Introduction

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

2. 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.

3. 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.

4. 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

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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.
assessment. This justification should demonstrate that the choice for any alternate performance levels is protective of human health and the environment.

### Applicability

5. 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 processes, is covered in the **EHS Guidelines for Construction Materials Extraction**.³ Annex A contains a full description of industry activities for this sector. This document is organized **according to the following sections as follows:**

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

### 1. Industry-Specific Impacts and Management

6. The following section **Section 1** 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

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

- **Energy use**
- **Greenhouse gases (GHGs)**
- **Air emissions**
- **Energy consumption and fuels**
  - Wastewater
  - Solid waste generation

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³ Limestone’s particular chemistry, hydrology, geology, and associated microclimates can lead to the evolution of unique biodiversity and associated ecosystem services. Potential impacts due to a project on limestone-restricted biodiversity, including the associated species, their habitats, and ecosystem services provided by them, must be assessed and mitigated where necessary. For more information, see BirdLife, FFI, IUCN, and WWF (2014); IUCN (n. d.); WBCSD (2011c); and WBCSD (2014a).
8. Cement and lime manufacturing are generated by energy-intensive industries. In addition to energy conservation recommendations provided in the handling and storage of intermediate and final materials, and by General EHS Guidelines, the operation of kiln systems, clinker coolers, and mills following sections provide sector-specific energy-efficiency guidance for thermal and electrical energy use.

Cement and Lime Kilns

8.9. Several types of kilns are currently used in cement manufacturing (including preheater—precalciner (PHP), preheater (PH), and long-dry (LD) kilns, and semidry, semiwet, and (Lepol) wet process kilns). PHP kilns are generally preferred in terms of environmental performance. While, and shaft kilns are still in operation, they are generally only economically viable for small plants and are being phased out due to the superior energy efficiency of dry rather than non-dry kilns. PHP kilns are the most commonly used kilns in the cement manufacturing industry. PHP kilns have the lowest thermal energy demand (due to the high rate of heat recovery from kiln gas in the cyclones, and the utilization of recovered waste heat in the precalciner) and no water to evaporate (unlike a semi-wet or wet kiln whose raw material is in a damp or slurry form), while also offering the highest production capacity. Specific thermal energy demand of PH kilns is typically 5–15 percent higher than that of PHP kilns. The other types of kilns (long dry, semidry, semiwet, and wet process kilns) are considered obsolete. For new cement plants and major upgrades, GIIP for the production of cement clinker therefore involves the use of a dry process kiln equipped with multistage...
10. In addition to cement kiln technology selection, additional thermal energy efficiencies can be realized through optimization techniques for the kiln, including high-capacity utilization, optimized length/diameter ratio, optimized kiln design in regard to the fuel type utilized, optimized kiln firing systems, maintenance of uniform and stable operating conditions, optimization of process controls, provision of tertiary air ducts (for precalciner), maintaining near-stoichiometric but oxidizing kiln conditions, use of mineralizers, reduction of air-in leakage, and maintenance of kiln refractory specifications. Under optimized conditions, specific thermal energy use of a multistage PHP kiln should be in the range of 2.9–3.3 gigajoule (GJ)/tonne of clinker.

11. For lime manufacturing, various types of kilns—such as long rotary kilns (LRK), rotary kilns with preheater (PRK), parallel flow regenerative kilns (PFRK), annular shaft kilns (ASK)—are employed. Mixed-feed shaft kilns such as ASK, PFRK, and other vertical/shaft kilns have significantly lower thermal energy consumption (in the range of 3–5 GJ/tonne of lime) and higher fuel flexibility than rotary kiln applications (in the range of 5–8 GJ/tonne). In addition to energy use considerations, other key factors influencing the kiln selection include the characteristics of the limestone (for example, PRFK kilns generally cannot process very small limestone grain sizes), fuel availability and properties, and lime product properties as required by customers. Where lime product volumes and quality considerations allow, the use of vertical kilns is considered GIIP for their superior environmental/energy efficiency performance (among vertical kilns, the PRFK technology is the most energy efficient). Lime kiln thermal energy efficiency can be optimized (i) through the use of energy management and process controls, including optimizing fuel quality (high calorific value/low moisture), flow rates, and combustion conditions; (ii) optimizing stone grain size; (iii) limiting excess air in LRK and PRK kilns; (iv) maintenance of equipment, including ensuring kiln refractory/insulation lining integrity; and (v) other techniques specific to different lime production kiln types.

Clinker Coolers

12. The objective of the cooler is to lower the clinker temperature as quickly as possible to control product quality and allow clinker temperatures suitable for final grinding/mixing stages. Hot air recovered from the

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7 EC (2013), sec. 4.2.3.2, Technique C, 343.
8 Additional techniques to optimize the thermal efficiency of the calciner and preheater are discussed in EC (2013), sec. 1.4.2.1.1, page 100.
9 EC (2013), sec. 1.4.2.1.1, page 100.
10 EC (2013), table 2.23, page 223.
12 Additional energy optimization techniques for various types of lime kilns is discussed in EC (2013), sec 2.4.1, Table 2.34, page 252.
cooler provides combustion air for the kiln’s main burner flame and the preheater/precalciner, or can be used for other drying purposes, thus reducing fuel consumption. The only type of clinker cooler now being installed is the grate cooler (which is produced in many versions), primarily due to its high capacity and superior heat recovery efficiency compared with other cooler types (later generation grate coolers have heat recovery rates of ~65–75 percent).\textsuperscript{13} GIIP involves the use of high-efficiency grate coolers (for example, stationary preliminary grate) and the use of thermal optimization techniques, including, for example, the use of cooler grate plates offering a greater flow resistance to provide a more uniform distribution of cooling air, control of cooling air supply to the individual grate sections, and the use of variable speed drives for cooler fans.\textsuperscript{14}

Other Energy-Efficiency Measures\textsuperscript{15}

13. Electrical energy use varies in a range of approximately ~80–120 kilowatt hour (kWh)/tonne cement.\textsuperscript{16,17,18} Motors account for a significant portion of total electrical energy use (there are typically over 500 motors at a cement facility) to power fans and other equipment, in particular for grinding.\textsuperscript{19} Electrical energy demand at different stages of the cement production process includes raw material grinding and homogenization (~30 percent of total electrical energy use); clinker production (~25 percent); and cement production, including finishing grinding, mixing and packing/transport (~45 percent).\textsuperscript{20}

14. Electrical energy use in cement processing can be minimized through selection of high-efficiency equipment, and energy-efficiency techniques including the (i) use of automated process controls for mills and separators/classifiers in raw meal grinding/preparation, fuel management, and finishing grinding; (ii) the installation of power management systems; (iii) the use of energy-efficient equipment, including mechanical material conveyor systems (less power consumption than pneumatic systems) and gravity-type blending/homogenizing silo systems (less power consumption than air-fluidized systems); (iv) the use of vertical and horizontal (Horomill\textsuperscript{TM} roller mills and roller press/high pressure grinding systems (often 50 percent more efficient than ball mills)) and high-efficiency (third generation) separators/classifiers for raw

\textsuperscript{13} IIP (n.d.), Industrial Efficiency Technology Database. “Conversion to High-Efficiency Grate Coolers.”
\textsuperscript{14} EC (2013), sec. 1.4.2.1.1, page 100.
\textsuperscript{15} Additional useful information can be found in the EC’s Reference Document on Best Available Techniques for Energy Efficiency (EC (2009)).
\textsuperscript{16} Wang et al. (2012).
\textsuperscript{17} WBCSD (2016), “Getting the Numbers Right,” dataset 33AGW.
\textsuperscript{18} EC (2013), sec. 1.3.3.2, page 49.
\textsuperscript{19} See IIP (n.d.) Industrial Efficiency Technology Database. “High Efficiency Motors and Drives.”
\textsuperscript{20} CEMBUREAU (2013), chapter on “Electrical Energy Efficiency.” As noted in the introduction of this Guideline, the EHS elements of raw material extraction are covered in the IFC EHS Guidelines for Construction Materials Extraction.
meal and fuel preparation and cement grinding; (v) the use of high-efficiency, low pressure drop preheater cyclones (to reduce power use in the kiln exhaust gas system); (vi) the use of high-efficiency, well-maintained motors for transport, grinding, and kiln-related operations; and (vii) the use of variable speed drives for motors and fans in the kiln, cooler, preheater, separator, and mills, among others. Collectively, these techniques can realize electrical energy savings with favorable payback periods for investments.  

15. Electrical energy use in lime manufacturing accounts for a small portion (~10 percent) of energy use, typically in the range of 60 kWh/tonne of lime. Opportunities to improve the efficiency of electrical energy use are primarily related to (i) the use of process and power management controls; (ii) improving the efficiencies of motors; and (iii) optimizing the cooling and crushing/grinding processes through the use of high-efficiency equipment. These initiatives can yield electrical energy savings (for example, improvements to motor efficiencies can be in the range of 10 percent).

Greenhouse Gases

16. GHG emissions in the cement industry, in particular emissions of carbon dioxide (CO₂), are mainly associated with calcination of limestone during clinker production (~55 percent of total CO₂ emissions), fuel use to heat the kiln (~35 percent of CO₂ emissions typically from use of carbon-intensive fuels including coal and petcoke), and electricity use and transportation (~10 percent of total CO₂ emissions, depending on the electricity source). The GHG emissions’ intensity of cement production varies depending on (i) the composition of the kiln feedstock; (ii) the type of fuel used for combustion; (iii) the facility’s general level of energy efficiency and choice of kiln technology; (iv) the clinker-to-cement ratio; and (v) the carbon intensity of the electricity supply. While conventional fossil fuels remain the dominant fuel source among the leading global cement producing countries (including China and India (first and second rank in 2015 global...
cement production, respectively). The substitution of fossil fuel use with waste fuels and biomass is increasing globally.

17. Limestone decarbonation and fuel-related CO₂ emissions in the lime production process are similar to cement manufacturing. However, there is generally less electricity consumption and related CO₂ emissions from lime than cement manufacturing. Lime production is also dominated by conventional fossil fuel use among leading producers.

18. GHG emissions associated with the cement or lime manufacturing project and associated thermal power generation should be quantified annually in accordance with internationally recognized methodologies and good practices.

19. Recommendations for the management of GHG emissions are provided in the General EHS Guidelines. In addition to the energy efficiency measures discussed in preceding sections of this Guideline, sector-specific techniques for CO₂ emission minimization in cement manufacturing include the following:

- Production of blended cements (in which clinker is partially substituted with fly ash, blast furnace slag, natural volcanic materials, calcined clay, and/or ground limestone) or new cementitious materials which are less energy and GHG-intensive than clinker per unit of final product, resulting in significant reduction in fuel consumption and subsequent CO₂ emissions.
- Substitution/co-firing of conventional (coal/petcoke) fuels with alternative fuels with a lower ratio of carbon content to calorific value, including natural gas, fuel oil, select waste fuels (as discussed in

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30 CEMBUREAU (n.d.).
31 Typical waste fuels used in the cement industry can include non-hazardous and hazardous wastes with varying levels of calorific value. A list of commonly used waste fuels can be found in EC (2013), sec. 1.2.4.3.1, page 22, and may include used solvents, waste oil, used tires, refuse derived fuel (PDF), and waste plastics, among others.
32 As reported in the WBCSD “Getting the Numbers Right” database (whose reporting members covered 21 percent of global clinker production in 2013), conventional fossil fuels accounted for ~85 percent of global fuel use for cement manufacturing (on a % of total energy basis), followed by mixed fossil/waste fuels (~10 percent) and biomass fuels (~5 percent). Corresponding values in 2000 were ~95% conventional fossil fuels, ~4% mixed fossil/waste fuels, and ~1% biomass fuels. WBCSD, “Getting the Numbers Right,” dataset 25aAGFC, for “World” and “EU States 28.”
33 Carbon capture and storage or reuse technologies in the cement industry should be considered as their technical and commercial viability are more clearly demonstrated in the future. Further information is available in IEAGHG (2013).
34 For example, for cement containing 30 to 70 percent of granulated blast furnace slag (GBFS), CO₂ emissions can be reduced by 100 to 430 kg per every ton of cement, compared with typical emissions of 750 kg CO₂ per ton of cement. The increased use of blended cements depends on the availability, properties, and prices of substitute materials; the intended application of the cement product (market considerations), and national standards. See IIP (n.d.), Blended Cement Alternatives.
35 Clinker to cement ratios among the major cement producers vary, including China with a ratio of 63% in 2011 (73% in 2005); India with a ratio of 70.5% in 2013 (77.8% in 2005); the European Union with a ratio of 73.6% in 2013 (75.8% in 2005); and the United States with a ratio of 83.5% in 2013 (83.7% in 2005). For cement to clinker ratios for China, see Ke et al. 2013, p. 7. For information on India, the EU, and the U.S., see WBCSD, “Getting the Numbers Right,” dataset 92AGW, for “India”, “EU States 28”, and “United States.”
the Air Emissions section and the Waste Fuels, Wastes, and Associated Air Emissions sub-section below); biomass fuels such as rice, coffee husks, palm kernel shells, wood-waste, among others; and refuse-derived fuels (where such alternative fuels are available in sufficient quantities at economic cost).

- Partial substitution of limestone feedstock with non-carbonated sources of calcium oxide (such as blast furnace slag, lignite ash, coal ash, concrete crusher sand, etc.) to reduce process CO₂ emissions and fuel CO₂ emissions related to calcination. 

- Waste gases discharged from the kiln, the clinker cooler system, and the kiln pre-heater system all contain useful energy that can be used for raw material and fuel drying, and/or for power generation. Although cement manufacturing does not typically have significant low-temperature heating requirements, heat that remains after process heat recovery can be recovered via heat recovery boilers for use in a stand-alone power generation cycle, or to supplement steam produced from fuel combustion for on-site captive power generation. The amount of waste heat available for heat recovery power generation depends on kiln system design and production, the moisture content of the raw materials, and the amount of heat required for drying in the raw mill system, solid fuel system, and cement mill. Waste heat recovery power generation can provide up to 30 percent of a cement plant’s overall electricity needs through various types of Rankine Cycle-based systems, in particular the Steam Rankine Cycle, which accounts for the vast majority of waste heat recovery systems (other systems include the Organic Rankine Cycle, and Kalina Cycle).

9. 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

20. Lime Manufacturing. GHG emissions can be minimized through (i) the use of more efficient vertical kilns (depending on production volume and lime product specifications) and kiln optimization (as discussed in the Energy Use section above); (ii) waste heat recovery from the kiln and during lime hydration (waste heat can be used in raw material drying and milling); and (iii) fuel switching toward less GHG intensive

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37 See US EPA (2013), pages 76–80; and IIP (n.d.), Alternative Raw Materials. The extent to which alternative feedstocks can be used depends on the composition of the available conventional raw materials (e.g., limestone) and the availability, cost and composition of alternative feedstocks (such as silica, alumina, magnesia, and sulphur content, among others).

38 Selection of raw materials with lower organic matter content to avoid generation of additional emissions of CO₂, and minor emissions of carbon monoxide (CO), which is typically less than 0.5–1 percent of total emitted gases during clinker burning. 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 electrostatic precipitators are used, there is a risk of explosions related to CO concentrations higher than 0.5–1 percent.

39 Guidance on waste-heat recovery is available in IFC and IIP (2014).
fuels, including waste fuels, oil, natural gas, and biomass, subject to technical constraints. 40

Air Emissions

21. Point source air emissions in cement and lime manufacturing are generated by the operation of kiln systems, clinker coolers, and mills, and by the handling and storage of intermediate and final materials and products. Non-point source emissions of dust can also arise.

40.22. Combustion sources for power generation are common in this industry sector. Guidance for the management of small combustion source emissions with a thermal heat input capacity of up to 50 megawatt hours thermal megawatts (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

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

24. For PM emissions associated with the operation of kiln systems and clinker coolers, including clinker and limestone burning, the following pollution prevention and control techniques, in addition to proper smoothing of kiln operations, are recommended:

- Capturing kiln and clinker cooler dusts using filters and recycling the recovered particulates into the kiln feed and into the clinker, respectively.
- Using fabric filter systems as the preferred control option, with electrostatic precipitators (ESP) as an alternative option to collect and control fine particulate emissions (PM10 and PM2.5) in kiln exhaust gas and bypass gas dust, and exhaust air from coolers.

40 EULA 2014, sec. 5, pages 27–42.
41 Smoothing of kiln operations refers to maintaining the kiln in consistently optimum operating conditions.
42 Fabric filters are also referred to as “bag” filters or “baghouse” filters. This document uses the term fabric filter.
43 Although ESPs are reliable under normal operating conditions, there are risks of explosion when carbon monoxide 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 switch off electricity automatically when necessary. ESPs should also be properly dimensioned to absorb large kiln upset situations during which high quantities of hot, unburnt clinker are forced through the cooler exhaust gases.
25. For PM emissions associated with the operation of mills, the recommended control technique is to capture mill dust using fabric filters and recycle it within the mill.

42.26. For PM emissions from 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 systems for handling material (for example, crushing operations, raw milling, and clinker grinding) maintained under negative pressure by exhaust fans with dedusting of ventilation air using fabric filters;
- Use of enclosed belt conveyors for materials transportation and emission controls at transfer points, including systems for cleaning return belts;
- Cleaning of return belts in the conveyor belt systems;
- Design sufficiently large covered storage for clinker and solid fuels to avoid the need of frequent double handling to and from outside stock piles. For example, facilities typically maintain clinker covered storage or silo capacity of approximately 15–30 days of production to minimize clinker transfers, and to allow for cement production to continue during the annual kiln maintenance shutdown period;
- Implementation of automatic bag-filling and handling systems to the extent possible, including use of a rotary bag filling machine with automatic paper bag feeder and fugitive emission control; use of automatic weight control for each bag during discharge; use of conveyor belts for transporting bags to a palletizing and wrapping machine; and storing the finished pallets in covered bays for subsequent shipping;
- Storage of practices to reduce diffuse dust from material and fuel stocks include: (i) covered or closed bays for crushed and preblended raw materials in covered or closed bays;
- Storage of (ii) silos for conventional fuels such as pulverized coal and petroleum coke (pet–coke) in silos;
- Storage of waste-derived fuels in petcoke; (iii) areas protected from wind and other weather elements;

44 ESPs are not suitable for mill dedusting due to investment costs and the efficiency (relatively high emissions) during startups and shutdowns.

45 For lime hydrating activities, wet scrubbers may be effective when the use of fabric filters is limited by high moisture/low temperature of flue gases. EC (2013), sec. 4.6.3.2, page 361.
Storage of clinker in precipitation for waste-derived fuels; (iv) covered/closed bays or silos for clinker with automatic dust extraction;

Storage of cements in reclamation; (v) silos with automatic reclaiming and dust extraction/reclamation for cement connected to automated loading system for bulk tankers;

- Storage of (vi) bunkers or silos for screened sizes of burnt lime in bunkers, and (vii) sealed silos and for storage of fine grades of hydrated lime in sealed silos; PM emissions in storage/stockpile areas may also be reduced through the application of water spray and chemical dust suppressors, including humidification techniques, at material charging/discharging points.

- Implementation of routine plant maintenance and good housekeeping to keep small air leaks and spills to a minimum; and use of mobile and stationary vacuum systems for routine operations and upsets.

Conduct material Use of simple, linear layouts for materials-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 reduce the extent possible need for multiple transfer points, including: paving and wetting and cleaning routines for road transport areas.
  - 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 Additional recommendations for the finished pallets in covered bays for subsequent shipping management of PM

- For particulate matter emissions associated with the operation of kiln systems, clinker coolers, and mills from other diffuse sources, including clinker and limestone burning, the following pollution prevention and control techniques, in addition to proper smoothing of kiln operations, 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 (ESP) or fabric filter systems (baghouses) to collect and control fine particulate emissions in kiln gases;
  - Using cyclones to separate large particulates of cooler gases, followed by fabric filters;

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46. Smoothing of kiln operations refers to maintaining the kiln in consistently optimum operating conditions.
47. 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.
Capturing mill dust by fabric filters and recycling dust created by vehicle movements within the mill and adjacent to the cement or lime manufacturing facility, is available in the General EHS Guidelines.

**Nitrogen Oxides**

Nitrogen oxide (NOx) emissions 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** Using low NOx burners (in the main kiln, as well as the precalciner, as applicable) to avoid localized flame hot spots that promote NOx formation.
- **Developing a staged combustion process**, as applicable, in PHP and preheater PH kilns.
- **Optimizing primary and secondary air flow** as low as possible (e.g., to ensure appropriate combustion/burning conditions with tight control of excess oxygen reduction), thereby minimizing NOx formation and emissions.
- **Employing flame cooling** by adding water to the fuel or directly to the flame (e.g., to reduce the temperature decrease and hydroxyl radical increase). The use of flame cooling of hydroxyl radicals.

In addition to the aforementioned primary control techniques for NOx reduction, secondary techniques such as selective noncatalytic reduction (SNCR) can have a negative impact on fuel consumption, possibly resulting in a 2–3 percent increase, and a subsequent proportional increase of carbon dioxide (CO2) emissions; also be used as necessary, for example, in degraded airsheds.

- Using low NOx burners to avoid localized emission hot spots;
- Developing a staged combustion process, as applicable in preheater-precalciner (PHP) and preheater (PH) kilns;

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48 ESPs are not suitable for mill dedusting.
49 Nitrogen monoxide represents more than 90 percent of NOx emitted.
50 Nitrogen monoxide represents more than 90 percent of NOx emitted.
51 Regarding the use of low NOx burners with a precalciner, see EC (2013), sec. 4.2.6.1, page 349. Regarding burner optimization, if the initial burner runs on a low percentage of primary air, a low-NOx burner will have a marginal effect on NOx levels. The use of flame cooling can have a negative impact on fuel consumption, possibly resulting in a 2–3 percent increase in fuel use, and a resultant increase in CO2 emissions. See EC (2013), sec. 1.4.5.1.2, page 130.
52 For further description of flame cooling techniques, see ENVIS Centre (n.d.), Cleaner Production Opportunities in the Cement Manufacturing Sector.
53 For more information on SNCR and reducing agents and applications, see EC (2013), sec. 1.4.5.1.7, pages 134–139.
17.30. Lime manufacturing: Nitrogen oxide (NO\textsubscript{x}) production is due to lower limestone burning temperatures. NO\textsubscript{x} emissions are generally lower in lime manufacturing than in cement manufacturing. Because limestone burning usually takes place at lower temperatures, NO\textsubscript{x} emissions from this source are lower and in addition to the smoothing of kiln operating conditions, the control of NO\textsubscript{x} emissions can be achieved using optimized low-NO\textsubscript{x} burners.\textsuperscript{55}

\textbf{Sulfur Dioxide (SO\textsubscript{2})}

31. Sulfur dioxide (SO\textsubscript{2}) emissions in cement manufacturing are primarily associated with the content of volatile or reactive sulfur in the raw materials\textsuperscript{56} and, although less important to a lesser degree, with the quality of fuels for power generation used in the kiln.\textsuperscript{57} Recommended pollution control techniques for reduction of SO\textsubscript{2} in addition to proper include the following:

- Selection of raw materials and fuels with low volatile sulfur content.
- Optimization of the clinker burning process using techniques including smoothing of kiln operations, ensuring uniform distribution of the hot meal in the kiln riser, and prevention of reducing conditions in the burning process. Optimizing the oxygen concentration in the kiln inlet area will promote SO\textsubscript{2} capture in the kiln charge, however, this must be balanced with impacts to NO\textsubscript{x} and CO emissions.
- Use of a vertical raw mill and, with gases passing through the mill to recover energy and to reduce the sulfur content in the gas.\textsuperscript{58} (in the mill, the gas containing sulfur oxide (SO\textsubscript{x}) mixes with the calcium carbonate (CaCO\textsubscript{3}) of the raw meal and produces calcium sulfate (gypsum)).

55 Low NO\textsubscript{x} burners have been fitted to rotary kilns and can also be applied to annular shaft kilns for some specific conditions (high primary air). The direct transfer of the low NO\textsubscript{x} burner technique from cement kilns to lime kilns is not straightforward. In cement kilns, flame temperatures are higher and low NO\textsubscript{x} burners have been developed for reducing high initial levels of 'thermal NO\textsubscript{x}'. In most lime kilns, the levels of NO\textsubscript{x} are lower and the 'thermal NO\textsubscript{x}' is less significant. The burner technique has to be adjusted to the fuels used, i.e., conventional fossil or waste fuels. PFRKs have flameless combustion, thus rendering low NO\textsubscript{x} burners not applicable to this kiln type. See EC (2013), sections 2.4.6.1.3, page 274.

56 Raw materials with high content of organic sulfur or pyrite (FeS) result in elevated SO\textsubscript{2} emissions.

57 Raw materials with high content of organic sulfur or pyrite (FeS) result in elevated SO\textsubscript{2} emissions. Sulphur introduced into the kiln system with the fuels is oxidized to SO\textsubscript{2} and will not lead to significant SO\textsubscript{2} emissions, due to the strong alkaline nature in the sintering zone, the calcination zone, and the lower stage of the preheater. See EC (2013), sec. 1.3.4.3, page 66, and sec. 1.4.3.2, page 111.
• 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.  

48. Sulfur dioxide (SO₂) emissions in lime manufacturing are generally lower than in cement because of the lower associated with the sulfur content of the fuel and raw materials. Techniques to limit SO₂ emissions include the following:  

- 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 design/type of kiln.  

Greenhouse gases  
49. Greenhouse gas emissions, especially carbon dioxide (CO₂), are mainly associated with fuel combustion and with the decarbonation of limestone, which in its pure form is 44 percent CO₂ by weight. Recommended techniques for CO₂ 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 CO₂ emissions per ton of final product;  
- Process requirements. Shaft kilns, including PFR kilns, generally have lower SO₂ than rotary kilns or rotary kilns equipped with preheaters. The 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);  
20.32. Selection of low sulfur content fuels and raw materials with lower organic matter can reduce SO₂ emissions.  

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

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58 While SO₂ emissions are typically not a significant issue in cement manufacturing, dry and wet scrubbers may be used to control these emissions. Dry scrubbing is a more expensive and therefore less common technique than wet scrubbing and is typically used when the SO₂ emissions have the potential to be higher than 1500 milligrams per normal cubic meter (mg/Nm³).  
59 The greenhouse gas N₂O is not likely to be emitted from cement and lime plants because of the high temperatures and oxidizing conditions. The only potential source for N₂O would be direct releases from the raw material in the raw mill.  
60 For more information on control of SO₂ emissions in lime manufacturing, see EC (2013), sec. 2.4.6.2, page 279.  
61 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, there is a risk of explosions related to CO concentrations higher than 0.5–1 percent.
raw material. Additional recommendations for the management of GHGs are provided in the General EHS Guidelines.

**Heavy Metals and Other Air Pollutants**

33. Emissions of heavy metals (e.g., lead, cadmium, and mercury) during cement and lime manufacturing can be significant emissions from cement manufacturing, and are generated from the presence of heavy metals in raw materials, and fossil fuels, and waste fuel. Nonvolatile-derived fuels.

22. Non-volatile metals are mostly bound to the particulate matter. Volatile metal emissions, such as mercury, are usually generated from both the raw materials and the waste fuels, and they are not PM, and can be controlled through use of filters.

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

34. Implement efficient dust / PM abatement measures, as discussed in the above, to capture bound section. Captured waste materials should be managed as a hazardous waste, as described in the General EHS Guidelines.

35. Volatile metals, such as mercury are only partly adsorbed by the raw gas dust, depending on the temperature of the waste gas. Recommended techniques to limit emissions of volatile heavy metals include the following:

- Implement controls for the volatile heavy metal content in the input materials and waste fuels through use of monitoring and materials selection (including selective quarrying techniques to avoid materials with high levels of metal concentrations).

- For high concentrations of volatile heavy metals (in particular mercury), use of absorption on activated carbon may be necessary. Selective dust shuttling or “bleeding” of mercury-enriched kiln dust, combined with sorbent injection, can be used to limit the buildup of mercury levels within the kiln dust. The resulting solid waste should be managed as a hazardous waste as described in the

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

63 This dust shuttling or “bleeding” technique is more efficient in “raw mill off” mode (where kiln is operating alone, as opposed to operating in line with the raw mill in order to use kiln gases to dry raw meal in the raw mill), as the dust is from the preheater, which has higher mercury concentrations because it is not “diluted” inside the raw mill. The flue gas temperature should be as low as possible, preferably below 130 degrees celsius, in order to have a high rate of adsorption efficiency. See UNEP (2016), sections 3.2.1 and 3.2.2, pages 10–12.
General EHS Guidelines: Multi-pollutant control measures can also be effective in controlling high concentrations of volatile heavy metals, such as wet scrubbers and adsorption on activated carbon.  

Waste Fuels, Wastes, and Associated Air Emissions

36. Cement kilns, due to their strongly alkaline atmospheres and high flame temperatures (up to 2000°C), are capable of using high-calorific-value waste fuels, for example, used solvents, waste oil, used tires, refuse derived fuel (RDF), and waste plastics. In exceptional cases, cement kilns can also be used for the disposal of wastes that have little calorific or mineral value and do not contribute to the clinker production process. This co-processing of hazardous waste (including polychlorinated biphenyls (PCBs), obsolete organochlorine pesticides, and other chlorinated materials) should be considered only if certain requirements (as discussed below) with respect to input control (for example, control of heavy metal content, heating value, ash content, and chlorine content), process control, and emission control are met.

While the use of waste fuels can allow for the substitution of fossil fuels, depending on their composition, the use of waste fuels or co-processing of hazardous waste can lead to emissions of volatile organic compounds (VOCs), persistent organic pollutants such as polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs), in addition to hydrogen fluoride (HF), hydrogen chloride (HCl), and toxic metals and their compounds if not properly operated and controlled.

37. Facilities using waste fuel or co-processing hazardous waste in cement manufacturing should document the amounts and types of waste that are used and the quality standards such as minimum calorific value and maximum concentration levels of specific pollutants, for example, PCB, chlorine, polycyclic aromatic hydrocarbon, mercury, and other heavy metals. Adequate emissions monitoring (as discussed in Section 2 of this Guideline) should be conducted when wastes are fired in cement plants (either as an alternative fuel or for the purpose of waste destruction). Recommended prevention and control techniques for these types of air pollutants include the following:

- 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; materials selection and through control measures described in the Heavy Metals section. Non-volatile metals should be managed according to the recommendations in the Particulate Matter section.

Operate the kiln in a controlled and steady manner handling practices for hazardous and nonhazardous waste to avoid emergency shutoffs of the electrostatic precipitators (if present in the facility).

Waste fuels

24. 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.

25. 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.

26. 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 through 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;
- 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.
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- 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; 
- 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.
- Ensure rapid cooling of kiln exhaust gases to lower than 200°C in long wet and long dry kilns without preheating.

27.38. Waste fuel and waste raw materials are seldom rarely used in lime manufacturing because of due to product quality requirements.

Energy Consumption and Fuels
28. 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

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66 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.
67 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.
68 Additional information on the prevention and control of emissions of PCDDs and PCDFs is available at SINTEF, 2006.
69 PCDDs and PCDFs are destroyed in 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 possible in PHP and PH kilns, where the flow in the cyclones is quick, but this is more difficult to obtain in other kiln types. Use of activated carbon in the sector to adsorb trace volatile metals (for example, mercury), VOCs, or PCDD–PCDF is still at pilot stage due to the different gas composition. Good operating conditions and careful selection of input materials may avoid the need for use of activated carbon. Information on prevention and control of emissions of PCDDs and PCDFs is available in WBCSD (2006).
70 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 (petcoke) 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.
kilns (long-dry [LD], semidry, semiwet, and wet-process kilns) are considered obsolete. 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 precalceriner.

29. 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
30. The only type of clinker cooler now being installed is the ‘grate cooler,’ which is produced in many versions. The objective of 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
31. 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). 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.

32. Pollution abatement measures may be necessary to ensure that no toxic emissions are generated from the firing of waste in cement 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

33.39. Wastewater is generated mainly from utility operations for cooling purposes in different phases of the process (e.g., bearings and 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; and 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 is discussed in the General EHS Guidelines.

Other Wastewater Streams & Water Consumption

34.40. 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.

35.41. 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 PM to settle before separation, control, and recycling or discharge. Further recommendations on managing contaminated stormwater are provided in the General EHS Guidelines.

36.42. Although cement manufacturing is not a water-intensive industry, it can contribute to water stress in seasonally arid locations. Recommendations to reduce water consumption, especially where it may be a limited natural resource, are provided in the General EHS Guidelines. In addition to housekeeping...
measures, cement companies have successfully conserved water by adopting dry rather than evaporative cooling systems, for example in power generation cycle condensers.

**Solid Wastes**

37. Sources of solid waste in cement and lime manufacturing include clinker production waste, mainly composed of spoil rocks, which are separated at the quarry or removed from the raw materials during the raw meal preparation, as well as off-specification clinker wastes. Another potential waste stream involves the kiln dust removed from the bypass flow and the stack, if it is not recycled in the process, or in the final product. Limited waste is generated from plant maintenance (for example, used oil and scrap metal, kiln refractory materials that may contain heavy metals). Other waste materials may include alkali, chloride, or fluoride contained in dust buildup from the kiln.

38. 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. In lime production, dust, off-specification quicklime, and hydrated lime are reused or recycled in selected commercial products (e.g., lime for construction uses, lime for soil stabilization, hydrated lime, and palletized products).

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

**Noise**

40. 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.

1.2 Occupational Health and Safety

41. 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

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74 Older facilities still using largely discontinued semiwet processes may also generate alkaline filtrates from filter presses.

75 Older facilities still using largely discontinued semi-wet processes may also generate alkaline filtrates from filter presses.
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- Heat
- Noise and vibrations
- Physical hazards
- Radiation, and
- 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 or cement grinding. In particular, exposure to the respirable fraction of active (crystalline) silica dust (SiO₂), when present in the raw materials, and products (e.g., cement dust), is a relevant potential hazard in the cement and lime manufacturing sector. Methods to prevent and control exposure to dust include the following:

- Control of dust through implementation of good housekeeping and maintenance, including use of mobile vacuum cleaning systems to prevent dust buildup on paved areas.
- Use of air-conditioned, closed cabins.
- Use of closed conveyors/elevators with emission controls at transfer points for fugitive dust emissions.
- 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.
- Use of PPE, personal protective equipment, as appropriate (e.g., masks and respirators) to address residual exposures following adoption of the above-referenced processes and engineering controls.

Use of mobile vacuum cleaning systems to prevent dust buildup on paved areas;

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. Information on prevention and control of silica inhalation hazards is available from Health and Safety Ontario (2011). 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
Heat

43.48. 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, and 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.

Noise and Vibrations

Implementing specific personal protection safety procedures in the lime-hydrating process to avoid potential exposure to exothermic reactions.

Noise and Vibrations

49. Exhaust fans and grinding mills. Noise pollution is related to several cement and lime manufacturing phases, including raw material extraction (as 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 provide levels for recommended noise abatement measures and ambient noise levels.

44.50. Crushing/grinding operations, mills, chutes and hoppers, exhaust fans, and blowers 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

45.51. Injuries during cement and lime manufacturing operations are typically related to slips, trips, and falls; contact with falling or moving objects; and lifting over-exertion and overexertion. Other injuries may occur due to contact with, or capture in, moving machinery (e.g., dump trucks, front loaders, forklifts, bagging machines). 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.\textsuperscript{78}

**Radiation**

\textbf{46.52.} 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**

\textbf{47.53.} Chromium may contribute to allergic contact dermatitis among workers handling cement.\textsuperscript{79} 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.

\textbf{48.54.} The potential accidental contact with CaO / CaOH on skin / eyes / mucous membranes is a specific hazard in lime production plants that needs to be assessed, prevented, and mitigated through emergency procedures and equipment. The presence of moisture may result in burns. Calcium oxide (CaO), or “quicklime” reacts with water, producing calcium hydroxide (Ca(OH)\textsubscript{2}) “hydrated lime,” a highly corrosive caustic solution. Accidental contact of sufficient duration of quicklime or hydrated lime powders with moist skin, eyes, or mucous membranes will cause caustic tissue burns. This is a powerfully explosive exothermic reaction which generates lime-laden steam and hot water splashing, both of which are highly hazardous due to their high temperature and caustic properties. Areas in which these compounds are handled as powders should be covered and enclosed, if possible, to avoid generation of a dust hazard. Areas where lime is slaked should be similarly enclosed. 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. Personal protective equipment (such as use of safety goggles, gloves, protective clothing, and boot covers) should be provided in the lime-


\textsuperscript{79} Tests on American cement show 5–134 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.
hydrating process, and appropriate safety procedures adopted. 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. 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 (GIIP), 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.

Effluent guidelines are applicable for direct discharges of treated effluents to surface waters for general use. Site-specific discharge levels may be established based on the availability and conditions in the use of publicly-operated sewage collection and treatment systems or, if discharged directly to surface waters, on the receiving water-use classification as described in the General EHS Guidelines. 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, and larger power source emissions are 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 1. Air Emission Levels for Cement Manufacturing

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Units</th>
<th>Guideline value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate matter (new kiln system with dry flue gas cleaning with an ESP, fabric, and/or hybrid filter)</td>
<td>mg/Nm³</td>
<td>25 a</td>
</tr>
<tr>
<td>Particulate matter (existing kilns)</td>
<td>mg/Nm³</td>
<td>100</td>
</tr>
<tr>
<td>Dust (other point sources incl. clinker cooling, cement grinding)</td>
<td>mg/Nm³</td>
<td>25</td>
</tr>
<tr>
<td>SO₂</td>
<td>mg/Nm³</td>
<td>&lt; 50–400 b</td>
</tr>
<tr>
<td>NOₓ</td>
<td>mg/Nm³</td>
<td>600 NDA c</td>
</tr>
<tr>
<td>NH₃ slip in the flue-gases (when SNCR is applied)</td>
<td>mg/Nm³</td>
<td>&lt; 30–50 d</td>
</tr>
<tr>
<td>HCl</td>
<td>mg/Nm³</td>
<td>10 e</td>
</tr>
<tr>
<td>Hydrogen fluoride</td>
<td>mg/Nm³</td>
<td>1 e</td>
</tr>
<tr>
<td>Total organic carbon</td>
<td>mg/Nm³</td>
<td>10–30</td>
</tr>
<tr>
<td>Dioxins-furans</td>
<td>ng TEQ/Nm³</td>
<td>0.05–0.1 e</td>
</tr>
<tr>
<td>Cadmium and thallium (Cd+Tl)</td>
<td>mg/Nm³</td>
<td>0.05 e</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>mg/Nm³</td>
<td>0.05 e</td>
</tr>
<tr>
<td>Total metals</td>
<td>mg/Nm³</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Notes:** Emissions are from the kiln stack unless otherwise noted. Daily average values corrected to 273 K, 101.3 kPa, 10 percent O₂, and dry gas, unless otherwise noted. Mg/Nm³ = milligrams per normal cubic meter; ng TEQ/Nm³ = nanograms of dioxin toxic equivalent per normal cubic meter.


NDA = Non-degraded airshed; DA = Degraded airshed; Airshed should be considered as degraded if relevant ambient air quality standards (as defined in the General EHS Guidelines) are exceeded; DA/NDA to be determined for each pollutant. Environmental assessment (EA) may justify more stringent or less stringent guideline values due to environmental, community health, technical and economic considerations, whilst not exceeding nationally legislated limits. In all cases, the EA should demonstrate that ambient impacts from emissions are in compliance with the requirements of Section 1.1 of the General EHS Guidelines.

a Particulate matter emissions levels from flue gases of new kiln firing processes of <10–20 mg/Nm³ (daily average value) can be achieved when applying an ESP and/or fabric and hybrid filters. See EC (2013), sec. 4.2.5.3, page 348. The guideline is 10 mg/Nm³ if more than 40 percent of the resulting heat release comes from hazardous waste. See EC 2010 Industrial Emissions Directive (IED, 2010/75/EU) on the incineration of waste.

b For guideline value of SO₂, see EC (2013), table 4.4, page 351.

c The NOₓ guideline value of 600 mg/Nm³ is derived from IFC project benchmarks. The guideline range for degraded airsheds (<200–450 mg/nm³) is derived from EC (2013), table 4.2, page 348. Degraded airsheds may require the use of secondary pollution controls including SNCR. The use of SNCR should include assessment and mitigation of risks associated with transport, storage, and use of reducing agents (e.g., ammonia, urea) in accordance with the guidance on hazardous materials management in the General EHS Guidelines.

d The ammonia slip depends on the initial NOₓ level and on the NOₓ abatement efficiency.

e For hydrogen chloride (HCl), hydrogen fluoride (HF), cadmium and thallium, mercury, and total metals, the guideline is for a daily average value or average over a sampling period (spot measurements, for at least half an hour). See EC (2013), sec. 4.2.6.5, page 352, for HCl and HF, and sec. 4.2.8 (table 4.5, page 353, for metals. For dioxins-furans, the guideline is the average over a sampling period of six to eight hours. See EC (2009), section 4.2.7, page 353 for dioxins-furans. If more than 40 percent of the resulting heat release comes from hazardous waste, the guideline is for average values over the sample period of a minimum of 30 minutes and a maximum of eight hours. See EC (2010) on the incineration of waste.

f Total metals = Arsenic (As), Lead (Pb), Cobalt (Co), Chromium (Cr), Copper (Cu), Manganese (Mn), Nickel (Ni), Vanadium (V), and Antimony (Sb). See EC (2013), table 4.5, page 353.
### Table 2. Air Emission Levels: Lime Manufacturing

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Units</th>
<th>Guideline Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>mg/Nm³</td>
<td>≤ 25</td>
</tr>
<tr>
<td>SO₂</td>
<td>mg/Nm³</td>
<td>400 for PFRK, ASK, MFSK, OSK and PRK kilns or 400 for LRK kiln</td>
</tr>
<tr>
<td>NOₓ</td>
<td>mg/Nm³</td>
<td>500 for PFRK, ASK, MFSK, OSK kilns or 500 for LRK, PRK</td>
</tr>
<tr>
<td>HCl</td>
<td>mg/Nm³</td>
<td>10</td>
</tr>
</tbody>
</table>

**NOTES:**
- ASK = annular shaft kilns; LRK = long rotary kilns; MFSK = Mixed feed shaft kilns; OSK = other shaft kilns; PFRK = parallel flow regenerative kilns; PRK = rotary kilns with preheater.
- For guideline values of SO₂, see EC 2013, table 4.10, 365. For NOₓ, see ibid., table 4.9, 364.
- Daily average values corrected to 273°K, 101.3 kPa, 10% O₂, and dry gas, unless otherwise noted.

### Table 3. Effluent Levels: Cement and Lime Manufacturing

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Units</th>
<th>Guideline Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust (other point sources incl. clinker cooling, cement grinding)</td>
<td>mg/Nm³</td>
<td>50</td>
</tr>
<tr>
<td>SO₂</td>
<td>mg/Nm³</td>
<td>400</td>
</tr>
<tr>
<td>NOₓ</td>
<td>mg/Nm³</td>
<td>600</td>
</tr>
<tr>
<td>HCl</td>
<td>mg/Nm³</td>
<td>10²</td>
</tr>
<tr>
<td>Hydrogen fluoride</td>
<td>mg/Nm³</td>
<td>1²</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>mg/Nm³</td>
<td>10</td>
</tr>
<tr>
<td>Dioxins–fursans</td>
<td>mg TEQ/Nm³</td>
<td>≤ 0.1²</td>
</tr>
<tr>
<td>Cadmium &amp; Thallium (Cd+Tl)</td>
<td>mg/Nm³</td>
<td>≤ 0.00²</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>mg/Nm³</td>
<td>≤ 0.00²</td>
</tr>
<tr>
<td>Total Metals</td>
<td>mg/Nm³</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**NOTES:**
- Table 3: Emissions from the kiln stack unless otherwise noted. Daily average values corrected to 273 K, 101.3 kPa, 10% O₂, and dry gas, unless otherwise noted.
- For guideline values of SO₂, see EC 2013, table 4.10, 365. For NOₓ, see ibid., table 4.9, 364.
- Daily average values corrected to 273°K, 101.3 kPa, 10% O₂, and dry gas, unless otherwise noted.
- a 10 mg/Nm³ if more than 40 percent of the resulting heat release comes from hazardous wastes.
- If more than 40 percent of the resulting heat release comes from hazardous wastes, average values over the sample period of a minimum of 30 minutes and a maximum of 8 hours.
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 Efficiency and Waste**

53.58. 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. GIIP for new machinery in the sector and may be used to track performance changes over time.
### Table 4. Resource and Energy Consumption

<table>
<thead>
<tr>
<th>Inputs per unit of product</th>
<th>Unit</th>
<th>Industry benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel energy → cement</strong></td>
<td></td>
<td>PHP kiln: 2.9–3.04, 3.4, 2.85–3.1a</td>
</tr>
<tr>
<td>Electric Electrical energy → cement</td>
<td>kWh/t equivalent cement</td>
<td>90–150, 90–105b,c,d</td>
</tr>
<tr>
<td>Electric Electrical energy → clinker grinding</td>
<td>kWh/t cement</td>
<td>40–60</td>
</tr>
<tr>
<td><strong>Fuel energy → lime</strong></td>
<td></td>
<td>GJ/t lime: 4–4.7 mixed-feed shaft kilns, 3.6–6 advanced shaft and rotary kilns d</td>
</tr>
<tr>
<td>Electric Electrical energy → lime</td>
<td>kWh/t equivalent lime</td>
<td>5–15 mixed-feed shaft kilns, 20–40 advanced shaft and rotary kilns d</td>
</tr>
<tr>
<td>Materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substrate raw materials used in production of clinker GHG emissions</td>
<td>kg/t cement</td>
<td>2–10, 550–700 (including GHG emissions from power consumption)e</td>
</tr>
<tr>
<td>Substitute raw materials in production of Clinker to cement ratio</td>
<td>%</td>
<td>Clinker content of 30–0 percent (meaning 30–70 percent substitution of clinker with blast furnace slag, or 0–30 percent substitution of clinker with fly ash or pozzolana).</td>
</tr>
</tbody>
</table>

**NOTES:** Please see Table 5 for notes and sources. a IFC benchmarks; EC (2013); US EPA (2013). b IFC benchmarks; WBCSD (2016), “Getting the Numbers Right,” dataset 33AGW. c IIP, n.d., “Vertical Roller Mills for Finish Grinding.” d EC (2013). e IFC benchmarks include GHG emissions from electrical energy consumed, either generated onsite and/or imported from the grid.
### Table 6. Heat consumption and production capacity for cement manufacture kilns.

<table>
<thead>
<tr>
<th>Kiln type</th>
<th>Heat consumption (MJ/t clinker)</th>
<th>Maximum production capacity (t/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preheater-precalciner — 3-6 stages</td>
<td>3.000–3.500a</td>
<td>12.000</td>
</tr>
<tr>
<td>Preheater</td>
<td>3.100–4.200</td>
<td>4.000</td>
</tr>
<tr>
<td>Long dry</td>
<td>≤5.000</td>
<td>3.800</td>
</tr>
</tbody>
</table>

**NOTES:**
- aSix stage preheater–precalciner can achieve 2900 MJ/t clinker under optimum conditions.


### Table 7. Average heat and electric consumption for four types of lime kilns.

<table>
<thead>
<tr>
<th>Kiln type</th>
<th>Heat consumption (MJ/t lime)</th>
<th>Electric consumption (kWh/t lime)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaft kilns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotary kilns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traveling grate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas suspension preheater</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**a** Reactive calcium quicklime involves a higher consumption.

Only one plant reported, which has been operating in Norway since 1986.

### Table 5. Emission and waste generation.

<table>
<thead>
<tr>
<th>Outputs per unit of product</th>
<th>Waste</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg/t</td>
<td>g/t</td>
</tr>
<tr>
<td>Waste</td>
<td>0.25–0.6a</td>
<td>20–50</td>
</tr>
<tr>
<td>Emissions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dust</td>
<td>g/t equivalent cement</td>
<td>20–50a</td>
</tr>
<tr>
<td>NH₃</td>
<td>g/t equivalent cement</td>
<td>600–800b</td>
</tr>
<tr>
<td>SO₂</td>
<td>kg/t</td>
<td>0.1–2.0ah</td>
</tr>
<tr>
<td>CO₂ From decarbonation</td>
<td>kg/t</td>
<td>400–590c</td>
</tr>
<tr>
<td>From fuel</td>
<td>kg/t</td>
<td>360–500d</td>
</tr>
</tbody>
</table>

**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.

Environmental Monitoring

54.59. Environmental monitoring programs for this sector should be implemented to address all activities that have been identified as having potentially significant impacts on the environment, during both 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.

55.60. 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.

61. Facilities using waste fuel or waste raw material in cement manufacturing should document the amounts and types of waste that are used either as fuel or as raw material, and the quality standards such as minimum calorific value and maximum concentration levels of specific pollutants, such as PCB, chlorine, polycyclic aromatic hydrocarbon, mercury, and other heavy metals.

2.2 Occupational Health and Safety

Occupational Health and Safety Guidelines

56.62. 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); the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety—(NIOSH); Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United States

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80. Recommended environmental monitoring parameters and frequencies are available in EC (2013), sec. 4.2.2, page 341 and WBCSD (2012).
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**Accident and Fatality Rates**

57.63. **Projects** Project management 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).

**Occupational Health and Safety Monitoring**

58.64. The working environment should be monitored for occupational hazards relevant to the specific project. Monitoring should be designed and implemented by accredited professionals 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.

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83 Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992
86 Accredited professionals may include certified industrial hygienists, registered occupational hygienists or certified safety professionals or their equivalent.
87 Accredited professionals may include certified industrial hygienists, registered occupational hygienists, and certified safety professionals or their equivalent.
3.0 References and Additional Sources


http://eippcb.jrc.es/pages/FAActivities.htm


United States (US)Gujarat Cleaner Production Centre (ENVIS Centre). n.d. Cleaner Production Opportunities in Cement Manufacturing Sector.


http://ietd.iipnetwork.org/content/alternative-raw-materials.

http://ietd.iipnetwork.org/content/blended-cement-alternatives.

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Annex A: General Description of Industry Activities

65. 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 and lime manufacturing are energy-intensive industries, and require significant quantities of thermal and electrical energy depending on the type of production process employed and associated equipment.

Cement Manufacturing

59.66. Cement manufacturing uses energy to process raw materials consisting mainly of limestone (calcium carbonate), clay (aluminum silicates), sand (silica oxide), and iron ore to produce clinker, which is ground with gypsum, limestone, and other materials to produce cement. 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/tonnes per day clinker production capacity) typically needs around 400,000 square meters (m²) in a flat area, as well as an additional area (for example, 250,000 m²) for future expansion. The typical project facility lifespan is at least 40 to 50 years. The size of the plant is an important factor, (from approximately 2,500 to 12,000 metric tons per day), 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 unit of cement production than by large plants.

Cement Manufacturing

60. Cement manufacturing uses energy to process raw materials consisting mainly of limestone (calcium carbonate, CaCO₃), clay (aluminum silicates), sand (silica oxide), and iron ore to produce clinker, which is ground with gypsum, limestone, etc to produce cement.

64.67. After an initial crushing and 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 combination of preheaters, precalciner, and a rotary kiln by calcining the raw meal (e.g. decomposing CaCO₃, calcium carbonate at about 900°C), thus releasing carbon dioxide (CO₂) and leaving CaO, calcium oxide. This is followed by the clinkering process, in which
CaO \textit{calcium oxide} 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 (\textit{e.g.} for example, 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 at the same time facilitate heat recovery by heating secondary combustion air. Grate coolers are typically employed for this purpose (as opposed to the use of satellite coolers), which are now considered obsolete. The cooled clinker is then ground with gypsum and limestone to produce portland cement and 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 (\textit{e.g.} for example, 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. CaCO₃ \textit{Calcium carbonate} is sometimes added in small quantities as filler.

**Lime Manufacturing**

62.68 Lime is produced by burning CaCO₃ 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 quicklime (calcium oxide (CaO, known as quicklime)). The quicklime is then maintained at temperatures of 1,200°C to 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-burned 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 Cement Manufacturing Processes

- Limestone quarry
  - Crusher
  - Limestone storage
  - Additives (e.g., iron ore)
    - Mixer and raw meal grinding
  - Kiln feeder
  - Raw meal storage

- Clay quarry
  - Crusher
  - Clay storage
  - Preheater-precalciner

- Kiln
  - Cooler
  - Clinker storage
  - Gypsum storage
    - Additives storage (fly ash, slag, etc.)
  - Cement grinding
    - Cement silos
      - Bulk shipping
      - Bag shipping
    - Cement bagging