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# ENVIRONMENTAL, HEALTH, AND SAFETY GUIDELINES FOR CEMENT AND LIME MANUFACTURING

## 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).<sup>1</sup> When one or more members of the World Bank Group are involved in a project, these EHS Guidelines are applied as required by their respective policies and standards. These industry sector EHS guidelines are designed to be used together with the **General EHS Guidelines** document, which provides guidance to users on common EHS issues potentially applicable to all industry sectors. For complex projects, use of multiple industry sector guidelines may be necessary. A complete list of industry sector guidelines can be found at [www.ifc.org/ehsguidelines](http://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 are 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 level 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 processes. Extraction of raw materials, a common activity associated with cement

<sup>1</sup> GIIP is 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.

manufacturing processes, is covered in the **EHS Guidelines for Construction Materials Extraction**.<sup>2</sup> These EHS guidelines do not cover asbestos cement production, which is currently under the restrictions of the International Finance Corporation (IFC) [Exclusion List](#). Annex A contains a full description of industry activities for this sector. This document is organized as follows:

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## 1. INDUSTRY-SPECIFIC IMPACTS AND MANAGEMENT

6. Section 1 provides a summary of EHS issues associated with cement and lime manufacturing that 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 arise primarily in the following areas:

- Energy use
- Greenhouse gases (GHGs)
- Air emissions
- Noise and Vibrations
- Wastewater
- Solid wastes

<sup>2</sup> Limestone's particular chemistry, hydrology, geology, and associated microclimates can lead to the evolution of unique biodiversity and associated ecosystem services. It is important to assess and, where necessary, mitigate the potential impacts of a project on limestone-restricted biodiversity, including associated species, their habitats, and the ecosystem services they provide. For more information, see Birdlife International et al., *Extraction and Biodiversity in Limestone Areas* (2014), <https://www.birdlife.org/sites/default/files/Extraction-and-Biodiversity-in-Limestone-Areas.pdf>; International Union for Conservation of Nature (IUCN), *Biodiversity Management in the Cement and Aggregates Sector: Biodiversity Indicator and Reporting System* (Gland, Switzerland: IUCN, 2014), <https://www.iucn.org/content/biodiversity-management-cement-and-aggregates-sector-biodiversity-indicator-and-reporting-system-birs>; Global Cement and Concrete Association (GCCA), *Sustainability Guidelines for Quarry Rehabilitation and Biodiversity Management* (London: GCCA, 2020), [https://gccassociation.org/wp-content/uploads/2020/05/GCCA\\_Guidelines\\_Sustainability\\_Biodiversity\\_Quarry\\_Rehabilitation\\_May\\_2020-1.pdf](https://gccassociation.org/wp-content/uploads/2020/05/GCCA_Guidelines_Sustainability_Biodiversity_Quarry_Rehabilitation_May_2020-1.pdf).

## Energy Use

8. Cement and lime manufacturing are energy-intensive industries. In addition to the energy conservation recommendations provided in the **General EHS Guidelines**, the following sections offer sector-specific energy-efficiency guidance for thermal and electrical energy use.

### Cement and Lime Kilns

9. Several types of kilns are currently used in cement manufacturing, including preheater-precalsiner (PHP), preheater (PH), and long-dry (LD) kilns, as well as semidry, semiwet (Lepol), wet process, and shaft kilns.<sup>3</sup> PHP kilns are the most commonly used kilns in the cement manufacturing industry.<sup>4,5</sup> They 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.<sup>6</sup> 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 a multistage PHP (usually five or six stages, depending on the moisture content of the fuel and raw materials).<sup>7</sup>

<sup>3</sup> LD kilns have much higher heat consumption than PHP kilns 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 electricity consumption and higher maintenance costs due to the filter presses, and are now generally considered obsolete. The wet process kiln, now largely disused, is the oldest rotary kiln technology, with the highest heat consumption.

<sup>4</sup> As reported in *Getting the Numbers Right*, a database maintained by the GCCA, whose reporting members covered 22 percent of global clinker production in 2019, PHP kilns accounted for approximately 65 percent of GCCA members' global clinker production in 2019; PH and LD kilns accounted for approximately 20 percent and approximately 2 percent, respectively; and semidry, semiwet (Lepol), wet process, and shaft kilns collectively accounted for approximately 13 percent. See GCCA, dataset 8TGK%, "Total Production Volumes of Clinker by Kiln Type (%)" in "Getting the Numbers Right," *Global Cement Database on CO<sub>2</sub> and Energy Information* (London: GCCA, 2019), <https://gccassociation.org/gnr/>.

<sup>5</sup> In 2013, China produced 60 percent of total global cement. As of 2011, 86 percent of Chinese production used PHP kiln technology (up from 10 percent in 2000). See Jing Ke et al., "Estimation of CO<sub>2</sub> Emissions from China's Cement Production: Methodologies and Uncertainties," *Energy Policy* 57 (2013): 172–181, [https://china.lbl.gov/sites/all/files/6329\\_ep\\_cement\\_co2.pdf](https://china.lbl.gov/sites/all/files/6329_ep_cement_co2.pdf). In India, the second-ranked global producer of cement in 2013, almost all of the installed capacity in India uses dry-process manufacturing, and about 50 percent of capacity has been built in the last ten years. PHP kiln technology was used for 40 percent of cement production in 2013. See International Energy Agency (IEA) and WBCSD, *Technology Roadmap: Low-Carbon Technology for the Indian Cement Industry* (Paris: IEA, 2013), [https://docs.wbcsd.org/2013/02/Low\\_Carbon\\_Technology\\_for\\_the\\_Indian\\_Cement\\_Industry\\_IEA\\_WBCSD\\_Feb\\_2013.pdf](https://docs.wbcsd.org/2013/02/Low_Carbon_Technology_for_the_Indian_Cement_Industry_IEA_WBCSD_Feb_2013.pdf).

<sup>6</sup> This range for thermal energy use for PH and PHP kilns is based on data in Frauke Schorcht et al., *Best Available Techniques: Reference Document for the Production of Cement, Lime and Magnesium Oxide, Industrial Emissions Directive 2010/75/EU* (Brussels: European Commission (EU), 2013), Sec. 1.3.3, Table 1.18, 47, [https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/CLM\\_Published\\_def\\_0.pdf](https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/CLM_Published_def_0.pdf); and GCCA, "Getting the Numbers Right" database.

<sup>7</sup> Schorcht et al., *Best Available Techniques*, sec. 4.2.3.2, Technique C, 343.

10. In addition to the selection of cement kiln technology, further thermal energy efficiencies can be realized through optimization of design and plant operations. These include high-capacity utilization, optimized length/diameter ratio, optimized kiln design, optimized kiln-firing systems, uniform and stable operating conditions, optimization of process controls, provision of tertiary air ducts (for the precalciner), maintaining near-stoichiometric but oxidizing kiln conditions, use of mineralizers, reduction of air-in leakage, and maintenance of kiln refractory specifications.<sup>8</sup> Under optimized conditions, the specific thermal energy use of a multistage PHP kiln should be in the range of 2.9–3.3 gigajoule (GJ)/tonne of clinker.<sup>9</sup>

11. For lime manufacturing, various types of kilns—such as long rotary kilns (LRKs), rotary kilns with a preheater (PRKs), parallel flow regenerative kilns (PFRKs), annular shaft kilns (ASKs)—are employed. Mixed-feed shaft kilns such as ASKs, PFRKs, and other vertical/shaft kilns have significantly lower thermal energy consumption (3–5 GJ/tonne of lime) and higher fuel flexibility than rotary kiln applications, which fall in the 5–8 GJ/tonne range.<sup>10</sup> Besides energy use considerations, other key factors that influence 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 because of their superior environmental/energy efficiency performance. (Among vertical kilns, the PRFK technology is the most energy efficient.)<sup>11</sup>

12. Lime kiln thermal energy efficiency can be optimized through (i) the use of energy management and process controls, including optimizing fuel quality (high calorific value/low moisture), flow rates, and combustion conditions; (ii) the selection of the optimal stone grain size; (iii) limiting excess air in LRK and PRK kilns; (iv) regularly maintaining the equipment, including ensuring the integrity of the kiln refractory/insulation lining; and (v) the use of other techniques specific to different lime production kiln types.<sup>12</sup>

### *Clinker Coolers*

13. The purpose of the cooler is to lower the clinker temperature as quickly as possible to control product quality and generate clinker temperatures that are suitable for final grinding/mixing stages. Hot air recovered from the cooler provides combustion air for the kiln's main burner flame and the PHP, or can be used for other drying purposes, thus reducing fuel consumption. The only type of clinker cooler currently being installed is the *grate cooler*, which is produced in many versions, primarily because of its high capacity and superior heat recovery efficiency compared with other cooler types. (Later generation grate coolers

<sup>8</sup> Additional techniques to optimize the thermal efficiency of the calciner and PH are discussed in Schorcht et al., *Best Available Techniques*, sec. 1.4.2.1.1, 100.

<sup>9</sup> Schorcht et al., *Best Available Techniques*, sec. 1.4.2.1.1, 100–101. Depending on calorific and moisture content, the use of alternative fuels will increase energy consumption beyond this range. The use of a gas bypass will also increase energy consumption.

<sup>10</sup> Schorcht et al., *Best Available Techniques*, table 2.23, 223.

<sup>11</sup> European Lime Association (EULA), *A Competitive and Efficient Lime Industry, Cornerstone for a Sustainable Europe (Lime Roadmap)* (Brussels: EULA, 2014), sec. 3, 14, <https://www.eula.eu/a-competitive-and-efficient-lime-industry-cornerstone-for-a-sustainable-europe-lime-roadmap-summary/>.

<sup>12</sup> Additional energy optimization techniques for various types of lime kilns are discussed in Schorcht et al., *Best Available Techniques*, sec. 2.4.1, table 2.34, 252.



typically have heat recovery rates of 65–75 percent.)<sup>13</sup> GIIP involves the use of high-efficiency grate coolers—for instance, the stationary preliminary grate—and thermal optimization techniques. These techniques include using cooler grate plates that offer a greater flow resistance to provide a more uniform distribution of cooling air, controlling the cooling air supply to the individual grate sections, and using variable-speed drives for the cooler fans.<sup>14</sup>

### *Other Energy-Efficiency Measures<sup>15</sup>*

14. Electrical energy use varies in the range of approximately 80–120 kilowatt hour (kWh)/tonne cement.<sup>16,17,18</sup> Motors used to power fans and other equipment, especially for grinding, account for a significant portion of the total electrical energy used in a cement facility (a typical cement facility has more than 500 motors).<sup>19</sup> Different stages of the cement production process require different electrical energy demands: raw material grinding and homogenization (approximately 30 percent of total electrical energy use); clinker production (approximately 25 percent); and cement production, including finishing grinding, mixing and packing/transport (approximately 45 percent).<sup>20</sup>

15. Electrical energy use in cement processing can be minimized through the use of high-efficiency equipment and energy-efficiency techniques. These include using (i) automated process controls for mills and separators/classifiers in raw-meal grinding/preparation, fuel management, and finishing grinding; (ii) power-management systems; (iii) energy-efficient equipment such as 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) vertical and horizontal grinding systems—roller mills and roller-press/high-pressure grinding systems are often 50 percent more efficient than ball mills—and high-efficiency, third-generation separators/classifiers for raw meal and fuel preparation and cement grinding;<sup>21</sup> (v) high-efficiency, low-pressure drop PH cyclones (to reduce power use in the kiln exhaust gas system); (vi) high-efficiency, well-maintained motors for transport, grinding, and kiln-related

<sup>13</sup> Institute for Industrial Productivity (IIP), “Conversion to High-Efficiency Grate Coolers,” *Energy Efficiency Technology Database* (n.d.), <http://www.iipinetwork.org/wp-content/letd/content/conversion-high-efficiency-grate-coolers.html>.

<sup>14</sup> Schorcht et al., *Best Available Techniques*, sec. 1.4.2.1.1, 100.

<sup>15</sup> Additional useful information can be found in EC, *Reference Document on Best Available Techniques for Energy Efficiency* (Brussels: EC, 2009), [https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/ENE\\_Adopted\\_02-2009.pdf](https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/ENE_Adopted_02-2009.pdf).

<sup>16</sup> Wang, Yufei, Zhengping Hao, and Samuel Höller, “Analysis of CO<sub>2</sub> Mitigation Policies in the Chinese Cement Industry” *ECEEE 2012 Summer Study on Energy Efficiency in Industry* (Wuppertal, Germany: Wuppertal Institute, 2012), [http://epub.wupperinst.org/files/4635/4635\\_Wang.pdf](http://epub.wupperinst.org/files/4635/4635_Wang.pdf)

<sup>17</sup> GCCA, “Getting the Numbers Right,” dataset 33AGW.

<sup>18</sup> Schorcht et al., *Best Available Techniques*, sec. 1.3.3.2, 49.

<sup>19</sup> See IIP, “High Efficiency Motors & Drives” (n.d.), <http://www.iipinetwork.org/wp-content/letd/content/high-efficiency-motors-drives.html>.

<sup>20</sup> The European Cement Association (CEMBUREAU), “Electrical Energy Efficiency,” in *The Role of Cement in the 2050 Low Carbon Economy* (Brussels: CEMBUREAU, 2013), 39–41, <https://lowcarboneconomy.cembureau.eu/wp-content/uploads/2018/09/cembureau-full-report.pdf>. As noted in the introduction of this Guideline, the EHS elements of raw material extraction are covered in IFC’s **EHS Guidelines for Construction Materials Extraction**.

<sup>21</sup> IIP, “Vertical Roller Mills for Finish Grinding” (n.d.), <http://www.iipinetwork.org/wp-content/letd/content/vertical-roller-mills-finish-grinding.html>.

operations; and (vii) variable-speed drives for the motors and fans in the kiln, cooler, PH, separator, and mills, among others. Collectively, these techniques can realize electrical energy savings with favorable payback periods for investments.<sup>22,23</sup>

16. Electrical energy use in lime manufacturing accounts for a small portion (approximately 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) using process and power management controls; (ii) improving the efficiencies of motors; and (iii) optimizing the cooling and crushing/grinding processes by using high-efficiency equipment.<sup>24</sup> These steps can yield significant energy savings, for example, improvements to motor efficiencies can be in the range of 10 percent.<sup>25</sup>

### **Greenhouse Gases**

17. GHG emissions in the cement industry, in particular emissions of carbon dioxide (CO<sub>2</sub>),<sup>26</sup> are mainly associated with the calcination of limestone during clinker production (approximately 55 percent of total CO<sub>2</sub> emissions), the fuel used to heat the kiln (approximately 35 percent of CO<sub>2</sub> emissions typically from the use of carbon-intensive fuels including coal and petcoke), and electricity use and transportation (approximately 10 percent of total CO<sub>2</sub> emissions, depending on the electricity source).<sup>27</sup> The intensity of GHG emissions during 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.<sup>28</sup> While conventional fossil fuels remain the dominant fuel source in the leading global cement-producing

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<sup>22</sup> Ibid., "Cement" (n.d.).

<sup>23</sup> Worrell, Ernst, Katerina Kermeli, and Christina Galitsky, *Energy Efficiency Improvement and Cost Saving Opportunities for Cement Making—An ENERGY STAR® Guide for Energy and Plant Managers* (Washington, D.C.: Environmental Protection Agency (EPA), 2013), 19–82, [http://www.energystar.gov/sites/default/files/tools/ENERGY%20STAR%20Guide%20for%20the%20Cement%20Industry%202027\\_08\\_2013\\_Rev%20js%20reformat%2011192014.pdf](http://www.energystar.gov/sites/default/files/tools/ENERGY%20STAR%20Guide%20for%20the%20Cement%20Industry%202027_08_2013_Rev%20js%20reformat%2011192014.pdf).

<sup>24</sup> EULA, *A Competitive and Efficient Lime Industry, Cornerstone for a Sustainable Europe (Lime Roadmap)*, sec. 5.1.1, 27–36.

<sup>25</sup> Ibid., 14.

<sup>26</sup> The potent GHG nitrous oxide (N<sub>2</sub>O) is not likely to be emitted from cement and lime plants because of the high temperatures and oxidizing conditions. The only potential source of N<sub>2</sub>O would be direct releases from the raw material in the raw mill.

<sup>27</sup> WBCSD, *CO<sub>2</sub> and Climate Protection* (Geneva: WBCSD, n.d.), <https://www.wbcsd.org/Programs/Climate-and-Energy>.

<sup>28</sup> Renewable energy options—including wind power, solar photovoltaic power, solar thermal power and small hydropower generation—may be employed for cement production. Deployment of these technologies depends on factors such as the availability of renewable energy sources, electricity prices, and plant size. See IEA, *Technology Roadmap: Low-Carbon Transition in the Cement Industry* (Paris: IEA, 2018), 37, <https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry>. The EHS sector's use of captive renewable power generation is low.

countries<sup>29</sup>—including China and India, ranked first and second in global cement production, respectively, in 2015<sup>30</sup>—the substitution of fossil fuel use with waste fuels<sup>31</sup> and biomass is increasing globally.<sup>32</sup>

18. Limestone decarbonation and fuel-related CO<sub>2</sub> emissions in the lime-production process are similar to cement manufacturing. However, there is generally less electricity consumption and related CO<sub>2</sub> emissions from lime than cement manufacturing. Lime production is also dominated by conventional fossil fuel use among the leading producers.

19. The GHG emissions associated with cement or lime manufacturing projects, and associated thermal power generation, should be quantified annually in accordance with internationally recognized methodologies and good practices.

20. 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 minimizing CO<sub>2</sub> emissions in cement manufacturing include the following:<sup>33</sup>

- Producing blended cements—in which the clinker is partially substituted with fly ash, blast furnace slag, natural volcanic materials, calcined clay, and/or ground limestone—or new cementitious

<sup>29</sup> The most commonly used fuel in the cement industry is pulverized coal (black coal and lignite). However, the lower cost of petcoke has resulted in its increased use. Coal and petcoke generate higher emissions of GHGs than less carbon-intensive fuels—about 65 percent more unit emissions than natural gas, for example. In addition, high sulfur content in the fuel (a characteristic of petcoke) may create problems, including sulfur buildup on the rings in the kiln.

<sup>30</sup> CEMBUREAU, *Cement and Concrete: Key Facts and Figures* (Brussels: EC, 2020), <https://cembureau.eu/cement-101/key-facts-figures>.

<sup>31</sup> Typical waste fuels used in the cement industry can include nonhazardous and hazardous wastes with varying levels of calorific value. A list of commonly used waste fuels can be found in Schorcht et al., *Best Available Techniques*, sec. 1.2.4.3.1, 22. They may include such waste fuels as used solvents, waste oil, used tires, refuse-derived fuel (RDF), and waste plastics.

<sup>32</sup> Conventional fossil fuels accounted for approximately 85 percent of global fuel use for cement manufacturing (on a percentage of total energy basis), followed by mixed fossil/waste fuels (approximately 10 percent) and biomass fuels (approximately 5 percent). Corresponding values in 2000 were approximately 95 percent conventional fossil fuels, approximately 4 percent mixed fossil/waste fuels, and approximately 1 percent biomass fuels. See GCCA, *Getting the Numbers Right*, dataset 25aAGFC, for “World” and “EU States 28.”

<sup>33</sup> 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 International Energy Agency Greenhouse Gas R&D Programme (IEAGHG), *Deployment of CCS in the Cement Industry* (2013), [https://ieaghg.org/docs/General\\_Docs/Reports/2013-19.pdf](https://ieaghg.org/docs/General_Docs/Reports/2013-19.pdf).



materials that are less energy- and GHG-intensive than clinker per unit of final product, resulting in a significant reduction in fuel consumption and subsequent CO<sub>2</sub> emissions.<sup>34,35,36</sup>

- Substituting/co-firing conventional (coal/petcoke) fuels with alternative fuels that have a lower ratio of carbon content to calorific value, including switching to less carbon-intensive fuel (for example, natural gas, or, if not feasible, fuel oil), select waste fuels—as discussed in the “Air Emissions” section and the “Waste Fuels, Wastes, and Associated Air Emissions” subsection below—biomass fuels such as rice, coffee husks, palm kernel shells, wood-waste, and so on, or RDFs (where such alternative fuels are available in sufficient quantities at economic cost).<sup>37</sup>
- Partially substituting limestone feedstock with noncarbonated sources of calcium oxide or quicklime (CaO)—such as blast furnace slag, lignite ash, coal ash, concrete crusher sand, and so on—to reduce process CO<sub>2</sub> emissions and fuel CO<sub>2</sub> emissions related to calcination.<sup>38,39</sup>
- 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, the heat that remains after the recovery of process heat can be recovered through heat recovery boilers for use in a standalone power generation cycle, or to supplement steam produced from fuel combustion for onsite captive power generation. The amount of waste heat available for heat recovery power generation depends on the 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. Power generation from waste heat

<sup>34</sup> For example, for cement containing 30–70 percent of granulated blast furnace slag (GBFS), CO<sub>2</sub> emissions can be reduced by 100–430 kg per every ton of cement, compared with typical emissions of 750 kg CO<sub>2</sub> per ton of cement. The increased use of blended cements depends on the availability, properties, and prices of substitute materials, national standards, and market considerations such as the intended application of the cement product. See IIP, *Blended Cement Alternatives* (n.d.), <http://www.iipinetwork.org/wp-content/letd/content/blended-cement-alternatives.html>.

<sup>35</sup> Clinker-to-cement ratios among the major cement producers vary. The ratio in China in 2011 was 63 percent (73 percent in 2005); India 70.5 percent in 2013 (77.8 percent in 2005); the European Union 73.6 percent in 2013 (75.8 percent in 2005); and the US 83.5 percent in 2013 (83.7 percent in 2005). For cement-to-clinker ratios for China, see Ke et al., “Estimation of CO<sub>2</sub> Emissions,” 7. For information on India, the EU, and the US, see GCCA, “Getting the Numbers Right,” dataset 92AGW. For “India,” “EU States 28,” and “United States.”

<sup>36</sup> IEA and WBCSD (2018), “*Low-Carbon Transition in the Cement Industry*,” 32–35.

<sup>37</sup> IFC, *Increasing the Use of Alternative Fuels at Cement Plants: International Best Practice* (Washington, DC: IFC, 2017), [https://www.ifc.org/wps/wcm/connect/33180042-b8c1-4797-ac82-cd5167689d39/Alternative\\_Fuels\\_08+04.pdf?MOD=AJPERES&CVID=IT3Bm3Z](https://www.ifc.org/wps/wcm/connect/33180042-b8c1-4797-ac82-cd5167689d39/Alternative_Fuels_08+04.pdf?MOD=AJPERES&CVID=IT3Bm3Z).

<sup>38</sup> See Worrell, Kermeli, and Galitsky, *Energy Efficiency Improvement and Cost Saving Opportunities for Cement Making—An ENERGY STAR® Guide for Energy and Plant Managers*, 76–80; and IIP, *Alternative Raw Materials* (n.d.). The extent to which alternative feedstocks can be used depends on the composition of the available conventional raw materials (for example, limestone) and the availability, cost and composition of alternative feedstocks such as silica, alumina, magnesia, and sulphur content.

<sup>39</sup> Selection of raw materials with lower organic matter content to avoid generating additional emissions of CO<sub>2</sub>, 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). CO should be continuously monitored. In addition, when electrostatic precipitators (ESPs) are used, there is a risk of explosions related to CO concentrations higher than 0.5–1 percent.

recovery 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 the Kalina Cycle.<sup>40</sup>

21. For 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 fuels, including waste fuels, natural gas (or, if not feasible, fuel oil), and biomass, subject to technical constraints.<sup>41</sup>

### **Air Emissions**

22. 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. Nonpoint source emissions of dust can also arise.

23. Combustion sources for power generation are prevalent in this industry sector. The **General EHS Guidelines** provide guidance for the management of small combustion source emissions with a thermal heat input capacity of up to 50 megawatts thermal (MWth), including air emission standards for exhaust emissions. The **EHS Guidelines for Thermal Power** present guidance applicable to emissions sources greater than 50 MWth.

### **Particulate Matter**

24. Particulate matter (PM) emissions are a potentially significant impact arising from cement and lime manufacturing. The main sources of PM emissions, and their respective recommended prevention and control methods, are summarized in the following paragraphs.

25. 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,<sup>42</sup> are recommended:

- Capturing kiln and clinker cooler dusts using filters and recycling the recovered particulates into the kiln feed and into the clinker, respectively.

<sup>40</sup> Guidance on waste-heat recovery is available in IFC and IIP, *Waste Heat Recovery for the Cement Sector: Market and Supplier Analysis* (Washington, DC: IFC and IIP, 2014), [https://www.ifc.org/wps/wcm/connect/topics\\_ext\\_content/ifc\\_external\\_corporate\\_site/sustainability-at-ifc/publications/report\\_waste\\_heat\\_recovery\\_for\\_the\\_cement\\_sector\\_market\\_and\\_supplier\\_analysis](https://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/sustainability-at-ifc/publications/report_waste_heat_recovery_for_the_cement_sector_market_and_supplier_analysis).

<sup>41</sup> EULA, *Competitive and Efficient Lime Industry*, sec. 5, 27–42.

<sup>42</sup> Smoothing of kiln operations refers to maintaining the kiln in consistently optimum operating conditions.

- Using fabric filter systems<sup>43</sup> as the preferred control option, with ESPs as an alternative option<sup>44</sup> to collect and control fine particulate emissions (PM<sub>10</sub> and PM<sub>2.5</sub>) in kiln exhaust gas and bypass gas dust, and exhaust air from coolers.

26. For PM emissions associated with the operation of mills, the recommended control technique is to capture mill dust using fabric filters<sup>45</sup> and recycle it within the mill.

27. For PM emissions and fugitive dusts from the handling and storage of intermediate and final materials (including crushing and grinding of raw materials), handling and storage of solid fuels, transportation of materials (for example, by trucks or conveyor belts), and bagging activities, the recommended pollution prevention and control techniques include the following:

- Using 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.<sup>46</sup>
- Using enclosed belt conveyors for transporting materials and emission controls at transfer points, including systems for cleaning return belts.
- Designing sufficiently large covered storage for clinker and solid fuels to avoid the need for frequent double handling to and from outside stockpiles. 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.
- Implementing automatic bag-filling and handling systems to the extent possible, including the use of (i) a rotary bag-filling machine with an automatic paper bag feeder and fugitive emission control, (ii) automatic weight control for each bag during discharge, (iii) conveyor belts for transporting bags to a palletizing and wrapping machine, and (iv) storing the finished pallets in covered bays for subsequent shipping.
- Reducing diffuse or fugitive dust from material and fuel stocks through storage practices such as using (i) covered or closed bays for crushed and preblended raw materials; (ii) silos for conventional fuels such as pulverized coal and petroleum coke (petcoke); (iii) areas protected from wind and precipitation for waste-derived fuels; (iv) covered/closed bays or silos for the clinker with automatic dust extraction/reclamation; (v) silos with automatic dust extraction/reclamation for cement, connected to an automated loading system for bulk tankers; (vi) bunkers or silos for screened sizes of burnt lime; and (vii) sealed silos for storing fine grades of hydrated lime. PM

<sup>43</sup> Fabric filters are also referred to as “bag” filters or “baghouse” filters. This document uses the term fabric filter.

<sup>44</sup> Although ESPs are reliable under normal operating conditions, there is a risk of explosion when CO concentrations in the kiln exhaust exceed 0.5 percent. To prevent this, 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 the 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.

<sup>45</sup> ESPs are not suitable for mill dedusting due to investment costs and the efficiency (relatively high emissions) during startups and shutdowns.

<sup>46</sup> For lime-hydrating activities, wet scrubbers may be effective when the use of fabric filters is limited by the high moisture/low temperature of the flue gases. Schorcht et al., *Best Available Techniques*, sec. 4.6.3.2, 361.

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.

- Undertaking routine plant maintenance and good housekeeping to keep small air leaks and spills to a minimum and using mobile and stationary vacuum systems for routine operations and upsets.
- Using simple, linear layouts for materials-handling operations to reduce the need for multiple transfer points, including paving and wetting and cleaning routines for road transport areas.

28. Additional recommendations for the management of PM emissions from other diffuse sources, including dust created by vehicles moving in or adjacent to the cement or lime manufacturing facility, are available in the **General EHS Guidelines**.

### *Nitrogen Oxides*

29. Nitrogen oxide (NO<sub>x</sub>) emissions are generated in the high-temperature combustion process of the cement kiln.<sup>47</sup> The following prevention and control techniques, in addition to the smoothing of kiln operations, are recommended:

- Using low NO<sub>x</sub> burners (in the main kiln, as well as the precalciner, as applicable) to avoid localized flame hot spots that promote NO<sub>x</sub> formation.<sup>48</sup>
- Using Low NO<sub>x</sub> calciner.
- Using fuels with reduced N content.
- Developing a staged combustion process, as applicable, in PHP and PH kilns.
- Optimizing primary and secondary air flow to ensure appropriate combustion/burning conditions with tight control of excess oxygen, thereby minimizing NO<sub>x</sub> formation and emissions.
- Employing flame cooling<sup>49</sup> by adding water to the fuel or directly to the flame to reduce the temperature and increase the concentration of hydroxyl radicals.

30. In addition to the aforementioned primary control techniques for NO<sub>x</sub> reduction, secondary techniques such as selective noncatalytic reduction (SNCR) can also be used as necessary.<sup>50</sup>

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<sup>47</sup> Nitrogen monoxide represents more than 90 percent of NO<sub>x</sub> emitted.

<sup>48</sup> Regarding the use of low NO<sub>x</sub> burners with a precalciner, see Schorcht et al., *Best Available Techniques*, sec. 4.2.6.1, 349. Regarding burner optimization, if the initial burner runs on a low percentage of primary air, a low-NO<sub>x</sub> burner will have a marginal effect on NO<sub>x</sub> 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 hence a resultant increase in CO<sub>2</sub> emissions. See Schorcht et al., *Best Available Techniques*, sec. 1.4.5.1.2, 130.

<sup>49</sup> For a further description of flame-cooling techniques, see Gujarat Cleaner Production Centre (GCPC), *Cleaner Production Opportunities in Cement Manufacturing Sector* (n.d.), <http://www.gcpcenviis.nic.in/Experts/Cement%20sector.pdf>.

<sup>50</sup> For more information on SNCR and reducing agents and applications, see Schorcht et al., *Best Available Techniques*, sec. 1.4.5.1.7, 134–139.

31. Because of the lower limestone burning temperatures, NO<sub>x</sub> emissions are generally lower in lime manufacturing than in cement manufacturing. In addition to the smoothing of kiln operating conditions, the control of NO<sub>x</sub> emissions can be achieved using optimized low-NO<sub>x</sub> burners.<sup>51</sup>

### *Total Organic Compounds*

32. In heat (combustion) processes in general, the occurrence of Total Organic Compounds (TOC) or Volatile Organic Compounds (VOC) is often associated with incomplete combustion. In the kilns, the emissions will be low under normal steady-state conditions. Concentrations may increase during start-up or abnormal operating (upset) conditions. These events can occur with varying frequency, for example between once or twice per week to once per two or three months. TOC emissions can occur in the primary steps of the process (preheater, precalciner), when organic matter that is present in the raw meal, is volatilized as the feed is heated. The organic matter is released between temperatures of 400 and 600°C.

33. Under normal circumstances, emissions of TOCs are generally low but can be higher because of the organic volatile content in the raw material which is used at the plant. Natural or waste raw materials with a high content of volatile organic compounds should not, if a choice is possible, be fed into the kiln system via the raw material feeding route and fuels with a high content of halogens should not be used in a secondary firing. Optimization of the process, such as smoothing and optimizing the plant's operation, the firing process and/or homogenization of the fuel and raw material feedings, can be applied for keeping TOC emissions low. If elevated concentrations of TOCs occur, adsorption on activated carbon can be considered as in other sectors.<sup>52</sup>

### *Sulfur Dioxide*

34. Sulfur dioxide (SO<sub>2</sub>) emissions in cement manufacturing are associated primarily with the content of volatile or reactive sulfur in the raw materials and, to a lesser degree, with the quality of fuels used in the kiln.<sup>53</sup> Recommended pollution control techniques for reduction of SO<sub>2</sub> include the following:

- Selecting raw materials and fuels with low volatile sulfur content.
- Optimizing the clinker burning process using techniques that include smoothing kiln operations, ensuring uniform distribution of the hot meal in the kiln riser, and preventing reducing conditions in the burning process. Optimizing the oxygen concentration in the kiln inlet area will promote SO<sub>2</sub> capture in the kiln charge, but this must be balanced with impacts to NO<sub>x</sub> and CO emissions.

<sup>51</sup> Low NO<sub>x</sub> 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<sub>x</sub> burner technique from cement kilns to lime kilns is not straightforward. In cement kilns, flame temperatures are higher and low NO<sub>x</sub> burners have been developed to reduce high initial levels of "thermal NO<sub>x</sub>." In most lime kilns, the levels of NO<sub>x</sub> are lower and the "thermal NO<sub>x</sub>" is less significant. The burner technique has to be adjusted to the fuels used, that is, conventional fossil or waste fuels. Parallel flow regenerative kilns have flameless combustion, thus rendering low NO<sub>x</sub> burners not applicable to this kiln type. See Schorcht et al., *Best Available Techniques*, sections 2.4.6.1.3, 274.

<sup>52</sup> See Schorcht et al., *Best Available Techniques*

<sup>53</sup> Raw materials with a high content of organic sulfur or pyrite (FeS) result in elevated SO<sub>2</sub> emissions. Sulphur introduced into the kiln system with the fuels is oxidized to SO<sub>2</sub> and will not lead to significant SO<sub>2</sub> emissions, due to the strong alkaline nature in the sintering zone, the calcination zone, and the lower stage of the PH. See Schorcht et al., *Best Available Techniques*, sec. 1.3.4.3, 66, and sec. 1.4.3.2, 111.

- Using a vertical raw mill, with 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 (SO<sub>x</sub>) mixes with the calcium carbonate (CaCO<sub>3</sub>) of the raw meal and produces calcium sulfate (gypsum)).
- Injecting absorbents such as calcium hydroxide or hydrated lime (Ca(OH)<sub>2</sub>), CaO, or fly ashes with high CaO content into the exhaust gas before filters.
- Using wet or dry scrubbers.<sup>54</sup>

35. SO<sub>2</sub> emissions in lime manufacturing are associated with the sulfur content of the fuel and raw materials, the design/type of kiln, and product requirements. Shaft kilns, including PFR kilns, generally have lower SO<sub>2</sub> emissions than rotary kilns or rotary kilns equipped with PHs. The selection of low-sulfur-content fuels and raw materials with low sulfur content can reduce SO<sub>2</sub> emissions.<sup>55</sup>

### *Heavy Metals*

36. Emissions of heavy metals—such as lead, cadmium, and mercury—during cement and lime manufacturing can be significant depending on the presence of heavy metals in raw materials and fossil and waste-derived fuels.

37. Nonvolatile metals are mostly bound to the PM and can be controlled using dust/PM measures, as discussed in the above section. Captured waste materials should be managed as a hazardous waste, as described in the **General EHS Guidelines**.

38. 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 the emissions of volatile heavy metals include the following:

- Implementing controls for the volatile heavy metal content in the input materials and waste fuels through 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), 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.<sup>56</sup> The resulting solid waste should be managed

<sup>54</sup> While SO<sub>2</sub> 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 SO<sub>2</sub> emissions have the potential to be higher than 1500 milligrams per normal cubic meter (mg/Nm<sup>3</sup>).

<sup>55</sup> For more information on control of SO<sub>2</sub> emissions in lime manufacturing, see Schorcht et al., *Best Available Techniques*, sec. 2.4.6.2, 279.

<sup>56</sup> This dust shuttling or “bleeding” technique is more efficient in “raw mill off” mode, where the 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 PH, 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 (°C), in order to have a high rate of adsorption efficiency. See United Nations Environment Programme (UNEP), “Cement Clinker Production Facilities” in *Guidance on Best Available Techniques and Best Environmental Practices* (New York: UNEP, 2016), sections 3.2.1 and 3.2.2, 10–12, [http://mercuryconvention.org/Portals/11/documents/publications/BAT\\_BEP\\_E\\_interactif.pdf](http://mercuryconvention.org/Portals/11/documents/publications/BAT_BEP_E_interactif.pdf).



as a hazardous waste as described in the **General EHS Guidelines**. Multi-pollutant control measures such as wet scrubbers and adsorption on activated carbon, can also be effective in controlling high concentrations of volatile heavy metals.<sup>57</sup>

### *Waste Fuels, Wastes, and Associated Air Emissions*

39. Cement kilns, because of their strong 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, RDF, and waste plastics. In exceptional cases, cement kilns can also be used for disposing wastes that have little calorific or mineral value and do not contribute to the clinker production process. This coprocessing of hazardous waste (including polychlorinated biphenyls (PCBs), obsolete organochlorine pesticides, and other chlorinated materials) should be considered only if certain requirements (discussed below) are met regarding process control, emission control, and input control (for example, controlling the heavy metal content, heating value, ash content, and chlorine content). Although using waste fuels can allow for the substitution of fossil fuels, depending on their composition, the use of waste fuels or coprocessing of hazardous waste, if not properly operated and controlled, can lead to the emission of volatile organic compounds (VOCs), persistent organic pollutants such as polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs), as well as hydrogen fluoride (HF), hydrogen chloride (HCl) (that could also be generated by VOCs from raw materials containing chloride), and toxic metals and their compounds.

40. Facilities using waste fuel or coprocessing 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 (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. The recommended prevention and control techniques for these air pollutants include the following:<sup>58</sup>

- Implementing monitoring and control of the volatile heavy metal content in the input materials and waste fuels through materials selection and the control measures described in the [Heavy Metals](#) section. Nonvolatile metals should be managed according to the recommendations in the [Particulate Matter](#) section.
- 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**.

<sup>57</sup> Wet scrubbers are most effective in cases where the dominant emissions of mercury are in the oxide form. If there are high levels of elemental mercury, wet scrubbers are not as effective unless additives are used to oxidize the mercury. Activated carbon filters are constructed as a packed bed with modular filter sizing to accommodate varying levels of gas throughputs and kiln capacity. See UNEP, "Cement Clinker Production Facilities," sections 3.3.1 and 3.3.3.

<sup>58</sup> GCCA provides additional guidance on the management of waste fuels and materials in GCCA, *Guidelines for Co-Processing Fuels and Raw Materials in Cement Manufacturing* (London: GCCA, 2019b), [https://gccassociation.org/wp-content/uploads/2019/10/GCCA\\_Guidelines\\_FuelsRawMaterials\\_v04\\_AMEND.pdf](https://gccassociation.org/wp-content/uploads/2019/10/GCCA_Guidelines_FuelsRawMaterials_v04_AMEND.pdf).

- Directly injecting fuels that have volatile metals or high VOC concentrations into the main burner rather than via the secondary burners.
- Avoiding fuels with high halogen content during secondary firing and during the startup and shutdown phases.
- Ensuring rapid cooling of kiln exhaust gases to below 200°C in long wet and long dry kilns without preheating.<sup>59</sup>

41. In manufacturing lime, waste fuel and waste raw materials are rarely used because of product-quality requirements.<sup>60</sup>

### **Noise and Vibrations**

42. There are many cement- and lime-manufacturing phases that are sources of high levels of noise. They include extracting raw materials (as discussed in the **EHS Guidelines for Construction Materials Extraction**); grinding and storage; handling and transporting raw materials or intermediate and final products; and operating exhaust fans. Control of noise emissions may include the use of silencers for fans, room enclosures for mill operators, noise barriers, sound deflectors, insulation. The **General EHS Guidelines** provide levels for recommended noise abatement measures and ambient and workplace noise levels.

### **Wastewater**

#### **Industrial Process Wastewater Treatment**

43. Wastewater is generated mainly from cooling utilities in different phases of the process (for example, bearings and kiln rings). Techniques for treating industrial-process wastewater 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**.

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<sup>59</sup> PCDDs and PCDFs are destroyed in flame and high-temperature gases, but at a lower temperature range (250–500°C) they can re-synthesize. Short cooling times at 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 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, *Formation and Release of POPs in the Cement Industry*, 2nd ed. (Geneva: WBCSD, 2006), <http://docs.wbcsd.org/2006/01/FormationAndReleaseOfPOPsInCementIndustry.pdf>.

<sup>60</sup> 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 petcoke can be used when the resulting sulfur content in the product is not a concern.

### *Other Wastewater Streams and Water Consumption*

44. Guidance on the management of noncontaminated wastewater from utility operations, noncontaminated stormwater, and sanitary sewage is provided in the **General EHS Guidelines**. Contaminated streams should be routed to the treatment system for industrial-process wastewater.

45. Stormwater flowing through petcoke, coal, and waste-material stockpiles may become contaminated. Stormwater should be prevented from contacting stockpiles by covering or enclosing the stockpiles and by installing runoff controls. Recommended pollution-prevention techniques for dust emissions from stockpiles of raw materials, clinker, coal, and waste 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 runoff controls around them, and collecting the stormwater in a lined basin to allow the PM to settle before separation, control, and recycling or discharge. The **General EHS Guidelines** provide further recommendations on managing contaminated stormwater.

46. 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**

47. Sources of solid waste in cement and lime manufacturing include clinker production waste (composed mainly 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, that can be classified as hazardous waste, 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. There is also some limited waste generated from plant maintenance—for example, used oil and scrap metal, and kiln refractory materials that may contain heavy metals. Other waste materials may include alkali, chloride, or fluoride contained in dust buildup from the kiln.<sup>61</sup>

48. In lime production, dust, off-specification quicklime, and hydrated lime are often reused or recycled to make selected commercial products—for example, in producing lime for construction uses, lime for soil stabilization, hydrated lime, and pelletized products.

49. Guidance on the management of hazardous/nonhazardous wastes is available in the **General EHS Guidelines**.

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<sup>61</sup> Older facilities still using largely discontinued semiwet processes may also generate alkaline filtrates from filter presses.

## 1.2 Occupational Health and Safety

50. The most significant occupational health and safety impacts occur during the operational phase of the cement and lime manufacturing projects, and primarily include the following:<sup>62</sup>

- Hazardous dusts
- Explosions and fires
- Hazardous energies
- Electric hazards
- Confined spaces
- Complex and critical lift
- Welding, cutting, and brazing (hot work)
- Heat
- Noise and vibrations
- Physical hazards
- Radiation
- Chemical hazards and other industrial hygiene issues

### **Hazardous Dusts**

51. Exposure to fine particulates is associated with work in most of the dust-generating stages of cement and lime manufacturing, but most notably during quarry operation (see **EHS Guidelines for Construction Materials Extraction**), raw material handling, and clinker or cement grinding. In particular, exposure to the respirable fraction of active (crystalline) silica dust ( $\text{SiO}_2$ ), and to asbestos when it is present in the raw materials and products (for example, cement dust), is a relevant potential hazard in the cement and lime manufacturing sector, and specific health and safety standards must be followed to control these hazards.<sup>63</sup> Methods to prevent and control exposure to dust include the following:

<sup>62</sup> More detailed information about occupational health and safety impacts can be obtained by consulting GIIP occupational health and safety (OHS) standards such as Occupational Safety and Health Administration (US OSHA), 1910—General Industry; UK Health and Safety Executive (HSE) regulations and Codes of Practice; and Australian and New Zealand guidelines and Codes of Practice.

<sup>63</sup> Information on preventing and controlling the hazards of silica inhalation can be obtained from several sources, including Health and Safety Ontario, *Silica in the Workplace* (2011); OSHA, *OSHA's Respirable Crystalline Silica Standard for General Industry and Maritime* (2018); American Conference of Governmental Industrial Hygienists (ACGIH), *2021 Threshold Limit Values (TLVs) and Biological Exposure Indices (BEIs)*; US OSHA, *Occupational and Safety Health Standards, 1910.1053 Subpart Z, Toxic and Hazardous Substances, Respirable Crystalline Silica*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.1053> and *1910.1001 Subpart Z, Asbestos*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.1001>; ASTM International, *ASTM E1132 13e1: Standard Practice for Health Requirements Relating to Occupational Exposure to Respirable Crystalline Silica* (West Conshohocken, PA, 2013), <https://www.astm.org/Standards/E1132.htm>; UK HSE, *Control of Substances Hazardous to Health, Regulations 2002: Approved Code of Practice and Guidance*, L5 6th ed. (2013),

- Controlling dust through good housekeeping and maintenance, including using mobile vacuum-cleaning systems to prevent dust buildup on paved areas.
- Using air-conditioned closed cabins.
- Using closed conveyors/elevators with emission controls at transfer points for fugitive dust emissions.
- Using dust extraction and recycling systems to remove dust from work areas, especially in grinding mills.
- Using air ventilation (suction) in cement-bagging areas.
- Measuring workers' exposure to hazardous dusts.
- Using personal protective equipment (for example, masks and respirators) to address residual exposure following the adoption of the above-noted processes and engineering controls.<sup>64</sup>
- Implementing a respiratory protection program. A written respiratory protection program must specify the Standard Operation Procedures (SOPs) that are in place to protect all workers from respiratory hazards. It must include a designed program administrator, respirator selection, medical evaluation, fit-testing procedure, procedures for proper use, maintenance, and air-quality procedures (supplied-air respirators), program and workplace evaluation, and training.<sup>65</sup>

### **Explosions and Fires**

52. Fires and explosions can result from many different processes and the fuels used in the cement industry. On average 0.2–0.3 tonnes of coal are consumed in a kiln per kilogram of clinker cement production, making coal storage, handling, and conveying some of the most common fire hazards in the cement industry. Other major fire hazards include dedicated onsite power plants, electrical components such as transformers and switch gear, and empty bag storage.

53. The most common explosion hazards in cement plants are associated with coal dust (dust explosion). Because coal is pulverized into smaller particles before it is used in a kiln, this dramatically increases the risk of a fire/explosion. Bag filters used in the coal mill can explode spontaneously or as a result of static electricity. Moreover, the buildup of explosive mixtures, such as finely dispersed coal dust in air or carbon monoxide in air, can result in an explosion hazard in electrostatic precipitators.

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<https://www.hse.gov.uk/pubns/priced/l15.pdf>; and Cecala, Andrew B. et al., *Dust Control Handbook for Industrial Minerals Mining and Processing*, Report no. RI9701, 2nd ed. (Cincinnati: NIOSH Publications, 2019), <https://www.cdc.gov/niosh/mining/UserFiles/works/pdfs/2019-124.pdf>.

<sup>64</sup> For more information, consult UK HSE, *Respiratory Protective Equipment at Work, A Practical Guide*, HSG53 4th ed. (2013), <https://www.hse.gov.uk/pubns/priced/hsg53.pdf>; ASTM International, *ASTM F3387–19: Standard Practice for Respiratory Protection* (West Conshohocken, PA, 2019), doi: [10.1520/F3387-19](https://doi.org/10.1520/F3387-19), <https://www.astm.org/Standards/F3387.htm>; and/or Nancy J. Bollinger and Robert H. Schultz, *NIOSH Guide to Industrial Respiratory Protection*, DHHS Publication Number 87–116 (1987), <https://www.cdc.gov/niosh/docs/87-116/pdfs/87-116.pdf?id=10.26616/NIOSH-PUB87116>.

<sup>65</sup> For more information, consult US OSHA, *Occupational and Safety Health Standards, 1910.134(c) Subpart I, Respiratory Protection Program*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.134>, or ASTM, *Standard Practice for Respiratory Protection*, <https://www.astm.org/Standards/F3387.htm>.

54. For recommended practices, refer to the **General EHS Guidelines** and appropriate GIIP standards.<sup>66</sup>

### **Hazardous Energy Sources**

55. Energy sources—including electrical, mechanical, hydraulic, pneumatic, chemical, thermal, or other sources—in machines and equipment can be hazardous to workers. During the servicing and maintenance of machines and equipment, the unexpected startup or release of stored energy can result in serious injury or even death to workers. For recommended practices, refer to the **General EHS Guidelines** and appropriate GIIP OHS standards.<sup>67</sup>

### **Electric Hazards**

56. Cement manufacturing is energy-intensive and cement plants have heavy-duty electrical equipment installed for control, distribution, and utilization of electric power. Very often, cement plants are equipped with dedicated power-generation units. The operation and maintenance of electric circuits and powered machines, tools and equipment are a common source of electrical hazards such as electrocutions, arc-flash, burns, fires and explosions. For recommended practices, refer to the **General EHS Guidelines** and appropriate GIIP OHS standards.<sup>68</sup>

<sup>66</sup> See US OSHA, 1910 Subpart H, *Hazardous Materials*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910SubpartH>; Subpart L, *Fire Protection*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910SubpartL>; Subpart S, *Electrical*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910SubpartS>; National Fire Protection Association (NFPA), *NFPA 68-2002: Guide for Venting of Deflagrations*, 2002 edition, in vol. 13, the 2004/2005 National Fire Codes, <https://webstore.ansi.org/standards/nfpa-fire/nfpa682002>; NFPA 69: *Standard on Explosion Prevention Systems*, <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=69>; NFPA 70: *National Electric Code* (2020) <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70>; NFPA 77: *Recommended Practice on Static Electricity* (2019), <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=77>; NFPA 85: *Boiler and Combustion Systems Hazards Code* (2019), <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=85>; NFPA 86: *Standard for Ovens and Furnaces* (2019), <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=86>; NFPA 499: *Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas* (2021), <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=499>; NFPA 654: *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids* (2020), <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=654>; and American Society of Mechanical Engineers (ASME), *Boiler and Pressure Vessel Code* (2021), <https://www.asme.org/codes-standards/find-codes-standards/bpvc-complete-code-boiler-pressure-vessel-code-complete-set>.

<sup>67</sup> Examples include US OSHA, 1910 Subpart J, *General Environmental Controls*, 1910.147: *The Control of Hazardous Energy (Lockout/Tagout)* <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.147>; US OSHA, 1910 Subpart S, *Electrical*, 1910.333 *Selection and Use of Work Practices*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.333>; American Society of Safety Professionals (ASSP), ANSI/ASSP Z244.1-2016 (R2020) *The Control of Hazardous Energy: Lockout, Tagout and Alternative Methods*, <https://webstore.ansi.org/standards/asse/ansiasspz2442016r2020>; and UK HSE, HSG253, *The Safe Isolation of Plant and Equipment* (2006), <https://www.hse.gov.uk/pubns/books/hsg253.htm>.

<sup>68</sup> See US OSHA, 1910 Subpart S, *Electrical*; ANSI/NEC and HSE, *HSG85 Electricity at Work: Safe Working Practices* (2013), <https://www.hse.gov.uk/pubns/books/hsg85.htm>.



## ***Confined Spaces***

57. In a cement plant operation, workers regularly have to enter confined spaces such as furnaces, baghouses, bins, crushers, chutes, silos, and grinding mills as part of their work. Confined-space fatalities and serious injuries still occur, often due to a lack of proper hazard identification, control, and/or training. For recommended practices, refer to the **General EHS Guidelines** and appropriate GIIP OHS standards.<sup>69</sup>

## ***Complex and Critical Lifting***

58. Cement plants have large heavy equipment that often needs to be replaced or removed for maintenance. This may require lifting operations that involve complex and critical situations, including lifting of personnel or hazardous materials, obstructed approaches or removal paths, hoisting operations that exceed 75 percent of the nominal capacity of the equipment, boom clearance that is less than 3 feet, proximity hazards such as having to pass within 20 feet of an energized line, and tandem or multiple crane lifts. For recommended practices refer to the **General EHS Guidelines** and appropriate GIIP OHS standards.<sup>70</sup>

## ***Welding, Cutting, and Brazing (Hot Works)***

59. Cement plants rely heavily on metal structures and equipment that wear out over time and need continual maintenance. For the maintenance division in a cement plant, welding and cutting are everyday activities that are often associated with other hazards such as working at heights or entering confined spaces. For recommended practices, refer to the **General EHS Guidelines** and appropriate GIIP standards.<sup>71</sup>

## ***Heat***

60. Heat hazards in a cement plant can occur in two different forms: direct contact with heated surfaces and materials, or heat stress and heat strain from prolonged work under high temperatures.

61. Heat injuries can occur during the operation and maintenance of kilns, preheater towers, electrostatic precipitators or other hot equipment, through direct contact with hot cement, hot clinker, bypass dust from

<sup>69</sup> US OSHA, 1910 Subpart J, *General Environmental Controls* 1910.146, *Permit-Required Confined Spaces*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.146>; ASTM D4276-02: *Standard Practice for Confined Area Entry* (2020), <https://www.astm.org/Standards/D4276.htm>; and Standards Australia, AS 2865-2009, *Confined Spaces*, <https://www.standards.org.au/standards-catalogue/sa-snz/publicsafety/sf-037/as--2865-2009>.

<sup>70</sup> ASME, ASME B30.19-2016, *Safety Standard for Cableways, Cranes, Derricks, Hoists, Hooks, Jacks, and Slings*, [https://webstore.ansi.org/Standards/ASME/ASMEB30192016?source=blog&\\_ga=2.74808987.801118766.1632709424-2025001869.1632150268](https://webstore.ansi.org/Standards/ASME/ASMEB30192016?source=blog&_ga=2.74808987.801118766.1632709424-2025001869.1632150268); US OSHA, 1910 Subpart N, *Materials Handling and Storage*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910SubpartN>; and US OSHA, *Safety and Health Regulations for Construction, 1926 Subpart CC, Cranes and Derricks in Construction*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926SubpartCC>.

<sup>71</sup> US OSHA, 1910 Subpart Q, *Welding, Cutting and Brazing*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910SubpartQ>; UK HSE, *Health and Safety Welding Resources*, <https://www.hse.gov.uk/welding/publications.htm>; Safe Work Australia, *Model Code of Practice: Welding Processes*, <https://www.safeworkaustralia.gov.au/doc/model-code-practice-welding-processes>; and NIOSH, Publication No. DHHS-NIOSH-88-110, *Criteria for a Recommended Standard: Welding, Brazing, and Thermal Cutting* (1988), <https://www.cdc.gov/niosh/docs/88-110/default.html>.

precipitators or other material, and/or through exothermic reactions in the lime-hydrating process. Likewise, heat stress and heat strain can result from prolonged work outdoors under high temperatures or indoors in high-temperature areas, especially for kiln workers. For recommended practices, refer to the **General EHS Guidelines** and appropriate GIIP standards.<sup>72</sup>

### **Noise and Vibrations**

62. There are many cement- and lime-manufacturing phases that can expose workers to noise. They include extracting raw materials (as discussed in the **EHS Guidelines for Construction Materials Extraction**); grinding and storage; handling and transporting raw materials or intermediate and final products; and operating exhaust fans. The **General EHS Guidelines** provide levels for recommended noise abatement measures and ambient and workplace noise levels.

63. The main sources of noise and vibrations in cement and lime plants are crushing/grinding operations, mills, chutes, and hoppers, mobile equipment, exhaust fans, and blowers. Control of noise emissions may include the use of silencers for fans, room enclosures for mill operators, noise barriers, sound deflectors, insulation, and, if noise cannot be reduced to acceptable levels, personal hearing protection, as described in the **General EHS Guidelines**.

### **Physical Hazards**

64. Injuries during cement and lime manufacturing operations are typically related to slips, trips, and falls; contact with falling or moving objects; and lifting and overexertion. Other injuries may occur from traffic accidents in relation to contact with, or capture in, moving machinery—for example, dump trucks, front loaders, forklifts, and bagging machines. Activities related to the maintenance of equipment—including crushers, mills, mill separators, fans, coolers, and belt conveyors—are significant sources of exposure to physical hazards. The **General EHS Guidelines** describe ways to manage these hazards.<sup>73</sup>

### **Radiation**

65. X-ray stations are sometimes used to continuously monitor the raw material mix on the belt conveyor feeding a raw mill. X-ray station operators should be protected by ionizing radiation protection measures, as described in the **General EHS Guidelines**.

<sup>72</sup> See the heat stress and heat strain section of ACGIH, *2016 TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices* (Cincinnati: ACGIH, 2016); NIOSH, *Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments*, <https://www.cdc.gov/niosh/docs/2016-106/default.html>; and the NIOSH Heat Stress webpage, <https://www.cdc.gov/niosh/topics/heatstress/default.html>.

<sup>73</sup> Further guidance is available in WBCSD, *Health and Safety in the Cement Industry: Examples of Good Practice* (Geneva: WBCSD, 2004), <http://ficem.org/CIC-descargas/Suiza/CSI/Health-and-Safety-in-the-Cement-Industry-Examples-of-Good-Practice-2004.pdf>.

### ***Chemical Hazards and Other Industrial Hygiene Issues***

66. Exposure to chromium may contribute to allergic contact dermatitis in workers handling cement.<sup>74</sup> Preventing and controlling this potential hazard includes reducing the proportion of soluble chromium in cement mixes and using proper personal protective equipment to prevent dermal contact, as described in the **General EHS Guidelines**.

67. Calcium oxide (CaO), or “quicklime,” reacts with water to produce calcium hydroxide (Ca(OH)<sub>2</sub>), “hydrated lime,” a highly corrosive caustic solution. Accidental contact of sufficient duration with quicklime or hydrated lime powders with moist skin, eyes, or mucous membranes will cause caustic tissue burns. This is also a powerfully explosive exothermic reaction which generates lime-laden steam and hot water splashing, both of which are highly hazardous because of their high temperature and caustic properties. Areas in which these compounds are handled as powder, or areas where lime is slaked, should be covered and enclosed, if possible, to avoid generating a dust hazard. Facilities for immediate washing of the affected body surface should be available, including eyewash facilities where quicklime is handled. Personal protective equipment, such as safety goggles, gloves, protective clothing, and boot covers, should be provided in the lime-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**

68. 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**.

69. Among those health and safety impacts and risks to the community, it is important to highlight (i) traffic and the increased number of vehicles stationed close to the plant waiting to be loaded, (ii) overloading of trucks, and (iii) the influx of workers, especially during project construction. In the first case, if left unmanaged, those waiting areas might develop into informal settlements that could lead to increased exposure of the local community to health and safety risks. These waiting areas should be gated, supervised, and off the road, and should have dedicated facilities with locker rooms and restrooms for the drivers and other operators. Regarding the overloading of trucks, specific directions and management instructions on the loading procedures and limits should be enforced at the plant to avoid increased risks of road safety accidents. Regarding workers influx, specific workforce management plans should be put in place to safeguard the health and safety of local communities.

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<sup>74</sup> To prevent allergic contact dermatitis, the EU limits the content of soluble chromium in cement to a maximum of 0.0002 percent of the total dry weight of the cement.

## 2. PERFORMANCE INDICATORS AND MONITORING

### 2.1 Environment

#### *Emissions and Effluent Guidelines*

70. 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 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 the 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 its annual operating hours. Deviation from these levels in specific, local project conditions should be justified in the environmental assessment.

71. Effluent guidelines are applicable for direct discharge 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 into surface waters, based 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 to 50 MWth are addressed in the **General EHS Guidelines**. 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**.

#### *Resource Efficiency and Waste*

72. Table 4 provides examples of resource use and waste generation in this sector that can be considered as indicators of GIIP for new machinery in the sector and may be used to track performance changes over time.<sup>75</sup>

<sup>75</sup> Table 4 errata fix dated April 2025 to correct the industry benchmark for 'clinker to cement ratio', which should be 'below 70-75%' and not '30%', clarification on cement additives included, and new footnote 'f' with references. Footnote 'e' expanded to clarify clinker ratio influence on GHG emissions.

TABLE 1. AIR EMISSION LEVELS FOR CEMENT MANUFACTURING

POLLUTANTS	UNITS	GUIDELINE VALUE
<b>Particulate matter</b> (new kiln system with dry flue gas cleaning using an ESP, fabric, and/or hybrid filter)	mg/Nm <sup>3</sup>	25 <sup>a</sup>
<b>Particulate matter</b> (existing kilns)	mg/Nm <sup>3</sup>	100
<b>Dust</b> (other point sources including clinker cooling, cement grinding)	mg/Nm <sup>3</sup>	25
<b>SO<sub>2</sub></b>	mg/Nm <sup>3</sup>	400 <sup>b</sup>
<b>NO<sub>x</sub></b>	mg/Nm <sup>3</sup>	600 NDA <sup>c</sup> see footnote for DA <sup>c</sup>
<b>NH<sub>3</sub> slip in the flue-gases (when SNCR is applied)</b>	mg/Nm <sup>3</sup>	<30–50 <sup>d</sup>
<b>HCl</b>	mg/Nm <sup>3</sup>	10 <sup>e</sup>
<b>Hydrogen fluoride</b>	mg/Nm <sup>3</sup>	1 <sup>e</sup>
<b>Total organic carbon</b>	mg/Nm <sup>3</sup>	30 <sup>f</sup>
<b>Dioxins-furans</b>	ng TEQ/Nm <sup>3</sup>	0.1 <sup>e</sup>
<b>Cadmium and thallium (Cd+Tl)</b>	mg/Nm <sup>3</sup>	0.05 <sup>e</sup>
<b>Mercury (Hg)</b>	mg/Nm <sup>3</sup>	0.05 <sup>e</sup>
<b>Total metals <sup>g</sup></b>	mg/Nm <sup>3</sup>	0.5

**Notes:**

Emissions are from the kiln stack unless otherwise noted. Daily average values corrected to 273°K 101.3 kilopascals (kPa), 10 percent O<sub>2</sub>, and dry gas, unless otherwise noted.

ng TEQ/Nm<sup>3</sup> = nanograms of dioxin toxic equivalent per normal cubic meter.

See Van den Berg et al., "The 2005 World Health Organization Re-evaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-like Compounds," *Toxicological Sciences* 93, no.2 (October 2006): 223–241. doi:

[10.1093/toxsci/kfl055](https://doi.org/10.1093/toxsci/kfl055); and WHO, *International Programme on Chemical Safety* guidelines, [http://www.who.int/ipcs/assessment/tef\\_values.pdf](http://www.who.int/ipcs/assessment/tef_values.pdf).

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

<sup>a</sup> Particulate matter emission levels from flue gases of new kiln-firing processes of <10–20 mg/Nm<sup>3</sup> (daily average value) can be achieved when applying an ESP and/or fabric and hybrid filters. See Schorcht et al., *Best Available Techniques*, sec. 4.2.5.3, 348. The guideline is 10 mg/Nm<sup>3</sup> if more than 40 percent of the resulting heat release comes from hazardous waste. See European Commission (EC), *Directive 2010/75/EU* on the incineration of waste.

<sup>b</sup> For guideline value of SO<sub>2</sub>, see Schorcht et al., *Best Available Techniques*, table 4.4, 351.

<sup>c</sup> The NO<sub>x</sub> guideline value of 600 mg/Nm<sup>3</sup> is derived from IFC project benchmarks and it should be applied in NDAs. For projects located in DAs or ecologically sensitive areas, NO<sub>x</sub> levels may need to be lower than the guideline value to be protective of human health and environment. The application of the guideline value of 600 mg/Nm<sup>3</sup> should be justified in the project Impact

Assessment, including a detailed technical and financial feasibility analysis of the measures required to achieve lower values than the guideline value. The use of secondary pollution controls including SNCR may be necessary to achieve the guideline value or lower. The use of SNCR should include assessment and mitigation of risks associated with transport, storage, and use of reducing agents (for example, ammonia, urea) in accordance with the guidance on hazardous materials management in the **General EHS Guidelines**.

<sup>d</sup> The ammonia slip depends on the initial NO<sub>x</sub> level and on the NO<sub>x</sub> abatement efficiency.

<sup>e</sup> 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 30 minutes). See Schorcht et al., *Best Available Techniques*, sec. 4.2.6.5, 352, for HCl and HF, and sec. 4.2.8 table 4.5, 353, for metals. For dioxins-furans, the guideline is the average over a sampling period of 6–8 hours. See EC, *Reference Document on Best Available Techniques*, section 4.2.7, 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 8 hours. See EC, *Directive 2010/75/EU* on the incineration of waste.

<sup>f</sup> A detailed deposit evaluation should be carried out to determine the level of total organic carbon in the deposit and define the final TOC threshold to follow below the indicated 30 mg/Nm<sup>3</sup> guideline value.

<sup>g</sup> Total metals = Arsenic (As), Lead (Pb), Cobalt (Co), Chromium (Cr), Copper (Cu), Manganese (Mn), Nickel (Ni), Vanadium (V), and Antimony (Sb). See Schorcht et al., *Best Available Techniques*, table 4.5, 353.



TABLE 2. AIR EMISSION LEVELS: LIME MANUFACTURING		
POLLUTANTS	UNITS	GUIDELINE VALUE <sup>a</sup>
Dust	mg/Nm <sup>3</sup>	25
SO <sub>2</sub>	mg/Nm <sup>3</sup>	200 for PFRK, ASK, MFSK, OSK and PRK kilns or 400 for LRK kiln
NO <sub>x</sub>	mg/Nm <sup>3</sup>	350 for PFRK, ASK, MFSK, OSK kilns or 500 for LRK, PRK
HCl	mg/Nm <sup>3</sup>	10
<b>Notes:</b> For guideline values of SO <sub>2</sub> , see Schorcht et al., <i>Best Available Techniques</i> , table 4.10, 365. For NO <sub>x</sub> , see <i>ibid.</i> , table 4.9, 364. <sup>a</sup> Daily average values corrected to 273°K, 101.3 kPa, 10% O <sub>2</sub> , and dry gas, unless otherwise noted.		

TABLE 3. EFFLUENT LEVELS: CEMENT AND LIME MANUFACTURING		
POLLUTANTS	UNITS	GUIDELINE VALUE
pH	S.U.	6–9
Total suspended solids	mg/L	50
Oil and grease	mg/L	10
Temperature increase	°C	<3 <sup>a</sup>
<sup>a</sup> At the edge of a scientifically established mixing zone, which takes into account ambient water quality, receiving water use, potential receptors, and assimilative capacity.		

TABLE 4. RESOURCE AND ENERGY CONSUMPTION		
INPUTS PER UNIT OF PRODUCT	UNIT	INDUSTRY BENCHMARK
Fuel energy: cement	GJ/t clinker	PHP kiln: 2.9–3.3 <sup>a</sup>
Electrical energy: cement	kWh/t cement	80–105 <sup>b</sup>
Electrical energy: clinker grinding	kWh/t cement	28–45 <sup>c</sup>
Fuel energy: lime	GJ/t lime	4–4.7 mixed-feed shaft kilns <sup>d</sup> 3.6–6 advanced shaft and rotary kilns <sup>d</sup>
Electrical energy: lime	kWh/t equivalent lime	5–15 mixed-feed shaft kilns <sup>d</sup> 20–40 advanced shaft and rotary kilns <sup>d</sup>
GHG emissions	CO <sub>2</sub> (equivalent) emissions in kg/t cement	550–700 (including GHG emissions from power consumption) <sup>e</sup>
Clinker to cement ratio	%	Clinker content below 70–75 percent (meaning >25–30 percent additives as gypsum and substitutes of clinker with alternate cementitious materials such as blast furnace slag, fly ash, pozzolana, silica fume, burnt shale, limestone and other materials such as calcined clay). <sup>f</sup>

<sup>a</sup> IFC benchmarks; Schorcht et al., *Best Available Techniques*; and Worrell, Kermeli, and Galitsky, *Energy Efficiency Improvement*.  
<sup>b</sup> IFC benchmarks; GCCA, “Getting the Numbers Right 2018,” dataset 33AGW. Most recent GCCA data should be consulted.  
<sup>c</sup> IIP, n.d., “Vertical Roller Mills for Finish Grinding.”  
<sup>d</sup> Schorcht et al., *Best Available Techniques*.  
<sup>e</sup> IFC benchmarks include GHG emissions from electrical energy consumed, either generated onsite and/or imported from the grid. Note that these emissions may vary even wider than this range depending on clinker to cement ratio, influenced by cement product portfolio, the kiln fuels source, and other factors.  
<sup>f</sup> Note that clinker to cement ratio varies widely depending on the cement product composition and the standards allowable for those products (e.g. EN 197-6, ASTM C150, C595, IS 269:2015 or local cement quality standards). Benchmark values are indicative, some end user applications require a higher clinker ratio cement than others, so values should be adapted accordingly. However, the trend is to promote lower clinker ratio cements, which are becoming more commonly used in the industry.

## Environmental Monitoring

73. Environmental monitoring programs for this sector should be implemented to address all activities that have been identified as having a potentially significant impact 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 of a particular project.<sup>76</sup>

74. 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

<sup>76</sup> Recommended environmental monitoring parameters and frequencies are available in Schorcht et al., *Best Available Techniques*, sec. 4.2.2, 341 and WBCSD (2012).

corrective actions can be taken. The **General EHS Guidelines** provide additional guidance on applicable sampling and analytical methods for emissions and effluents.

75. 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 the minimum calorific value and the maximum concentration levels of specific pollutants like PCB, chlorine, polycyclic aromatic hydrocarbon, mercury, and other heavy metals.

## 2.2 Occupational Health and Safety

### *Occupational Health and Safety Guidelines*

76. Occupational health and safety performance should be evaluated against internationally published exposure guidelines. Examples include the threshold limit values for occupational exposure and biological exposure indices, published by the ACGIH;<sup>77</sup> *NIOSH Pocket Guide to Chemical Hazards*, published by the United States National Institute for Occupational Health and Safety (NIOSH);<sup>78</sup> permissible exposure limits, published by the US Occupational Safety and Health Administration (OSHA);<sup>79</sup> and *Indicative Occupational Exposure Limit Values*, published by the European Agency for Safety and Health at Work (EU-OSHA).<sup>80</sup>

### *Accident and Fatality Rates*

77. Project management should aim to reduce the number of accidents among project workers (whether directly employed or subcontracted) to zero, especially accidents that could result in lost work time, disability, or worse, fatalities. Fatality rates may be benchmarked against the performance of facilities in this sector in developed countries by consulting authoritative publications from sources such as the US Bureau of Labor Statistics, Mines Safety and Health Administration (MSHA), the UK HSE, and the Cement Sustainability Initiative of the WBCSD / Global Cement and Concrete Association (GCCA).<sup>81</sup>

### *Occupational Health and Safety Monitoring*

78. 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.<sup>82</sup> Facilities should also maintain a record of

<sup>77</sup> The publication is available at <https://portal.acgih.org/s/store#/store/browse/cat/a0s4W00000g02f8QAA/tiles>.

<sup>78</sup> See Centers for Disease Control and Prevention (CDC), *NIOSH Pocket Guide to Chemical Hazards*, DHHS Publication Number 2005-149 (Cincinnati: NIOSH Publications, 2007), <https://www.cdc.gov/niosh/docs/2005-149/pdfs/2005-149.pdf>.

<sup>79</sup> See OSHA, *TABLE Z-1 Limits for Air Contaminants* (n.d.), retrieved from [http://www.osha.gov/pls/oshaweb/owadisp.show\\_document?p\\_table=STANDARDS&p\\_id=9992](http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992).

<sup>80</sup> See EU-OSHA, *Directive 2019/1831: Indicative Occupational Exposure Limit Values*, 2019 <https://osha.europa.eu/en/legislation/directive/directive-20191831-indicative-occupational-exposure-limit-values>.

<sup>81</sup> Available at <http://www.bls.gov/iif/>, <http://www.hse.gov.uk/statistics/index.htm>, and <https://www.wbcds.org> or <https://www.wbcds.org/Sector-Projects/Cement-Sustainability-Initiative> or <https://gccassociation.org/>, respectively.

<sup>82</sup> Accredited professionals may include certified industrial hygienists, registered occupational hygienists, and certified safety professionals, or their equivalent.

occupational accidents, diseases, and dangerous occurrences and other accidents. The working environment should also be monitored for concentrations and exposure to silica, asbestos, and other particulates. The incidence of lung disease within the workforce should be periodically monitored. The **General EHS Guidelines** provide additional guidance on OHS monitoring programs.

### 3. REFERENCES AND ADDITIONAL SOURCES

- ACGIH. 2018. *2018 TLVs and BEIs*. <https://www.acgih.org/science/tlv-bei-guidelines>.
- ACGIH. 2021. *2021 Threshold Limit Values (TLVs) and Biological Exposure Indices (BEIs)*. [https://www.techstreet.com/standards/2021-threshold-limit-values-tlvs-and-biological-exposure-indices-beis?product\\_id=2198547](https://www.techstreet.com/standards/2021-threshold-limit-values-tlvs-and-biological-exposure-indices-beis?product_id=2198547).
- ACGIH. 2016. *2016 TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. Cincinnati: ACGIH.
- ANSI/NEC and HSE. 2013. *HSG85 Electricity at Work: Safe Working Practices*. <https://www.hse.gov.uk/pubns/books/hsg85.htm>.
- ASME. 2021. *Boiler and Pressure Vessel Code*. <https://www.asme.org/codes-standards/find-codes-standards/bpvc-complete-code-boiler-pressure-vessel-code-complete-set>.
- ASME. n.d. *ASME B30: Safety Standard for Cableways, Cranes, Derricks, Hoists, Hooks, Jacks, and Slings*. <https://blog.ansi.org/2019/01/asme-b30-volumes-safety-standard-lifting/#gref>.
- ASSP. 2020. *ANSI/ASSP Z244.1-2016 (R2020) The Control of Hazardous Energy: Lockout, Tagout and Alternative Methods*. <https://webstore.ansi.org/standards/asse/ansiasspz2442016r2020>.
- ASTM International. 2012. *ASTM C150-07: Standard Specification for Portland Cement*. <https://store.astm.org/c0150-07.html>
- ASTM International. 2013. *ASTM E1132 13e1: Standard Practice for Health Requirements Relating to Occupational Exposure to Respirable Crystalline Silica*. West Conshohocken, PA. <https://www.astm.org/Standards/E1132.htm>.
- ASTM International. 2019. *ASTM F3387-19: Standard Practice for Respiratory Protection*. West Conshohocken, PA. doi: [10.1520/F3387-19](https://doi.org/10.1520/F3387-19). <https://www.astm.org/Standards/F3387.htm>.
- ASTM International. 2020. *ASTM D4276-02: Standard Practice for Confined Area Entry*. <https://www.astm.org/Standards/D4276.htm>.
- ASTM International. 2024. *ASTM C595-24: Standard Specification for Blended Hydraulic Cements*. [https://store.astm.org/c0595\\_c0595m-24.html](https://store.astm.org/c0595_c0595m-24.html)
- Australian and New Zealand guidelines and codes of practice. 2016. <https://www.commerce.wa.gov.au/worksafe/australian-standards-and-australiannew-zealand-standards>.

- BirdLife International, Fauna & Flora International, FFI, IUCN, and WWF. 2014. *Extraction and Biodiversity in Limestone Areas*. Joint Briefing Paper.  
<https://www.birdlife.org/sites/default/files/Extraction-and-Biodiversity-in-Limestone-Areas.pdf>.
- Bollinger, Nancy J. and Robert H. Schultz. 1987. *NIOSH Guide to Industrial Respiratory Protection*. DHHS NIOSH Publication Number 87-116. <https://www.cdc.gov/niosh/docs/87-116/pdfs/87-116.pdf?id=10.26616/NIOSH PUB87116>.
- CDC. 2007. *NIOSH Pocket Guide to Chemical Hazards*. DHHS (NIOSH) Publication No. 2005-149. <https://www.cdc.gov/niosh/docs/2005-149/default.html>.
- Cecala, Andrew B et al. 2019. *Dust Control Handbook for Industrial Minerals Mining and Processing*, Report no. RI9701 (2nd ed.). Cincinnati: NIOSH Publications.  
<https://www.cdc.gov/niosh/mining/UserFiles/works/pdfs/2019-124.pdf>.
- CEMBUREAU. 2013. *The Role of Cement in the 2050 Low Carbon Economy*. Brussels: CEMBUREAU.  
<https://lowcarboneyconomy.cembureau.eu/wp-content/uploads/2018/09/cembureau-full-report.pdf>.
- CEMBUREAU. 2020. *Cement and Concrete: Key Facts and Figures*. Brussels: EC.  
<https://cembureau.eu/cement-101/key-facts-figures>.
- EC. 2009. *Reference Document on Best Available Techniques for Energy Efficiency*. Brussels: EC.  
[https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/ENE\\_Adopted\\_02-2009.pdf](https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/ENE_Adopted_02-2009.pdf).
- EC. 2010. *Directive 2010/75/EU of the European Parliament and of the Council of 24 of November 2010 on Industrial Emissions (Integrated Pollution Prevention and Control)*. Official Journal of the European Union. L 334/17. Brussels: EC.  
*I think they refer to this* <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32010L0075>.
- EU-OSHA. n.d. *Exposure to Chemical Agents and Chemical Safety*.  
<https://osha.europa.eu/en/legislation/directives/exposure-to-chemical-agents-and-chemical-safety/osh-related-aspects/council-directive-91-414-eeec>.
- EU-OSHA, *Directive 2019/1831: Indicative Occupational Exposure Limit Values*, 2019,  
<https://osha.europa.eu/en/legislation/directive/directive-20191831-indicative-occupational-exposure-limit-values>
- EULA. 2014. *A Competitive and Efficient Lime Industry, Cornerstone for a Sustainable Europe (Lime Roadmap)*. Brussels: EULA. <https://www.eula.eu/a-competitive-and-efficient-lime-industry-cornerstone-for-a-sustainable-europe-lime-roadmap-summary/>.
- European Norm (EN). 2023. EN-197-6 2023. Cement with Recycled Building Materials, Part 6. [Available for purchase].
- GTZ-Holcim Public Private Partnership. 2006. *Guidelines on Pre- and Co-processing of Waste in Cement Production*. [https://www.giz.de/de/downloads/giz-2020\\_en\\_guidelines-pre-coprocessing.pdf](https://www.giz.de/de/downloads/giz-2020_en_guidelines-pre-coprocessing.pdf).

- GCCA. n.d. *Global Cement and Concrete Association* <https://gccassociation.org/>
- GCCA. 2019a. *GCCA Sustainability Guidelines for the monitoring and reporting of emissions from cement manufacturing*. Version 0.1. London: GCCA. [https://gccassociation.org/wp-content/uploads/2019/10/GCCA\\_Guidelines\\_Emissions\\_v05\\_AMEND.pdf](https://gccassociation.org/wp-content/uploads/2019/10/GCCA_Guidelines_Emissions_v05_AMEND.pdf).
- GCCA. 2019b. *GCCA Sustainability Guidelines for co-processing fuels and raw materials in cement manufacturing*. Version 0.1. London: GCCA. [https://gccassociation.org/wp-content/uploads/2019/10/GCCA\\_Guidelines\\_FuelsRawMaterials\\_v04\\_AMEND.pdf](https://gccassociation.org/wp-content/uploads/2019/10/GCCA_Guidelines_FuelsRawMaterials_v04_AMEND.pdf).
- GCCA. 2019c. "Getting the Numbers Right." *Global Cement Database on CO<sub>2</sub> and Energy Information*. London: GCCA. <https://gccassociation.org/gnr/>.
- GCCA. 2020. *GCCA Sustainability Guidelines for Quarry Rehabilitation and Biodiversity Management*. Version 0.1. London: GCCA. [https://gccassociation.org/wp-content/uploads/2020/05/GCCA\\_Guidelines\\_Sustainability\\_Biodiversity\\_Quarry\\_Rehabilitation\\_May\\_2020-1.pdf](https://gccassociation.org/wp-content/uploads/2020/05/GCCA_Guidelines_Sustainability_Biodiversity_Quarry_Rehabilitation_May_2020-1.pdf).
- GCPC. n.d. *Cleaner Production Opportunities in Cement Manufacturing Sector*. <http://www.gcpcenvi.nic.in/Experts/Cement%20sector.pdf>.
- IIP. n.d. *Alternative Raw Materials*. <http://www.iipinetwork.org/wp-content/letd/content/alternative-raw-materials.html>.
- IIP. n.d. *Blended Cement Alternatives*. Industrial Efficiency Technology Database. <http://www.iipinetwork.org/wp-content/letd/content/blended-cement-alternatives.html>.
- IIP. n.d. *Cement*. Industrial Efficiency Technology Database. <http://www.iipinetwork.org/wp-content/letd/content/cement.html>.
- IIP. n.d. *Conversion to High-Efficiency Grate Coolers*. Energy Efficiency Technology Database. <http://www.iipinetwork.org/wp-content/letd/content/conversion-high-efficiency-grate-coolers.html>.
- IIP. n.d. *High Efficiency Motors & Drives*. Industrial Efficiency Technology Database. <http://www.iipinetwork.org/wp-content/letd/content/high-efficiency-motors-drives.html>.
- IIP. n.d. *Industrial Efficiency Technology Database*. <http://www.iipinetwork.org/wp-content/letd/index.html>.
- IIP. n.d. *Vertical Roller Mills for Finish Grinding*. Industrial Efficiency Technology Database. <http://www.iipinetwork.org/wp-content/letd/content/vertical-roller-mills-finish-grinding.html>.
- IEA and WBCSD. 2013. *Technology Roadmap: Low-Carbon Technology for the Indian Cement Industry*. Paris: IEA. [https://docs.wbcsd.org/2013/02/Low\\_Carbon\\_Technology\\_for\\_the\\_Indian\\_Cement\\_Industry\\_IEA\\_WBCSD\\_Feb\\_2013.pdf](https://docs.wbcsd.org/2013/02/Low_Carbon_Technology_for_the_Indian_Cement_Industry_IEA_WBCSD_Feb_2013.pdf).



- IEA. 2018. *Technology Roadmap: Low-Carbon Transition in the Cement Industry*. Technology Report. Paris: IEA. <https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry>.
- IEAGHG. 2013. *Deployment of CCS in the Cement Industry*. [https://ieaghg.org/docs/General\\_Docs/Reports/2013-19.pdf](https://ieaghg.org/docs/General_Docs/Reports/2013-19.pdf).
- IFC. 2017. *Increasing the Use of Alternative Fuels at Cement Plants: International Best Practice*. Washington, DC: IFC. [https://www.ifc.org/wps/wcm/connect/33180042-b8c1-4797-ac82-cd5167689d39/Alternative\\_Fuels\\_08+04.pdf?MOD=AJPERES&CVID=IT3Bm3Zbn](https://www.ifc.org/wps/wcm/connect/33180042-b8c1-4797-ac82-cd5167689d39/Alternative_Fuels_08+04.pdf?MOD=AJPERES&CVID=IT3Bm3Zbn).
- IFC and IIP. 2014. *Waste Heat Recovery for the Cement Sector: Market and Supplier Analysis*. Washington, DC: IFC and IIP. [https://www.ifc.org/wps/wcm/connect/topics\\_ext\\_content/ifc\\_external\\_corporate\\_site/sustainability-at-ifc/publications/report\\_waste\\_heat\\_recovery\\_for\\_the\\_cement\\_sector\\_market\\_and\\_supplier\\_analysis](https://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/sustainability-at-ifc/publications/report_waste_heat_recovery_for_the_cement_sector_market_and_supplier_analysis).
- IS. 2015. IS 269:2015. ISI Marked Certification for Ordinary Portland Cement.
- IUCN. 2014. *Biodiversity Management in the Cement and Aggregates Sector: Biodiversity Indicator and Reporting System (BIRS)*. Gland, Switzerland: IUCN. <https://www.iucn.org/content/biodiversity-management-cement-and-aggregates-sector-biodiversity-indicator-and-reporting-system-birs>.
- Ke, Jing, Michael McNeil, Lynn Price, Nina Zheng Khanna, and Nan Zhou. 2013. "Estimation of CO<sub>2</sub> Emissions from China's Cement Production: Methodologies and Uncertainties." *Energy Policy* 57 (June): 172–181. <https://doi.org/10.1016/j.enpol.2013.01.028>; [https://china.lbl.gov/sites/all/files/6329\\_ep\\_cement\\_co2.pdf](https://china.lbl.gov/sites/all/files/6329_ep_cement_co2.pdf).
- Madloul, Naseer Abboodi, Rahman Saidur, Md Shouquat Hossain, and Nasrudin Abd Rahm. 2011. "A Critical Review on Energy Use and Savings in the Cement Industry." *Renewable and Sustainable Energy Reviews* 15: 2042–2060. [https://www.researchgate.net/publication/215599462\\_A\\_critical\\_review\\_on\\_energy\\_use\\_and\\_savings\\_in\\_the\\_cement](https://www.researchgate.net/publication/215599462_A_critical_review_on_energy_use_and_savings_in_the_cement).
- Ministry of Labour, Training and Skills Development of Ontario, Canada. 2011. *Silica on Construction Projects*. <https://www.labour.gov.on.ca/english/hs/pubs/silica/>.
- NFPA. 2002. *NFPA 68-2002: Guide for Venting of Deflagrations, 2002 edition*. Vol. 13, 2004/2005 National Fire Codes. <https://webstore.ansi.org/standards/nfpa-fire/nfpa682002>.
- NFPA. n.d. *NFPA 69: Standard on Explosion Prevention Systems*. <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=69>.
- NFPA. 2020. *NFPA 70: National Electric Code*. <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70>.

- NFPA. 2019. *NFPA 77: Recommended Practice on Static Electricity*. <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=77>.
- NFPA. n.d. *NFPA 85: Boiler and Combustion Systems Hazards Code*. <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=85>.
- NFPA. 2019. *NFPA 86: Standard for Ovens and Furnaces*. <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=86>.
- NFPA. 2021. *NFPA 499: Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*. <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=499>.
- NFPA. 2020. *NFPA 654: Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*. <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=654>.
- NIOSH. 1988. Publication No. DHHS-NIOSH-88-110. *Criteria for a Recommended Standard: Welding, Brazing, and Thermal Cutting*. <https://www.cdc.gov/niosh/docs/88-110/default.html>.
- NIOSH. *Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments*. <https://www.cdc.gov/niosh/docs/2016-106/default.html>.
- NIOSH Heat Stress webpage. <https://www.cdc.gov/niosh/topics/heatstress/default.html>.
- US OSHA. n.d. 1910 General Industry Standards. <https://www.osha.gov/laws-regs/regulations/standardnumber/1928>.
- OSHA. n.d. *Occupational and Safety Health Standards, 1910.1001 Subpart Z, Asbestos*. <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.1001>.
- OSHA. n.d. *Occupational and Safety Health Standards, 1910.1053 Subpart Z, Toxic and Hazardous Substances, Respirable Crystalline Silica*. <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.1053>.
- OSHA. n.d. *Occupational and Safety Health Standards, 1910.134(c) Subpart I, Respiratory Protection Program*. <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.134>.
- OSHA. n.d. *1910, Subpart H, Hazardous Materials*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910SubpartH>.
- OSHA. n.d. *Subpart L, Fire Protection*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910SubpartL>.
- OSHA. n.d. *Subpart S, Electrical*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910SubpartS>.

- OSHA. n.d. 1910 Subpart J, General Environmental Controls 1910.147: *The Control of Hazardous Energy (Lockout/Tagout)* <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.147>.
- OSHA. n.d. 1910 Subpart S, Electrical, 1910.333 *Selection and Use of Work Practices*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.333>.
- OSHA. n.d. 1910 Subpart J, General Environmental Controls 1910.146: *Permit-Required Confined Spaces*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.146>.
- OSHA. n.d. 1910 Subpart N, Materials Handling and Storage, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910SubpartN>.
- OSHA. n.d. *Safety and Health Regulations for Construction: 1926 Subpart CC, Cranes and Derricks in Construction*, <https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926SubpartCC>.
- OSHA. n.d. 1910 Subpart Q, Welding, Cutting and Brazing, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910SubpartQ>.
- OSHA. 2018. *OSHA's Respirable Crystalline Silica Standard for General Industry and Maritime. Fact Sheet*. <https://www.osha.gov/Publications/OSHA3682.pdf>.
- Passant, Neil, Martin Peirce, Howard J. Rudd, David W. Scott, Ian Marlowe, and John D. Watterson. *UK Particulate and Heavy Metal Emissions from Industrial Processes*. AEA Technology. [https://uk-air.defra.gov.uk/assets/documents/reports/empire/AEAT6270Issue2finaldraft\\_v2.pdf](https://uk-air.defra.gov.uk/assets/documents/reports/empire/AEAT6270Issue2finaldraft_v2.pdf).
- Renzoni, Roberto, Christophe Ullrich, Sandra Belboom, and Albert Germain. 2010. *Mercury in the Cement Industry*. CEMBUREAU and the WBCSD Cement Sustainability Initiative. [https://wedocs.unep.org/bitstream/handle/20.500.11822/11617/CEMENT\\_Industry\\_-\\_Hg\\_report\\_CEMBUREAU\\_April\\_2010.pdf?sequence=1&isAllowed=y](https://wedocs.unep.org/bitstream/handle/20.500.11822/11617/CEMENT_Industry_-_Hg_report_CEMBUREAU_April_2010.pdf?sequence=1&isAllowed=y).
- Safe Work Australia. n.d. *Model Code of Practice: Welding Processes*. <https://www.safeworkaustralia.gov.au/doc/model-code-practice-welding-processes>.
- Schorcht, Frauke, Ioanna Kourti, Bianca Maria Scalet, Serge Roudier, and Luis Delgado Sancho. 2013. *Best Available Techniques (BAT): Reference Document for the Production of Cement, Lime and Magnesium Oxide*. Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control). Joint Research Center Reference Reports. Brussels: European Commission. <https://publications.jrc.ec.europa.eu/repository/handle/JRC83006>.
- Shan, Yuli, Zhu Liu, and Dabo Guan. 2015. "CO<sub>2</sub> Emissions from China's Lime Industry." *Applied Energy* 166 (May). doi:[10.1016/j.apenergy.2015.04.091](https://doi.org/10.1016/j.apenergy.2015.04.091); [https://www.researchgate.net/publication/277907090\\_CO2\\_emissions\\_from\\_China%27s\\_lime\\_industry](https://www.researchgate.net/publication/277907090_CO2_emissions_from_China%27s_lime_industry).
- Standards Australia. 2009. *AS 2865-2009: Confined Spaces*. <https://www.standards.org.au/standards-catalogue/sa-snz/publicsafety/sf-037/as--2865-2009>.

- UK HSE. n.d. *Health and Safety Statistics*. <http://www.hse.gov.uk/statistics/index.htm>.
- UK HSE. n.d. *Health and Safety Welding Resources*. <https://www.hse.gov.uk/welding/publications.htm>.
- UK HSE. n.d. *Regulations and codes of practice*. <https://www.hse.gov.uk/pubns/books/index-legal-ref.htm>.
- UK HSE. 2006. *HSG253: The Safe Isolation of Plant and Equipment*. <https://www.hse.gov.uk/pubns/books/hsg253.htm>.
- UK HSE. 2013. *Control of Substances Hazardous to Health, Regulations 2002: Approved Code of Practice and Guidance*, L5 (6th ed.). <https://www.hse.gov.uk/pubns/priced/l5.pdf>.
- UK HSE. 2013. *Respiratory Protective Equipment at Work, A Practical Guide*, HSG53 (4th ed.). <https://www.hse.gov.uk/pubns/priced/hsg53.pdf>.
- UNEP. 2016. "Cement Clinker Production Facilities" in *Guidance on Best Available Techniques and Best Environmental Practices*. New York: UNEP. [http://mercuryconvention.org/Portals/11/documents/publications/BAT\\_BEP\\_E\\_interactif.pdf](http://mercuryconvention.org/Portals/11/documents/publications/BAT_BEP_E_interactif.pdf).
- United States Department of Labor. n.d. *Injuries, Illnesses, and Fatalities*. Bureau of Labor Statistics. <https://www.bls.gov/iif>.
- United States Department of Labor. n.d. *Occupational Safety and Health Standards—Toxic and Hazardous Substances. Table Z-1 Limits for Air Contaminants*. [https://www.osha.gov/pls/oshaweb/owadisp.show\\_document?p\\_table=STANDARDS&p\\_id=9992](https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992).
- US EPA. 1999. *Code of Federal Regulation Title 40, Part 63, Subpart LLL—National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry*. Washington, DC: US EPA. [www.ecfr.gov/cgi-bin/text-idx?node=sp40.12.63.lll](http://www.ecfr.gov/cgi-bin/text-idx?node=sp40.12.63.lll).
- US EPA. 2004. *Code of Federal Regulation Title 40, Part 63, National Emission Standards for Hazardous Air Pollutants for Source Categories; Lime Manufacturing Plants*. Washington, DC: USA EPA. <https://www.epa.gov/stationary-sources-air-pollution/lime-manufacturing-plants-national-emission-standards-hazardous-air>.
- US EPA. 2008. *Code of Federal Regulation Title 40, Part 63, Subpart EEE—National Emission Standards for Hazardous Air Pollutants from Hazardous Waste Combustor*. Washington, DC: US EPA. <https://www.epa.gov/stationary-sources-air-pollution/hazardous-waste-combustors-national-emission-standards-hazardous>.
- US EPA. 2012. *Title 40, Chapter I, Subchapter N, Part 411 Cement Manufacturing Point Source Category*. Washington, DC: USA EPA. <https://www.gpo.gov/fdsys/pkg/CFR-2014-title40-vol29/pdf/CFR-2014-title40-vol29-part411.pdf>.
- Van den Berg, Martin, Linda Birnbaum, Michael Denison, Mike Vito, William Farland, Mark Feeley, Heidelore Fiedler et al. 2006. "The 2005 World Health Organization Re-evaluation of Human and

- Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-Like Compounds.” *Toxicological Sciences* 93, no.2 (October): 223–241. doi: [10.1093/toxsci/kfl055](https://doi.org/10.1093/toxsci/kfl055).
- Wang, Yufei, Zhengping Hao, and Samuel Höller. 2012. “Analysis of CO<sub>2</sub> Mitigation Policies in the Chinese Cement Industry.” *ECEEE 2012 Summer Study on Energy Efficiency in Industry*. Wuppertal, Germany: Wuppertal Institute. [http://epub.wupperinst.org/files/4635/4635\\_Wang.pdf](http://epub.wupperinst.org/files/4635/4635_Wang.pdf).
- WBCSD. n.d. Cement Sustainability Initiative. <https://www.wbcsd.org/Sector-Projects/Cement-Sustainability-Initiative>.
- WBCSD. n.d. *CO<sub>2</sub> and Climate Protection*. Geneva: WBCSD. <https://www.wbcsd.org/Programs/Climate-and-Energy>.
- WBCSD. 2004. *Health and Safety in the Cement Industry: Examples of Good Practice*. Geneva: WBCSD. [http://ficem.org/CIC-descargas/Suiza/CSI/Health-and-Safety-in-the-Cement-Industry\\_Examples-of-Good-Practice-2004.pdf](http://ficem.org/CIC-descargas/Suiza/CSI/Health-and-Safety-in-the-Cement-Industry_Examples-of-Good-Practice-2004.pdf).
- WBCSD. 2005a. *Environmental and Social Impact Assessment (ESIA) Guidelines*. Geneva: WBCSD. <https://www.wbcsd.org/Sector-Projects/Cement-Sustainability-Initiative/Resources/Guidelines-for-Environmental-and-Social-Impact-Assessment-ESIA>.
- WBCSD. 2005b. *Guidelines for the Selection and Use of Fuels and Raw Materials in the Cement Manufacturing Process*. Geneva: WBCSD. <https://www.wbcsd.org/contentwbc/download/2429/30121>.
- WBCSD. 2006. *Formation and Release of POPs in the Cement Industry* (2nd ed). Geneva: WBCSD. <http://docs.wbcsd.org/2006/01/FormationAndReleaseOfPOPsInCementIndustry.pdf>.
- WBCSD. 2011a. *CO<sub>2</sub> and Energy Accounting and Reporting Standard for the Cement Industry*. Version 3.0. Geneva: WBCSD. <https://www.wbcsd.org/Sector-Projects/Cement-Sustainability-Initiative/Resources/CO2-Accounting-and-Reporting-Standard-for-the-Cement-Industry>.
- WHO. International Programme on Chemical Safety guidelines. [http://www.who.int/ipcs/assessment/tef\\_values.pdf](http://www.who.int/ipcs/assessment/tef_values.pdf).
- Worrell, Ernst, Katerina Kermeli, and Christina Galitsky. 2013. *Energy Efficiency Improvement and Cost Saving Opportunities for Cement Making—An ENERGY STAR Guide for Energy and Plant Managers*. Washington, DC: EPA. [http://www.energystar.gov/sites/default/files/tools/ENERGY%20STAR%20Guide%20for%20the%20Cement%20Industry%2027\\_08\\_2013\\_Rev%20js%20reformat%2011192014.pdf](http://www.energystar.gov/sites/default/files/tools/ENERGY%20STAR%20Guide%20for%20the%20Cement%20Industry%2027_08_2013_Rev%20js%20reformat%2011192014.pdf).

## **ANNEX A. GENERAL DESCRIPTION OF INDUSTRY ACTIVITIES**

79. 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 facilities are typically located adjacent to the sources of raw materials and in proximity to product markets. Cement manufacturing and lime manufacturing are energy-intensive industries that require significant quantities of thermal and electrical energy, depending on the type of production process employed and associated equipment.

### ***Cement Manufacturing***

80. To manufacture cement, raw materials—mainly limestone (calcium carbonate), clay (aluminum silicates), sand (silica oxide), and iron ore—are processed to produce clinker, which is ground with gypsum, limestone, and other materials to make cement. A compact single production line—a preheater-precaciner (PHP) or preheater (PH) kiln with a clinker production capacity of 3,000 tonnes per day—typically requires a flat area of approximately 400,000 square meters (m<sup>2</sup>), and an additional area—typically 250,000 m<sup>2</sup> or more—for future expansion. The lifespan of project facility tends to run at least 40 to 50 years. Plants typically process 2,500 to 12,000 tonnes of cement a day. The size of the plant is important because production scale differences can significantly impact production costs and, consequently, investment costs for pollution abatement and control technologies. The same level of environmental performance can be achieved by both small and large plants, but the smaller the plant, the higher the cost per unit of cement production.

81. After an initial crushing and pre-blending stage, the raw materials are mixed together and ground to form a homogeneous blend—called the raw meal—that has the required chemical composition. The fineness and particle size distribution of the raw meal are important characteristics for the burning process. After mixing, the process proceeds in a combination of PHs, precaciner, and a rotary kiln by calcining the raw meal, which decomposes calcium carbonate at about 900°C, thereby releasing carbon dioxide and leaving calcium oxide. This leads into the clinkering process, in which the calcium oxide reacts at a temperature of 1,400–1,500°C with silica, alumina, and ferrous oxides. At this point, other constituents—for example, silica sand, foundry sand, iron oxide, alumina residues, blast furnace slag, and/or gypsum residues—may be added to the raw material mix to create a particular desired composition. 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 at the same time facilitate heat recovery by heating secondary combustion air. Today, grate coolers are typically employed for this, as opposed to the now obsolete satellite coolers. The cooled clinker is then ground with gypsum and limestone to produce portland cement and further ground with additional constituents to produce composite or blended cements. The cement is then stored in silos or bags. The blending constituents—for example, natural pozzolans, fly ash, blast furnace slag, and occasionally bottom ash—are materials that have hydraulic properties. In fly and bottom ashes, carbon residues (typically from coal-fired power plants) should not be present. Calcium carbonate is sometimes added in small quantities as filler.



## Lime Manufacturing

82. Lime is produced by burning  $\text{CaCO}_3$ —or less frequently dolomite, which is a mix of calcium and magnesium carbonate—at temperatures above  $800^\circ\text{C}$  to cause decarbonation of the raw material to produce quicklime (calcium oxide). The quicklime is then maintained at temperatures of  $1,200^\circ\text{C}$  to  $1,300^\circ\text{C}$  to adjust reactivity. The burned lime can be delivered to the end user in the form of quicklime (hard, medium, or soft burned, based on its reactivity). Soft-burned lime is the most reactive and commonly employed by steel producers. Alternatively, the quicklime is transferred to a hydrate plant where, with a strong exothermic reaction, it reacts with water to produce slaked lime (calcium hydroxide). Slaked lime has two forms: dry (powder) or milk of lime (liquid). The slaked lime production process consists of size separation and hydrating, followed by storage in tanks (in the case of milk of lime) or in silos (dry slaked lime) for sale in bulk or bags.

**FIGURE A.1 CEMENT MANUFACTURING PROCESSES**

