Environmental, Health, and Safety Guidelines for Cement and Lime Manufacturing

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 cement and lime manufacturing include information relevant to cement and lime manufacturing projects. Extraction of raw materials, which is a common activity associated with cement manufacturing projects, is covered in the EHS Guidelines for Construction Materials Extraction. Annex A contains a full description of industry activities for this sector. This document is organized according to the following sections:

[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 cement and lime manufacturing, 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 Environment

Environmental issues in cement and lime manufacturing projects primarily include the following:

- Air Emissions
- Energy consumption and fuels
- Wastewater
- Solid waste generation
- Noise

Air Emissions

Air emissions in cement and lime manufacturing are generated by the handling and storage of intermediate and final materials, and by the operation of kiln systems, clinker coolers, and mills. Several types of kilns are currently used in cement manufacturing (preheater– precalciner (PHP), preheater (PH), long-dry (LD), semidry, semiwet, and wet process kilns). PHP kilns are generally preferred in terms of environmental performance. While shaft kilns are still in operation, they are generally only economically viable for small plants and are being phased out with the renewal of installations.

For lime manufacture, there are 4 basic types of kilns used to produce different types (reactivity) of quicklime: rotary, shaft vertical (more than 10 types), traveling grate, and gas suspension calcination.

Exhaust Gases

Combustion sources for power generation are common in this industry sector. Guidance for the management of small combustion source emissions with a capacity of up to 50 megawatt hours thermal (MWth), including air emission standards for exhaust emissions, is provided in the **General EHS Guidelines**. Guidance applicable to emissions sources greater than 50 MWth are presented in the **EHS Guidelines for Thermal Power**.

Particulate matter

Particulate matter (PM) emissions are among the most significant impacts of cement and lime manufacturing. The main sources of PM emissions and their respective recommended prevention and control methods include the following, as below.

For PM emissions associated with intermediate and final materials handling and storage (including crushing and grinding of raw materials); handling and storage of solid fuels; transportation of materials (e.g. by trucks or conveyor belts), and bagging activities, the recommended pollution prevention and control techniques include the following:

- Use of a simple, linear layout for materials handling operations to reduce the need for multiple transfer points;
- Use of enclosed belt conveyors for materials transportation and emission controls at transfer points;
- Cleaning of return belts in the conveyor belt systems;
- Storage of crushed and preblended raw materials in covered or closed bays;
- Storage of pulverized coal and petroleum coke (pet–coke) in silos;

- Storage of waste-derived fuels in areas protected from wind and other weather elements;
- Storage of clinker in covered / closed bays or silos with automatic dust extraction;
- Storage of cements in silos with automatic reclaiming and loading of bulk tankers;
- Storage of screened sizes of burnt lime in bunkers or silos and storage of fine grades of hydrated lime in sealed silos;
- Implementation of routine plant maintenance and good housekeeping to keep small air leaks and spills to a minimum;
- Conduct material handling (e.g. crushing operations, raw milling, and clinker grinding) in enclosed systems maintained under negative pressure by exhaust fans. Collecting ventilation air and removing dust using cyclones and bag filters;
- Implementation of automatic bag filling and handling systems to the extent possible, including:
  - Using a rotary bag filling machine with automatic paper bag feeder and fugitive emission control
  - Using automatic weight control for each bag during discharge
  - Using conveyor belts for transporting bags to a palletizing machine
  - Storing the finished pallets in covered bays for subsequent shipping

For particulate matter emissions associated with the operation of kiln systems, clinker coolers, and mills, including clinker and limestone burning, the following pollution prevention and control techniques, in addition to proper smoothing of kiln operations,[2] are recommended:

- Capturing kiln and cooler dusts using filters and recycling the recovered particulates into the kiln feed and into the clinker, respectively;
- Using electrostatic precipitators (ESPs) or fabric filter systems (baghouses) to collect and control fine particulate emissions in kiln gases;[3]
- Using cyclones to separate large particulates of cooler gases, followed by fabric filters;
- Capturing mill dust by fabric filters[4] and recycling within the mill.

Nitrogen Oxides

Nitrogen oxide (NO_X) emissions[5] are generated in the high-temperature combustion process of the cement kiln. The following prevention and control techniques, in addition to proper smoothing of kiln operations, are recommended:

- Maintaining secondary air flow as low as possible (e.g. oxygen reduction);
- Employing flame cooling by adding water to the fuel or directly to the flame (e.g. temperature decrease and hydroxyl radical concentration increase). The use of flame cooling can have a negative impact on fuel consumption, possibly resulting in a 2–3 percent increase, and a subsequent proportional increase of carbon dioxide (CO_2) emissions;
- Using low NO_X burners to avoid localized emission hot spots;

[2] Smoothing of kiln operations refers to maintaining the kiln in consistently optimum operating conditions.

[3] Although ESPs are reliable under normal operating conditions, there are risks of explosion when carbon monoxide (CO) concentrations in the kiln exhaust exceed 0.5 percent. To prevent these risks, operators should ensure appropriate and continuous management and control of the firing processes, including continuous monitoring of CO levels, particularly during kiln startup, in order to automatically switch off electricity when necessary.

[4] ESPs are not suitable for mill dedusting.

[5] Nitrogen monoxide represents more than 90 percent of NO_X emitted.

- Developing a staged combustion process[6],as applicable in preheater-precalciner (PHP) and preheater (PH) kilns;
- Lime manufacturing: Nitrogen oxide (NO_X) production is generally lower in *lime* manufacturing than in cement manufacturing. Because limestone burning usually takes place at lower temperatures, NO_X emissions from this source are lower and can be controlled using low NO_X burners.

Sulfur Dioxides

Sulfur dioxide (SO_2) emissions in cement manufacturing are primarily associated with the content of volatile or reactive sulfur in the raw materials[7] and, although less important, with the quality of fuels for power generation. Recommended pollution control techniques for reduction of SO_2, in addition to proper smoothing of kiln operations, include the following:

- Use of a vertical mill and gases passing through the mill to recover energy and to reduce the sulfur content in the gas. In the mill, the gas containing sulfur oxide mixes with the calcium carbonate ($CaCO_3$) of the raw meal and produces calcium sulfate (gypsum);
- Selection of fuel source with lower sulfur content;
- Injection of absorbents such as hydrated lime ($Ca(OH)_2$), calcium oxide (CaO), or fly ashes with high CaO content into the exhaust gas before filters;
- Use of wet or dry scrubbers.[8]

SO_2 emissions in lime manufacturing are generally lower than in cement because of the lower sulfur content of raw materials. Techniques to limit SO_2 emissions include the following:

[7] Raw materials with high content of organic sulfur or pyrite (FeS) result in elevated SO_2 emissions.

- Selection of quarried materials with lower volatile sulfur content;
- Injection of hydrated lime or bicarbonate into the exhausted gas stream prior to use of filters;
- Injection of finely divided quick or hydrated lime into the firing hood of the kiln.

Greenhouse gases

Greenhouse gas emissions, especially carbon dioxide (CO_2),[9] are mainly associated with fuel combustion and with the decarbonation of limestone, which in its pure form is 44 percent CO_2 by weight. Recommended techniques for CO_2 emission prevention and control, in addition to proper smoothing of kiln operations, include the following:

- Production of blended cements, which have the potential for significant reduction in fuel consumption and subsequent CO_2 emissions per ton of final product;
- Process selection and operation to promote energy efficiency (dry/ pre-heater / pre-calciner);
- Selection of fuel with a lower ratio of carbon content to calorific value (e.g. natural gas, fuel oil, or some waste fuel);
- Selection of raw materials with lower organic matter content.

Carbon monoxide (CO) makes a minor contribution to greenhouse gas emissions (less than 0.5–1 percent of total emitted gases).[10] These emissions are normally related to the

[8] Dry scrubbing is a more expensive and therefore less common technique than wet scrubbing and is typically used when the SO_2 emissions have the potential to be higher than 1500 mg/Nm^3.
[9] The greenhouse gas N_2O is not likely to be emitted from cement and lime plants because of the high temperatures and oxidizing conditions. The only potential source for N_20 would be direct releases from the raw material in the raw mill.
[10] CO represents an indicator of the conditions of the process. High CO readings are usually a warning sign that the manufacturing process is not performing properly (potentially involving higher fuel consumption). Carbon monoxide should be continuously monitored. In addition, when ESPs are used,

organic matter content of the raw material. Additional recommendations for the management of GHGs are provided in the **General EHS Guidelines.**

Heavy Metals and Other Air Pollutants

Heavy metals (e.g. lead, cadmium, and mercury) can be significant emissions from cement manufacturing, and are generated from the use of raw materials, fossil fuels, and waste fuel. Nonvolatile metals are mostly bound to the particulate matter. Volatile metal emissions, such as mercury,[11] are usually generated from both the raw materials and the waste fuels, and they are not controlled through use of filters.

Recommended techniques to limit emissions of heavy metals include the following:

- Implement efficient dust / PM abatement measures, as discussed above, to capture bound metals. For high concentrations of volatile heavy metals (in particular mercury), use of absorption on activated carbon may be necessary. The resulting solid waste should be managed as a hazardous waste as described in the **General EHS Guidelines**;
- Implement monitoring and control of the volatile heavy metal content in the input materials and waste fuels though implementation of materials selection. Depending on the type of volatile metals present in the flue gas, control options may include wet scrubbers and activated carbon adsorption;
- Operate the kiln in a controlled and steady manner to avoid emergency shutoffs of the electrostatic precipitators (if present in the facility);
- Waste fuel should not be used during start up or shut down.

Waste fuels

Cement kilns, due to their strongly alkaline atmospheres and high flame temperatures (2000°C), are capable of using high calorific value waste fuels (e.g. used solvents, waste oil, used tires, waste plastics, and organic chemical waste including polychlorinated biphenyls [PCBs], obsolete organochlorine pesticides, and other chlorinated materials). The use of waste fuel can lead to emissions of volatile organic compounds (VOCs), polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs), hydrogen fluoride (HF), hydrogen chloride (HCl), and toxic metals and their compounds if not properly controlled and operated.

Use of waste fuel or waste raw material in cement manufacturing requires a specific permit from the local authority. The permit should specify the amounts and types of waste that may be used either as fuel or as raw material, and it should also include quality standards such as minimum calorific value and maximum concentration levels of specific pollutants, such as PCB, chlorine, PAH, mercury, and other heavy metals.

Recommended prevention and control techniques for these types of air pollutants include the following:

- Implementing PM abatement techniques to reduce nonvolatile heavy metals emissions and managing the captured waste materials as a hazardous waste as described in the **General EHS Guidelines**;
- Implement monitoring and control of the volatile heavy metal content in the input materials and waste fuels though implementation of materials selection. Depending on the type of volatile metals present in the flue gas, control

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there is a risk of explosions related to CO concentrations higher than 0.5–1 percent.

[11] Mercury is primarily introduced into the kiln with raw materials (approximately 90 percent), with a minor amount (approximately 10 percent) coming from the fuels.

options may include wet scrubbers and activated carbon adsorption;

- Directly injecting fuels that have volatile metals or high VOC concentrations into the main burner rather than via the secondary burners;
- Avoiding the use of fuels with high content of halogens during secondary firing and during startup and shutdown phases;
- Keeping kiln gas cooling times (from 500 to 200°C) to a minimum to avoid or minimize the reformation of already destroyed PCDDs and PCDFs[12,13,14];
- Implementing proper storage and handling practices for hazardous and nonhazardous waste to be used as waste fuel or raw material, as described in the **General EHS Guidelines**.
- Waste fuel and waste raw materials are seldom used in *lime manufacturing* because of product quality requirements.[15]

Energy Consumption and Fuels

Cement and lime manufacturing are energy-intensive industries. Electric energy and fuel costs can represent 40–50 percent of total production costs. In addition to energy conservation recommendations provided in the **General EHS Guidelines**, sector specific includes the following.

Kilns

For new plants and major upgrades, good international practice for the production of cement clinker involves the use of a dry process kiln with multistage preheating and precalcination (PHP kilns). PHP kilns are the most common kiln used in the cement manufacturing industry. They have the lowest heat consumption (due to the high heat recovery from kiln gas in the cyclones, and the low kiln heat losses), and no water to evaporate (compared to wet kiln which uses slurry), while also offering the highest production capacity. PH kilns are also used widely due to their ease of operation. Heat consumption for PH kilns is only slightly higher than for PHP kilns, however their production capacity is significantly lower than PHP kilns. The remaining types of kilns (long-dry [LD], semidry, semiwet, and wet process kilns) are considered obsolete.[16] To further improve energy efficiency, the heat from the cooler should be used as hot process air, such as via a tertiary air duct in the precalciner.

For lime manufacture, annular shaft, parallel-flow regenerative, and other shaft kilns have lower energy consumption and higher fuel flexibility. Average heat and electric consumption in the different kilns is indicated in the 'Resource Use and Waste' section, below.

Coolers

The only type of clinker cooler now being installed is the 'grate cooler,' which is produced in many versions. The objective of

[12] PCDDs and PCDFs are destroyed in the flame and high-temperature gases, but at a lower temperature range (250–500°C), they can synthesize again. Short cooling times to below 200°C are usually possible in PHP and PH kilns, where the flow in the cyclones is quick, but this is much harder to obtain in other types of kilns.

[13] Use of activated carbon in the cement industry to adsorb trace volatile metals (e.g., mercury), VOCs, or PCDD–PCDF is still at pilot stage, mainly because of the different gas composition. Good operating conditions and careful selection of input materials may avoid the need for use of activated carbon.

[14] Additional information on the prevention and control of emissions of PCDDs and PCDFs is available at SINTEF, 2006.

[15] The fuel source used for lime manufacture has a significant impact on the quality of lime produced primarily due to the sulfur content, which is captured in the product and downgrades its value. Different fuels can have an impact on the product quality if combustion is not complete, therefore, due to their burning properties, natural gas and oil are the fuels most commonly used in lime manufacturing. Coal (low sulfur), or pet–coke, can be used when the resulting sulfur content in the product is not a concern. Waste fuel and waste raw materials are seldom used in lime manufacturing because of product quality requirements.

[16] Dry process kilns produce almost 80 percent of cement manufactured in Europe. Nondry kilns should be converted to the dry process when upgraded or expanded. Long-dry (LD) kilns have much higher heat consumption and typically have significant maintenance problems and related costs. Semidry and semiwet (Lepol) kilns have intermediate heat consumption because of the humidity content in the pelletized kiln feed. Semiwet kilns have higher electric consumption and higher maintenance costs due to the filter presses. The wet process kilns (now largely disused) is the oldest vertical kiln technology, with the

the cooler is to lower the clinker temperature as quickly as possible, and heat the secondary air to the highest temperature possible in order to reduce fuel consumption.

Fuels

The most commonly used fuel in the cement industry is pulverized coal (black coal and lignite), however the lower cost of petroleum coke (pet–coke) has resulted in increased use of this fuel type. Coal and pet–coke generate higher emissions of greenhouse gases (GHG) than fuel oil and natural gas (e.g. approximately 65 percent higher emissions than with gas).[17] In addition, high sulfur content in the fuel (characteristic of pet-coke) may create problems, including mainly sulfur buildup on rings in the kiln. Use of waste fuel as an alternative to traditional fuel is increasingly common in the cement industry, however related air emission concerns, as discussed above, should be considered.[18]

Pollution abatement measures may be necessary to ensure that no toxic emissions are generated from the firing of waste in cements kilns. Adequate monitoring (as discussed below in Section 2) should be conducted when waste fuels are being fired at cement plants.

Wastewater

Industrial Process Wastewater Treatment

Wastewater is generated mainly from utility operations for cooling purposes in different phases of the process (e.g. bearings, kiln rings) Process wastewater with high pH and suspended solids may be generated in some operations. Techniques for treating industrial process wastewater in this sector include flow and load equalization with pH adjustment; sedimentation for suspended solids reduction using settling basins or clarifiers; multimedia filtration for reduction in non-settleable suspended solids. 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.

Stormwater flowing through pet–coke, coal, and waste material stockpiles exposed to the open air may become contaminated. Stormwater should be prevented from contacting stockpiles by covering or enclosing stockpiles and by installing run-on controls. Recommended pollution prevention techniques for dust emissions from stockpiles of raw materials, clinker, coal, and waste (as above) may also help to minimize contamination of stormwater. If stormwater does contact stockpiles, soil and groundwater should be protected from potential contamination by paving or otherwise lining the base of the stockpiles, installing run-off controls around them and collecting the stormwater in a lined basin to allow particulate matter to settle before separation, control, and recycling or discharge. Further recommendations on managing contaminated stormwater are provided in the **General EHS Guidelines**.

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highest heat consumption and the lowest production capacity. Shaft kilns are no longer considered an appropriate technology for cement production.

[17] Fuel oil and natural gas account for less than 6 percent of total fuel consumption in Europe because they cost more than pet–coke and coal.

[18] Use of waste as alternative fuels has become a common practice in industrial countries. The average rate in the European Union (EU) is reported to be 12 percent. Alternative fuels include fuel residues, absorbent materials, shredded residues (e.g., plastics, rubber), low-chlorine plastics, tires, textiles, sewage sludge, and used filters.

Recommendations to reduce water consumption, especially where it may be a limited natural resource, are provided in the **General EHS Guidelines**.

Solid Wastes

Sources of solid waste in cement and lime manufacturing include clinker production waste, mainly composed of spoil rocks, which are removed from the raw materials during the raw meal preparation. Another potential waste stream involves the kiln dust removed from the bypass flow and the stack, if it is not recycled in the process.

Limited waste is generated from plant maintenance (e.g. used oil and scrap metal). Other waste materials may include alkali or chloride / fluoride containing dust buildup from the kiln.[19] In lime production, dust, off-specification quicklime, and hydrated lime are reused / recycled in selected commercial products (e.g. lime for construction uses, lime for soil stabilization, hydrated lime, and palletized products).

Guidance on the management of hazardous and non-hazardous wastes is provided in the **General EHS Guidelines**.

Noise

Noise pollution is related to several cement and lime manufacturing phases, including raw material extraction (discussed in the **EHS Guidelines for Construction Materials Extraction**); grinding and storage; raw material, intermediate and final product handling and transportation; and operation of exhaust fans. The **General EHS Guidelines** provides levels for recommended noise abatement measures and ambient noise levels.

[19] Older facilities still using largely discontinued semi-wet processes may also generate alkaline filtrates from filter presses.

1.2 Occupational Health and Safety

The most significant occupational health and safety impacts occur during the operational phase of cement and lime manufacturing projects and primarily include the following:

- Dust
- Heat
- Noise and vibrations
- Physical hazards
- Radiation
- Chemical hazards and other industrial hygiene issues

Dust

Exposure to fine particulates is associated with work in most of the dust-generating stages of cement and lime manufacturing, but most notably from quarry operation (see **EHS Guidelines for Construction Material Extraction**), raw material handling, and clinker / cement grinding. Exposure to active (crystalline) silica dust (SiO_2), when present in the raw materials, is a relevant potential hazard in the cement and lime manufacturing sector.[20] Methods to prevent and control exposure to dust include the following[21]:

- Control of dust through implementation of good housekeeping and maintenance;
- Use of air–conditioned, closed cabins;
- Use of dust extraction and recycling systems to remove dust from work areas, especially in grinding mills;
- Use of air ventilation (suction) in cement-bagging areas;

[20] Portland cement is considered to be a "nuisance dust" by the American Conference of Governmental Industrial Hygienists (ACGIH). Workers with long-term exposure to fine particulate dust are at risk of pneumoconiosis, emphysema, bronchitis, and fibrosis.

[21] Further information on prevention and control of silica inhalation hazards is available from the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA), Silica eTool, available at: http://www.osha.gov/SLTC/etools/silica/index.html

- Use of PPE, as appropriate (e.g. masks and respirators) to address residual exposures following adoption of the above-referenced process and engineering controls;
- Use of mobile vacuum cleaning systems to prevent dust buildup on paved areas;

Heat

The principal exposures to heat in this sector occur during operation and maintenance of kilns or other hot equipment, and through exothermic reactions in the lime-hydrating process. Recommended prevention and control techniques include the following:

- Shielding surfaces where workers' proximity and close contact with hot equipment is expected, using personal protective equipment (PPE), as needed (e.g. insulated gloves and shoes);
- Minimizing the work time required in high temperature environments by implementing shorter shifts at these locations;
- Making available and using, as needed, air- or oxygen-supplied respirators;
- Implementing specific personal protection safety procedures in the lime-hydrating process to avoid potential exposure to exothermic reactions.

Noise and Vibrations

Exhaust fans and grinding mills are the main sources of noise and vibrations in cement and lime plants. Control of noise emissions may include the use of silencers for fans, room enclosures for mill operators, noise barriers, and, if noise cannot be reduced to acceptable levels, personal hearing protection, as described in the **General EHS Guidelines**.

Physical hazards

Injuries during cement and lime manufacturing operations are typically related to slips, trips, and falls; contact with falling / moving objects; and lifting / over-exertion. Other injuries may occur due to contact with, or capture in, moving machinery (e.g. dump trucks, front loaders, forklifts). Activities related to maintenance of equipment, including crushers, mills, mill separators, fans, coolers, and belt conveyors, represent a significant source of exposure to physical hazards. Management of these types of hazards is described in the **General EHS Guidelines**.[22]

Radiation

An X-ray station is sometimes used to continuously monitor the raw material mix on the belt conveyor feeding the raw mill. Operators of this equipment should be protected through the implementation of ionizing radiation protection measures as described in the **General EHS Guidelines**.

Chemical Hazards and other Industrial Hygiene Issues

Chromium may contribute to allergic contact dermatitis among workers handling cement.[23] Prevention and control of this potential hazard includes a reduction in the proportion of soluble chromium in cement mixes and the use of proper personal protective equipment (PPE) to prevent dermal contact, as described in the **General EHS Guidelines**.

The potential accidental contact with CaO / CaOH on skin / eyes / mucous membranes is a specific hazard in lime production

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[22] Further guidance is available in World Business Council for Sustainable Development (WBCSD), Cement Sustainability Initiative (CSI), Health and Safety in the Cement Industry: Examples of Good Practice (2004) available at: http://www.wbcsdcement.org/pdf/tf3/tf3_guidelines.pdf

[23] Tests on American cement show 5–124 parts ppm chromium content, while European cements contain 32–176 ppm. The EU regulates soluble chromium (Cr VI) in cement to a maximum of 0.0002 percent of the total dry weight of the cement, to prevent allergic contact dermatitis.

plants that needs to be assessed, prevented, and mitigated through emergency procedures and equipment. The presence of moisture may result in burns. Facilities for immediate washing of the affected body surface should be available, including eyewash facilities where quicklime is handled. The handling areas should be covered and enclosed, if possible, to avoid generation of a dust hazard. Additional guidance on the management of chemical hazards is presented in the **General EHS Guidelines**.

1.3 Community Health and Safety

Community health and safety impacts during the construction, operation, and decommissioning of cement and lime manufacturing facilities are common to those of most industrial facilities and are discussed in the **General EHS Guidelines**.

2.0 Performance Indicators and Monitoring

2.1 Environment

Emissions and Effluent Guidelines

Tables 1, 2 and 3 present emission and effluent 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. 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. Air emission levels for cement manufacturing*

Pollutants	Units	Guideline Value
Particulate Matter (new kiln system)	mg/Nm³	30[a]
Particulate Matter (existing kilns)	mg/Nm³	100
Dust (other point sources incl. clinker cooling, cement grinding)	mg/Nm³	50
SO_2	mg/Nm³	400
NO_X	mg/Nm³	600
HCl	mg/Nm³	10[b]
Hydrogen fluoride	mg/Nm³	1[b]
Total Organic Carbon	mg/Nm³	10
Dioxins–furans	mg TEQ/Nm³	0.1[b]
Cadmium & Thallium (Cd+Tl)	mg/Nm³	0.05[b]
Mercury (Hg)	mg/Nm³	0.05[b]
Total Metals[c]	mg/Nm³	0.5

NOTES:
* Emissions from the kiln stack unless otherwise noted. Daily average values corrected to 273 K, 101.3 kPa, 10 percent O_2, and dry gas, unless otherwise noted.
[a] 10 mg/Nm³ if more than 40 percent of the resulting heat release comes from hazardous waste.
[b] If more than 40 percent of the resulting heat release comes from hazardous waste, average values over the sample period of a minimum of 30 minutes and a maximum of 8 hours.
[c] Total Metals = Arsenic (As), Lead (Pb), Cobalt (Co), Chromium (Cr), Copper (Cu), Manganese (Mn), Nickel (Ni), Vanadium (V), and Antimony (Sb)

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 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**. 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**.

Table 2. Air emission levels: Lime manufacturing

Pollutants	Units	Guideline Value[a]
Dust	mg/Nm^3	50
SO_2	mg/Nm^3	400
NO_X	mg/Nm^3	500
HCl	mg/Nm^3	10

NOTES:
[a] Daily average values corrected to 273°K, 101.3 kPa, 10% O_2, and dry gas, unless otherwise noted.

Table 3. Effluent levels: Cement and lime mnfg.

Pollutants	Units	Guideline Value
pH	S.U.	6–9
Total suspended solids	mg/L	50
Temperature increase	°C	<3[a]

[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

Resource Use and Waste

The following Tables 4–7 provide examples of resource use and waste generation in this sector that can be considered as indicators of this sector's efficiency and may be used to track performance changes over time.

Table 4. Resource and energy consumption.

Inputs per unit of product	Unit	Industry benchmark
Fuel energy – cement	GJ/t clinker	3.0–4.2[a,b,c,d,g]
Electric energy – cement	kWh/t equivalent cement	90–150[a,b,c]
Electric energy – clinker grinding	kWh/t	40–45
Fuel energy – lime	GJ/t lime	4–4.7 mixed-feed shaft kilns[b] 3.6–6 advanced shaft and rotary kilns[b]
Electric energy – lime	kWh/t equivalent lime	5–15 mixed-feed shaft kilns[b] 20–40 advanced shaft and rotary kilns[b]
Materials Substitute raw materials used in production of clinker	%	2–10[a,f,h]
Substitute raw materials in production of cement	%	0–70/80 with blast furnace slag =0–30 with fly ash

NOTES: Please see table 5 for notes and sources.

Table 5. Emission and waste generation.

Outputs per unit of product	Unit	Industry benchmark
Waste	kg/t	0.25–0.6[a]
Emissions Dust	g/t equivalent cement	20–50[a]
NO_x	g/t equivalent cement	600–800[b]
SO_x	kg/t	0.1–2.0[a,h]
CO_2 From decarbonation[i] From fuel[j]	kg/t kg/t equivalent cement	400–525[a,e,f,h,k] 150–350[a,e,f,h]

[a] Buzzi–Unicem (2004).
[b] IPPC (2001).
[c] Ernest Orlando Lawrence, Berkeley National Laboratory (2004).
[d] NRCan (2001).
[e] CIF (2003).
[f] Italcementi Group (2005).
[g] Environment Canada (2004).
[h] Lafarge (2004).
[i] Influenced by the variable quantities of fly ash and other additives used.
[j] CO2 emissions from waste incineration (at least from the biodegradable fraction) are regarded as neutral in several countries.
[k] World Business Council on Sustainable Development, Cement Sustainability Initiative, 2002.

Table 6. Heat consumption and production capacity for cement manufacture kilns.		
Kiln type	**Heat consumption (MJ/t clinker)**	**Maximum production capacity (t/day)**
Preheater–precalciner — 3–6 stages	3 000–3 800[a]	12 000
Preheater	3 100–4 200	4 000
Long dry	=5 000	3 800
Semidry–semiwet (Lepol)	3 300–4 500	2 500
Wet process	5 000–6 000	1 500–2 000

NOTES:
[a]Six stage preheater–precalciner can achieve 2900 MJ/t clinker under optimum conditions.
Source: IPPC (2001).

Table 7. Average heat and electric consumption for four types of lime kilns.		
Kiln type[24]	**Heat consumption (MJ/t lime)**	**Electric consumption (kWh/t lime)**
Shaft kilns	3600–4500	5–45
Rotary kilns	4600–5400	18–40
Traveling grate	3700–4800	31–38
Gas suspension preheater[25]	4600–5400	20–25

Source: IPPC (2001).

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),[26] the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety (NIOSH),[27] Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United States (OSHA),[28] Indicative Occupational Exposure Limit Values

[24] Reactive calcium quicklime involves a higher consumption.
[25] Only one plant reported, which has been operating in Norway since 1986.

[26] Available at: http://www.acgih.org/TLV/ and http://www.acgih.org/store/
[27] Available at: http://www.cdc.gov/niosh/npg/
[28] Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

published by European Union member states,[29] 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, UK Health and Safety Executive, World Business Council for Sustainable Development – Cement Sustainability Initiative).[30]

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[31] as part of an occupational health and safety monitoring program. Facilities should also maintain a record of occupational accidents, diseases, and dangerous occurrences and other accidents. Additional guidance on occupational health and safety monitoring programs is provided in the **General EHS Guidelines**.

[29] Available at: http://europe.osha.eu.int/good_practice/risks/ds/oel/
[30] Available at: http://www.bls.gov/iif/ and http://www.hse.gov.uk/statistics/index.htm and www.wbcsd.ch and http://www.wbcsdcement.org/
[31] 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

Cement and limestone production processes are similar. Both involve quarrying and mining, grinding, and homogenizing raw materials as illustrated in figure A.1. To minimize transportation costs and allow the opportunity for the use of belt conveyors, cement and lime manufacturing is typically located adjacent to the sources of raw materials and in proximity to product markets. Cement can be economically distributed by trucks in a relatively small radius (around 100–150 km from the plant), and if the plant is located on a water body, transport can be accomplished with barge or ships. A compact single production line (preheater-precalciner [PHP], preheater [PH] kiln with 3,000 tons / day clinker production capacity) typically needs around 400,000 m^2 in a flat area, as well as an additional area [for example, 250,000 m^2] for future expansion. The typical project facility lifespan is at least 40 to 50 years. The size of the plant is an important factor, as differences in production scale have a significant impact on production costs and, consequently, on investment costs for pollution abatement and control technologies. The same level of environmental performance can be achieved by small plants at a higher cost per cement production than by large plants.

Cement Manufacturing

Cement manufacturing uses energy to process raw materials consisting of mainly limestone (calcium carbonate, $CaCO_3$), clay (aluminum silicates), sand (silica oxide), and iron ore to produce clinker, which is ground with gypsum, limestone, etc to produce cement.

After an initial preblending stage, the raw materials are mixed together and ground to form a homogeneous blend with the required chemical composition (the raw meal). The fineness and particle size distribution of the raw meal are important characteristics for the burning process. Following mixing, the production process continues in a rotary kiln by calcining the raw meal (e.g. decomposing $CaCO_3$ at about 900°C), releasing carbon dioxide (CO_2) and leaving CaO. This is followed by the clinkering process, in which CaO reacts at a high temperature (1,400°C to 1,500°C) with silica, alumina, and ferrous oxides. Other constituents may be added in the raw material mix to meet the required composition (e.g. silica sand, foundry sand, iron oxide, alumina residues, blast furnace slag, and gypsum residues). The temperature of the flame and produced gases is close to 2,000°C. The hot clinker falls from the kiln onto the cooler, where it must be cooled as quickly as possible to improve the clinker quality and to recover energy by heating secondary air. Grate coolers are typically employed for this purpose (as opposed to the use of satellite coolers). The cooled clinker is then ground with gypsum and limestone to produce portland cement and ground with other additional constituents to produce composite or blended cements. Cement is then stored in silos or bags. The blending constituents are materials with hydraulic properties (e.g. natural pozzolane, fly ash, blast furnace slag, and occasionally bottom ash). In fly and bottom ashes, carbon residues (typically from coal-fired power plants) should not be present. $CaCO_3$ is sometimes added in small quantities as filler.

Lime Manufacturing

Lime is produced by burning $CaCO_3$ or (less frequently) dolomite (calcium and magnesium carbonate), providing sufficient heat to reach temperatures of above 800°C and cause decarbonation of the raw material to produce calcium oxide (CaO, known as quicklime). The quicklime is then maintained at temperatures of 1,200-1,300°C, to adjust reactivity. The burned lime can be delivered to the end user in the form of quicklime (hard, medium, and soft burned, based on their reactivity). Soft-burnt lime is the most reactive and commonly employed by steel producers. Alternatively, quicklime is transferred to a hydrate plant where, with a strong exothermic reaction, it reacts with water to produce slaked lime (calcium hydroxide, $Ca(OH)_2$). Slaked lime can have two forms: dry (powder) or milk of lime (liquid). The slaked lime production process consists of size separation, hydrating, and storage in silos (dry) for sale in bulk or bags, or in tanks (milk). Care should be taken to ensure that water is excluded from quicklime (in addition to air humidity), because it causes hydration that liberates heat and causes expansion, which can be dangerous for safety.

Figure A.1: Manufacturing Processes