
Total Suspended solids	All	mg/l	20
COD	All	mg/l	50
Fluoride	Aluminum	mg/l	5
Hydrocarbons	Aluminum	mg/l	5
Aluminum	Aluminum	mg/l	0.2
Copper (Cu)	Copper	mg/l	0.1
Lead (Pb)	Copper, Lead & Zinc	mg/l	0.1
Arsenic (As)	Copper, Lead & Zinc	mg/l	0.05
Nickel (Ni)	Nickel, Copper	mg/l	0.1
Cadmium (Cd)	Copper, Lead & Zinc	mg/l	0.05
Zinc (Zn)	Copper, Lead & Zinc	mg/l	0.2
Mercury (Hg)	All	mg/l	0.01
Temperature Increase	All	°C	< 3[a]
Toxicity	To be determined on a case specific basis		

Source: Based in part on EU BREF in the Non-Ferrous Metals Industries

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

Table 3. Energy and Water Consumption

Facility Type	Energy Use (GJ/t)[a]
Copper--production from concentrate	14 – 20
Copper—electro-refining	1.1 – 1.4
Alumina production	8 – 13.5
Aluminum--primary production (electrolysis, including anode production)	53 - 61
Lead—shaft furnace, primary	6.8 – 10.3[b]
Lead—shaft furnace, secondary	4.4 – 5.5[b]
Lead—rotary furnace, secondary, with CX system and Na2SO4 production	4.0 – 4.7[b]
Lead—QSL	2.3 – 3.5[b]
Lead—Kivcet	4.9[b]
Lead—top blown rotary converter	4.0 – 4.4[b]
Zinc—electrolysis	15
Zinc—imperial smelting furnace & New Jersey distillation	44[b]
Zinc—Waelz kiln	26[b,c]
Zinc—slag fuming	7.7[b,d]
Nickel—matte from sulfide ores containing 4 – 15% Ni	25 – 65
Nickel--refining	17 - 20
Facility Type	**Water Use (kg/t)**
Alumina production	1000 – 6000
Aluminum--primary production (electrolysis, including anode production)	200 - 12000

Sources: EU BREF in the Non-Ferrous Metals Industries

Notes:

a Gigajoules (10^9 Joules) per metric ton

b Calculated based on quantities of coke, coal, natural gas, and electric power used and typical heat values of the petroleum fuels.

c Per ton of Waelz oxide leached

d Per ton of slag

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),[19] the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety (NIOSH),[20] Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United States (OSHA),[21] Indicative Occupational Exposure Limit Values published by European Union member states,[22] 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)[23].

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[24] 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**.

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[19] Available at: http://www.acgih.org/TLV/ and http://www.acgih.org/store/

[20] Available at: http://www.cdc.gov/niosh/npg/

[21] Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

[22] Available at: http://europe.osha.eu.int/good_practice/risks/ds/oel/

[23] Available at: http://www.bls.gov/iif/ and http://www.hse.gov.uk/statistics/index.htm

[24] 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

Base Metals Smelting and Refining

The process steps in base metals (copper, lead/zinc and nickel)[25] smelting and refining are similar and are shown in Figure A.1. The aluminum smelting process is described later in this annex. Depending on the ore grade and type of ore (e.g., sulphidic or lateritic ore) there are potential residual metals, including gold, silver, cadmium, arsenic, selenium etc., that may be recovered as co-products. A brief description of each process step has been provided below:

Pretreatment

Pretreatment consists of concentrating the ore by milling and drying slurried concentrates, and sorting/separating scrap materials to provide a feed material appropriate for further processing.

Roasting

Roasting is a pyrometallurgical processing where the concentrate is heated/dried and oxidized to achieve a sulphur content which is considered to be optimal for smelting. Incomplete roasting is used to prepare copper and nickel sulphides for matte smelting, while complete roasting eliminates sulphur and is used to produce metal oxide for (1) reduction by carbon or carbon monoxide or (2) leaching in sulphuric acid followed by electro-winning. Sulphur dioxide released during roasting is recovered as sulphuric acid or liquefied sulphur dioxide if cost effective, or the sulfur dioxide is removed by off-gas treatment.

Smelting

Smelting produces molten metals and is used to separate valuable metals from less valuable metals and impurities through a process known as fluxing. Metal concentrate from the roasting step is added to a furnace in addition with fluxing agents, fuel and oxygen. Combustion and oxidation occur in the furnace and cause the metals to melt and partially separate. Smelting produces molten matte (copper, nickel, zinc) or bullion (lead) forms of concentrated metals. The matte may be cast and allowed to cool before further processing. Process off-gases are captured by furnace ducts or overhead canopies and treated to remove sulphur dioxide, particulate matter, fumes etc. Smelter slag is usually treated to recover any residual metals of value.

Converting

Converting is used to remove residual sulphur and iron in copper and nickel matte. High-grade scrap metals can also be processed in converters. Process gases are cooled followed by removal of particulates by gas cleaning devices. Both batch and continuous converters are used; continuous converters allow for better capture of process off-gases and enable the use of oxygen instead of air, resulting in high concentration of sulphur dioxide that can be captured to produce sulphuric acid.[26] The matte (copper-iron sulphides) from the smelting step is charged to converters where the molten material is oxidized in the presence of air to remove the iron and sulphur impurities (as converter slag). Oxides form a slag that is skimmed off. Slag with high copper/nickel concentrations generated during the converting process is returned to the smelting process for recovery of copper and nickel. Slags may be processed in an electric furnace prior to discard to recover nickel.

Fire or Anode Refining

Fire refining is used to remove impurities and lowers sulphur and oxygen levels in blister copper prior to casting or

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[25] Environment Canada – Environmental Code of Practice, Canadian Environmental Protection Act. Base Metals Smelters and Refineries.

[26] Relatively volatile metals such as zinc and lead can also be recovered from the off-gas.

electrorefining. Blister copper is further refined as either fire-refined copper or anode copper (99.5% pure copper), which is used in subsequent electrolytic refining. Molten blister copper is placed in a fire-refining furnace, a flux may be added and air is blown through the molten mixture to remove residual sulphur. Air blowing results in residual oxygen, which is removed by the addition of natural gas, propane, ammonia or wood. The fire-refined copper is cast into anodes for further refining by electrolytic processes or is cast into shapes for sale.

Electrorefining

Electrorefining is used in copper, nickel and lead refining to produce a purified form of metal from a less pure form. An electrolytic cell, of which the metal forms an anode, is utilized to dissolve the metal into an acidic aqueous electrolyte or molten salt. The pure metal is electroplated or placed on starter plates which act as cathodes. The metallic impurities dissolve in the electrolyte or precipitate out and typically form a sludge. Anode slimes generated by the process contain precious metals that are recovered. Cathode deposits are cast into shapes. Impure electrolyte solutions are purified to remove unwanted impurities and returned to the electrorefining process. The removed impurities are further processed to recover metal values.

Carbonyl Refining

Carbonyl refining is used to refine crude nickel oxide. Carbon monoxide is added to the crude nickel oxide, and under high pressure, nickel carbonyl is formed. Nickel carbonyl is highly volatile and therefore separates from the solid impurities and is recovered from the off-gas stream. With additional heating, carbon monoxide is released and pure nickel powder or pellets are produced. Carbon monoxide off-gas is recycled in the process.

Leaching

Leaching which occurs prior to refining and electrowinning, involves the dissolution of metal from ores/concentrates in acid or other solvent. The metal used for leaching is generally in an oxide form. Sulphidic ores are leached less frequently because they require conditions that promote oxidation. The resulting solution, known as the pregnant leach solution is processed by solvent extraction and then purified prior to undergoing electrowinning and refining.

Electrowinning

Electrowinning is used to refine copper, nickel, and involves the recovery of metals that were dissolved in the “pregnant” solution during leaching. The purified electrolyte solution from the leaching process is placed in electrolytic cells containing inert anodes and starter cathodes. The dissolved metal ions are deposited onto the cathode after electric current is applied to the cell. Electrowinning generates oxygen gas, acid mist and spent electrolyte (which is returned to the leaching process for reuse). Cathodes are subsequently sold or the metal is removed and cast.

Casting

In the casting process, metal is melted and passed through a holding furnace and into a caster where different metal shapes are produced. Casting is either continuous or stationary. Stationary casting uses a wheel containing a series of moulds that are cooled by jets of water. Continuous casting produces is used to produce wire. Tubes are extruded from heated billets. Sheets and strips of metal are produced from preheated slabs and cakes which are rolled into shape. A fixed mould casting process is used to produce ingots.

Aluminum Manufacturing

The production of aluminum begins with the mining and beneficiation of bauxite. At the mine, bauxite ore is moved to a crusher following which the crushed ore is screened and stockpiled ready for delivery to an alumina plant. In some cases, ore is upgraded by beneficiation (washing, size classification, liquid/solid separation) to remove unwanted materials such as clay and silica.

At the alumina plant the bauxite ore is further crushed and/or ground to the correct particle size for efficient extraction of the alumina through digestion by hot sodium hydroxide liquor. After removal of a mixture of metal oxides known as "red mud" and fine solids from the process liquor, aluminum trihydrate crystals are precipitated and calcined in rotary kilns or fluidized bed calciners to produce alumina. Some alumina processes include a liquor purification step.

Primary aluminum is produced by the electrolysis of the alumina. The molten alumina is dissolved in a bath of cryolite (Na_3AlF_6) and an electric current is passed through the bath that causes the alumina to dissociate to form liquid aluminum at the cathode and oxygen at the anode. The oxygen then reacts with carbon in the electrode to produce carbon dioxide and carbon monoxide. Molten aluminum collects in the bottom of the individual cells or pots and is removed by means of vacuum tapping. This electrolysis is carried out in large scale with a high number of pots connected in series and result in the creation of a strong magnetic field in the process building.

Raw materials for secondary aluminum production are scrap, chips and dross. Scrap pretreatment by shredding, sieving magnetic separation, drying, etc. is designed for the removal of undesirable substances, which affect both aluminum quality and air emissions. The prevailing process for secondary aluminum production is smelting in rotary kilns under a salt cover. Salt slag processing and re-utilization is possible. Other processes, smelting in induction furnaces and hearth furnaces, need no or substantially less salt and are associated with lower energy demand. However, they are only suitable for high grade scrap. Depending on the desired application, additional refining may be necessary.

Figure A.1: Process Modules for Smelting and Refinig