Energy Trends in Selected Manufacturing Sectors:

Opportunities and Challenges for Environmentally Preferable Energy Outcomes








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3.2 Cement

3.2.1 Base Case Scenario

Situation Assessment

Recent Sector Trends Informing the Base Case

Number of facilities: Virtually unchanged
Domestic production: ↑
Value of shipments: ↑
Avg. energy consumption/ton of cement produced: ↓

Major fuel sources: Coal & petroleum coke

Current economic and energy consumption data are summarized in Table 22 on page 3-13.

Cement manufacturing (NAICS 327310) requires the thermochemical processing (i.e., pyroprocessing) of substantial amounts of limestone, clay, and sand in huge kilns at very high and sustained temperatures to produce an intermediate product called clinker. Clinker is then ground up with a small quantity of gypsum to create portland cement, which is used as a binding agent in virtually all concrete.

Kilns can employ either wet or dry processes. The wet process was developed to improve the chemical uniformity of the raw materials, which was a deficiency in original dry kiln designs. Technological improvements in the grinding of raw materials have improved the chemical uniformity of the clinker, which has enabled producers to return to the dry process and benefit from its lower energy consumption. On average, wet process operations use 34 percent more energy per ton of production than dry process operations.[61] No new wet kilns have been built in the United States since 1975,[62] and approximately 80 percent of U.S. cement production capacity now relies on the dry process technology.[63]

While 39 companies operate 115 cement plants in 36 states,[64] cement production is somewhat concentrated geographically, with six states—Texas, California, Pennsylvania, Missouri, Michigan, and Alabama, in descending order—accounting for approximately 50 percent of production in 2005.[65] From 1997 to 2004 the cement industry showed economic growth in terms of value added and total value of shipments (see Table 22), mainly in response to a strong construction market. Most of the U.S. demand for cement is met by domestic production. Operating at maximum capacity, in 2004 U.S. facilities produced 95 million metric tons of cement, an increase of 2 percent over 2003.[66] Although a slowdown of the U.S. economy is expected, industry experts predict cement consumption in 2006 to reach 129.6 million tons, an increase of 2.3 percent compared with 2005 levels, extending a three-year period of continual growth. Additional growth in cement consumption of 1.2 percent is forecasted for 2007.[67] To meet increasing demand, U.S. cement manufacturers have announced plans to increase production capacity by 15 percent (nearly 15 million tons) by 2010.[68]

The cement industry currently participates in EPA's Sector Strategies Program.

The cement industry is highly dependent on emissions-intensive energy sources: coal (60 percent of fuel inputs in 2004) and petroleum coke (16 percent).[69] In recent years, the sector has shown increased use of lower-cost waste fuels (primarily tires and used motor oil), and slight decreases in the use of natural gas and coal.[70] In 2002, 15 plants used waste oil, and 40 plants in 23 states used scrap tires; solvents, unrecyclable plastics, and other waste materials were also used as fuels.[71] Cement kiln dust (CKD) is routinely recycled to the kilns, which also can burn a variety of waste fuels (e.g., scrap tires, used motor oil, and paint wastes) and alternative raw materials such as foundry sand, slags, and coal combustion fly ash.[72] Energy intensity (as measured in terms of energy use per ton of cement production) fell by 7 percent from 2001 to 2004.[73]

As is the case with other capital-intensive industries, replacing old equipment with state-of-the-art equipment holds potential for energy efficiency improvement.[74] Options include replacing wet process kilns with new dry process kilns, adding multistage suspension preheaters (i.e., a cyclone) or shaft preheaters, and using high-pressure roller mills and horizontal roller mills in place of ball mills as a grinding technology. In 2006, a cement industry Energy Performance Indicator (EPI) was developed by EPA's ENERGY STAR Industrial Focus program in cooperation with the Portland Cement Association (PCA) and with technical support from the Argonne National Laboratory. EPI scores the energy efficiency of a single cement plant and allows the plant to compare its performance to that of the entire industry. The tool is intended to help cement plant operators identify opportunities to improve energy efficiency, reduce GHG emissions, conserve conventional energy supplies, and reduce production costs.[75]

Table 22 summarizes current economic trend and energy consumption data originally presented in Chapter 2.

Table 22: Current economic and energy data for the cement industry

Economic Production Trends				
	Annual Change in Value Added 1997-2004	Annual Change in Value Added 2000-2004	Annual Change in Value of Shipments 1997-2004	Annual Change in Value of Shipments 2000-2004
	2.2%	1.2%	1.5%	1.6%
Energy Intensity in 2002				
	Energy Consumption per Dollar of Value Added (thousand Btu)	Energy Consumption per Dollar Value of Shipments (thousand Btu)	Energy Cost per Dollar of Value Added (share)	Energy Cost per Dollar Value of Shipments (share)
	95.5	56.0	24.5%	15.1%
Primary Fuel Inputs as Fraction of Total Energy Supply in 2002 (fuel use only)				
Coal	Other[kkk]	Net Electricity	Natural Gas	Coke & Breeze
58%	23%	11%	5%	2%
Fuel-Switching Potential in 2002: Natural Gas to Alternate Fuels				
			Switchable fraction of natural gas inputs	29%
		Coal	Fuel Oil	LPG
Fraction of natural gas inputs that could be met by alternate fuels		67%	50%	17%
Fuel-Switching Potential in 2002: Coal to Alternate Fuels				
			Switchable fraction of coal inputs	51%
		Natural Gas	Other	LPG
Fraction of coal inputs that could be met by alternate fuels		91%	8%	4%

kkk "Other" includes petroleum coke as well as waste materials that are incinerated for fuel.

Expected Future Trends

Cement is one of three sectors (along with paper and steel) for which CEF made detailed parameter modifications to the NEMS model used to produce AEO 99. Modifications included adjustments to baseline energy intensities and rates for annual improvements in energy intensity, which were adjusted to reflect best-available sector-specific research.

Under the reference case scenario, CEF projects the cement industry's fuel mix to be dominated by coal, as it is today.[lll] Economic energy intensity (energy consumption per dollar value of output) is projected to decrease very slightly at the rate of 0.1 percent per year, and overall energy consumption is projected to decline by 2 percent from 1997 to 2020. CEF's analysis suggests that as long as fuel prices remain low, facilities will have little incentive to invest in capital-intensive upgrades of existing facilities, and increases in energy efficiency will primarily be achieved through the retirement of old plants with wet kiln capacity and the construction of new plants with dry kiln capacity. Increased energy efficiency in cement kilns will result in reduced coal consumption.

> **Voluntary Commitments**
>
> Under its Climate VISION commitment, PCA seeks to achieve a 10 percent reduction in 1990-level carbon dioxide emissions per ton of cementitious product produced or sold by 2020. The industry will achieve this goal and foster further reductions by end users of cement products through the implementation of a three-part strategy to: (1) improve energy efficiency by upgrading plants with state-of-the-art equipment; (2) improve product formulation to reduce energy of production and minimize the use of natural resources; and (3) conduct research and develop new applications for cement and concrete that improve energy efficiency and durability. Efficiency improvement from the first two elements of this plan will contribute to achieving the 10 percent reduction goal. While reductions from the product application element will not count towards the goal, the carbon dioxide reduction benefits of cement and concrete use could be even more significant than those achieved through manufacturing and product formulation. The U.S. cement industry has also adopted a voluntary target of a 60 percent reduction (from a 1990 baseline) in the amount of CKD disposed per ton of clinker produced by 2020. See http://www.climatevision.gov/sectors/cement/index.html.

CEF's reference case projections for the cement industry are based on the assumptions that production will grow at 1 percent per year, and value of output will grow at 1.1 percent per year. The sector's declining energy intensity is thus a function both of slow rates of decline in energy consumption and faster rates of increase in economic production. CEF also assumes that wet process clinker production will decline at 2.2 percent per year, comprising 13 percent of total production by 2020.

CEF projections support the expectation of incremental efficiency improvement for the cement industry, rather than large-scale efficiency gains, and are summarized in Table 23.

[lll] According to USGS data presented in the 2006 *Sector Strategies Performance Report*, 16% of the sector's energy supply was met by petroleum coke, which is a slightly larger fraction than is represented by data used in the CEF analysis.

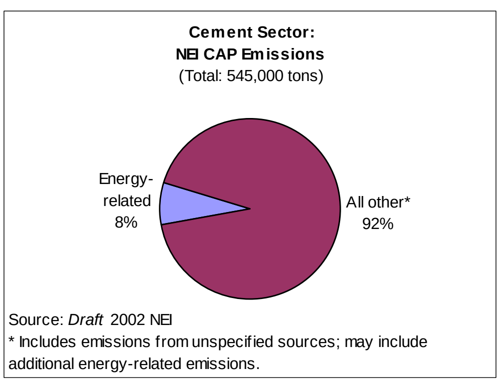
Table 23: CEF reference case projections for the cement industry

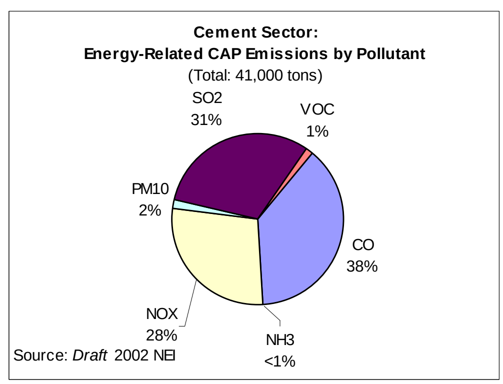
	1997 Reference Case		2020 Reference Case	
	Consumption (quadrillion Btu)	Percentage	Consumption (quadrillion Btu)	Percentage
Petroleum	0.036	9%	0.033	8%
Natural gas	0.018	5%	0.014	4%
Coal	0.315	79%	0.313	80%
Delivered electricity	0.030	8%	0.031	8%
Total	0.399	100%	0.391	100%
Annual % change in energy intensity (energy consumption per dollar value of output)				-0.1%
Overall % change in energy use (1997-2020)				-2.0%

In an effort to assess the impact of recent trends that may have affected cement industry energy consumption since the CEF report was produced, we also examined reference case energy consumption projections produced in connection with EIA's *Annual Energy Outlook 2006* (AEO 2006), which also uses the NEMS model but incorporates more recent energy and economic data. Where CEF projects a slight decline in sector energy consumption, AEO 2006 projects that sector energy consumption will increase by 10 percent from 2004 to 2020, driven by annual growth in the industry's value of shipments of 2.1 percent per year. However, energy intensity (energy consumption per dollar value of output) is expected to decrease at the rate of 0.7 percent per year—a faster rate of decline than projected by CEF. Though all fuel inputs are projected to increase, AEO 2006 projects the largest increases for natural gas and purchased electricity. Still, by 2020 AEO 2006 projects no substantial change in the overall fuel mix, with coal meeting 60 percent of the sector's energy demand and petroleum (mainly petroleum coke) meeting 23 percent (these fractions are similar to MECS energy consumption data from 2002).

Environmental Implications

Figure 8: Cement sector: energy-related CAP emissions





Effects of Energy-Related CAP Emissions

SO_2 and NO_x emissions contribute to respiratory illness and may cause lung damage. Emissions also contribute to acid rain, ground-level ozone, and reduced visibility.

Figure 8 compares NEI data on energy-related CAP emissions with non-energy-related CAP emissions for the cement sector. Although NEI data attribute emissions from electric power generation to the generating source rather than the purchasing entity, because purchased electricity comprises a small fraction of the cement sector's energy requirements, NEI data provide a relatively complete picture of the industry's energy-related CAP emissions. However, the ratio of energy-related CAP emissions to total CAP emissions appears smaller than expected for an energy-intensive sector. As noted in Section 2.3.3, the majority of the sector's energy requirements and associated emissions result from the thermoreduction of limestone, clay, and sand in a process that uses coal both as a fuel and a feedstock. Given that NEI data for the cement industry only classify 8 percent of the sector's total CAP emissions as "energy-related," it appears likely that NEI data misclassify some CAP emissions resulting from this process as non-energy-related.

According to NEI data, 66 percent of the sector's energy-related CAP emissions are due to coal consumption (see Figure 9). As a result, sulfur dioxide and nitrogen oxides (both linked to coal combustion) are fairly equal contributors to energy-related CAP emissions. (As noted in Section 2.3.3, NEI data on carbon monoxide emissions appear higher than would be expected for stationary sources, so we do not address carbon monoxide data in our assessment of CAP emissions for each sector.)

Figure 9: Cement sector: CAP emissions by source category and fuel usage

Figure 9 presents NEI data on the source categories for energy-related CAP emissions shown in Figure 8, as well as emissions by fuel usage. According to DOE data, fuel inputs into fired systems such as kilns, preheaters, and precalciners comprise the majority of sector energy consumption,[76] and these systems are classified under the "industrial processes" category in NEI. Given AEO 2006's projected increases in economic production and energy consumption for the cement industry, increases in energy-related CAP emissions are expected, which will primarily occur at the facility level from coal combustion.

As NEI data do not include carbon dioxide emissions, we use carbon dioxide emissions estimates from AEO 2006, which totaled 40.1 million metric tons in 2004. (Additional carbon emissions arise from the calcination of limestone, but such emissions are not classified as energy-related.) The projected increase in sector energy consumption is projected to increase carbon emissions to 44 million metric tons by 2020, at a slightly slower rate than the projected energy consumption increase due to expected energy efficiency improvements.

3.2.2 Best Case Scenario

Opportunities

Table 24 ranks the viability of five primary opportunities for improving environmental performance with respect to energy use (Low, Medium, or High). A brief assessment of the ranking is also provided, including potential barriers.

Table 24: Opportunity assessment for the cement industry

Opportunity	Ranking	Assessment (including potential barriers)
Cleaner fuels	Medium	The majority of the industry's energy inputs are met with coal—a relatively inexpensive but emissions-intensive energy source. To the extent possible, the cement industry uses inexpensive waste fuels in its kilns (tires, waste paints, oils, and carpet) to reduce energy costs. The primary environmental benefits of waste fuel use is avoided landfilling and more complete combustion than would be offered by most commercial incinerators due to higher temperatures and longer residence time in kilns.[77] Some waste fuels may be subject to either federal or state RCRA hazardous waste regulations or state solid waste regulations. For example, paint wastes and used oil may be categorized as hazardous waste and, thus, could require plants to obtain hazardous waste permits to burn these materials as fuels. The cement sector also faces technical barriers to greater waste fuel use (e.g., kilns can generally not use more than 25 percent tires, because the zinc slows down setting time) and supply constraints in terms of the long-term stability of sufficient quantities of alternate fuels to meet demand.
Increased CHP	Low	There may be opportunities for increased cogeneration of electricity in the cement industry, particularly if such applications are part of the design for new plants.[78] Such opportunities would primarily involve systems to recover heat from exhaust systems and generate electricity onsite. There are also opportunities for increased waste heat recovery, particularly through waste heat utilization in preheater heat exchange systems.[79] However, the CEF report notes that there may be little incentive to devote capital to waste heat recovery systems as long as the industry is able to obtain low-cost energy (coal, waste fuels, etc.).
Equipment retrofit/ replacement	High	Given the magnitude of kiln-related energy requirements, DOE references the following equipment replacement and retrofit opportunities to improve the efficiency of both wet and dry kilns: installation/upgrades of preheat systems, enhanced heat recovery in the clinker cooler, and more efficient grate coolers.[80] Grinding technology improvements such as replacing ball mills with high pressure roller mills or horizontal roller mills is another example of an energy efficiency improvement opportunity for the cement industry.[81] At the same time, ball mills generally provide better mixing than roller mills, so roller mills may not meet production-related requirements. The expected life of onsite limestone reserves may be a determinant in selecting a retrofit or equipment replacement option. If reserves are limited, small retrofits are more likely to be implemented than full-scale equipment replacement. If reserves are substantial, sites are more likely to undertake larger capital investments, which might include energy efficiency improvements.[82]
Process improvement	High	A recent study notes that the greatest opportunities for reducing energy consumption and lowering emissions lie with improvements in cement pyroprocessing, which currently operates at 34 percent thermal efficiency.[83] In an example of a full-scale process change, the cement industry is transitioning from wet process kilns to dry process kilns, which leads to substantial reductions in energy use per ton of production. The kiln replacement process is slow not due to regulatory considerations but economic considerations—specifically, capital constraints and the long operational lifetime for kilns (30-40 years), which mean that changes in the number and types of kilns occur slowly, and typically only when the kiln has reached the end of its useful life, because operating cost savings are insufficient to justify early retirement of the expensive capital. (At the same time, PCA estimates that nearly 44 percent of U.S. clinker production capacity is older than 30 years.) Opening new dry kilns would trigger NSR review and other requirements (e.g., Maximum Achievable Control Technology (MACT) standards for cement kilns; new NESHAPs for portland cement once finalized); however, the long-term and continuing conversion from wet to dry kilns indicates that this is not an insurmountable barrier to adopting the more energy-efficient dry process.

Opportunity	Ranking	Assessment (including potential barriers)
		CEF cites pollution prevention and waste recycling as having potential to achieve efficiency improvements in the cement industry. [84] Alternative raw materials for cement clinker production and cement blending (e.g., foundry sand) may be used; these alternative raw materials reduce energy consumption by reducing the amount of virgin raw materials that need to be quarried for the cement kilns or reducing the amount of cement clinker that needs to be blended into the cement product. Other process-related opportunities include reducing pyroprocessing energy use through increasing blending and using alternative clinker materials,[85] combustion system optimization, and adaptation to semi-wet conversion processes (wet kilns).[86]
R&D	Medium	Fluidized-bed kilns are an emerging technology that shows capital and operational savings over dry kilns and may be adopted when existing kilns are slated for replacement. R&D efforts focusing on reducing energy requirements in pyroprocessing offer the greatest opportunities for improved environmental performance. A recent study notes the following areas of R&D opportunities: developing less energy-intensive cement manufacturing processes; developing systems for biomass fuel usage in kilns; and developing systems for increased waste fuel utilization.[87]

Optimal Future Trends

Given more recent AEO 2006 projections that indicate an increasing energy consumption trend for the cement industry, CEF's reference case projections appear outdated, calling into question the validity of its advanced case projections. However, AEO 2006 does not provide sector-specific data for its advanced energy scenario, and we must use the CEF study to approximate an environmentally preferable energy consumption trend for the cement industry.

Under its advanced case projections, CEF projects no major change to the cement industry's dependence on coal but shows larger declines in coal inputs than in petroleum and electricity input, and a slight increase in natural gas consumption. Rather than a fuel-switching trend that replaces coal with other energy inputs, the declining coal fraction is the result of reduced energy use in kilns through more aggressive introduction of blended cements in the U.S. market, and faster retirement of wet process clinkers with replacement by modern preheater precalciner dry process kilns. For dry process plants, energy efficiency opportunities reflected in the CEF projections include optimized heat recovery in the clinker grate cooler and conversion to grate clinker coolers. For wet process plants, conversion to semi-wet processes and kiln combustion system improvements produce additional energy efficiency gains. Cross-cutting energy efficiency improvements are achieved through preventative maintenance best practices, improved process control through control system installations, and installation of energy management systems.

As with CEF's projections for all sectors, economic assumptions are the same under the advanced case scenario as the reference case (growth in production of 1 percent per year and growth in value of output at 1.1 percent per year). (See Appendix A-2 of the CEF report for more detailed descriptions of CEF's modeling assumptions under the business-as-usual and advanced energy scenarios.) Given current expectations of production growth for the industry and AEO 2006 reference case projections, it is unlikely that an advanced energy scenario would achieve such aggressive reductions in energy consumption.

CEF's advanced case projections are shown in Table 25.

Table 25: CEF advanced case projections for the cement industry

	1997 Advanced Case		2020 Advanced Case	
	Consumption (quadrillion Btu) [mmm]	Percentage	Consumption (quadrillion Btu)	Percentage
Petroleum	0.036	9%	0.034	11%
Natural gas	0.018	5%	0.030	10%
Coal	0.316	79%	0.216	70%
Delivered electricity	0.030	8%	0.028	9%
Total	0.4	100%	0.308	100%
Annual % change in energy intensity (energy consumption per dollar value of output)				-1.1%
Overall % change in energy use (1997-2020)				-23%

Environmental Implications

Though an advanced energy scenario may be unlikely to achieve the energy consumption reductions projected by CEF, such a scenario would produce lower CAP emissions at the facility level than are expected under a business-as-usual scenario. Conversion to precalciner kilns also contributes to NOx emissions reductions.

Under the advanced energy scenario, CEF projects the cement industry to achieve a 16 percent reduction in 1997 carbon dioxide emissions levels by 2020 (compared with an increase of 5.7 percent projected under the reference case).

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[mmm] As is the case with several sectors addressed in the CEF analysis, there are slight differences between 1997 fuel consumption data in the reference and advanced cases. We could find no explanation for such differences in the CEF analysis, but it could be that CEF made modifications to the base year (1997) parameters under the advanced case as compared with the reference case.

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