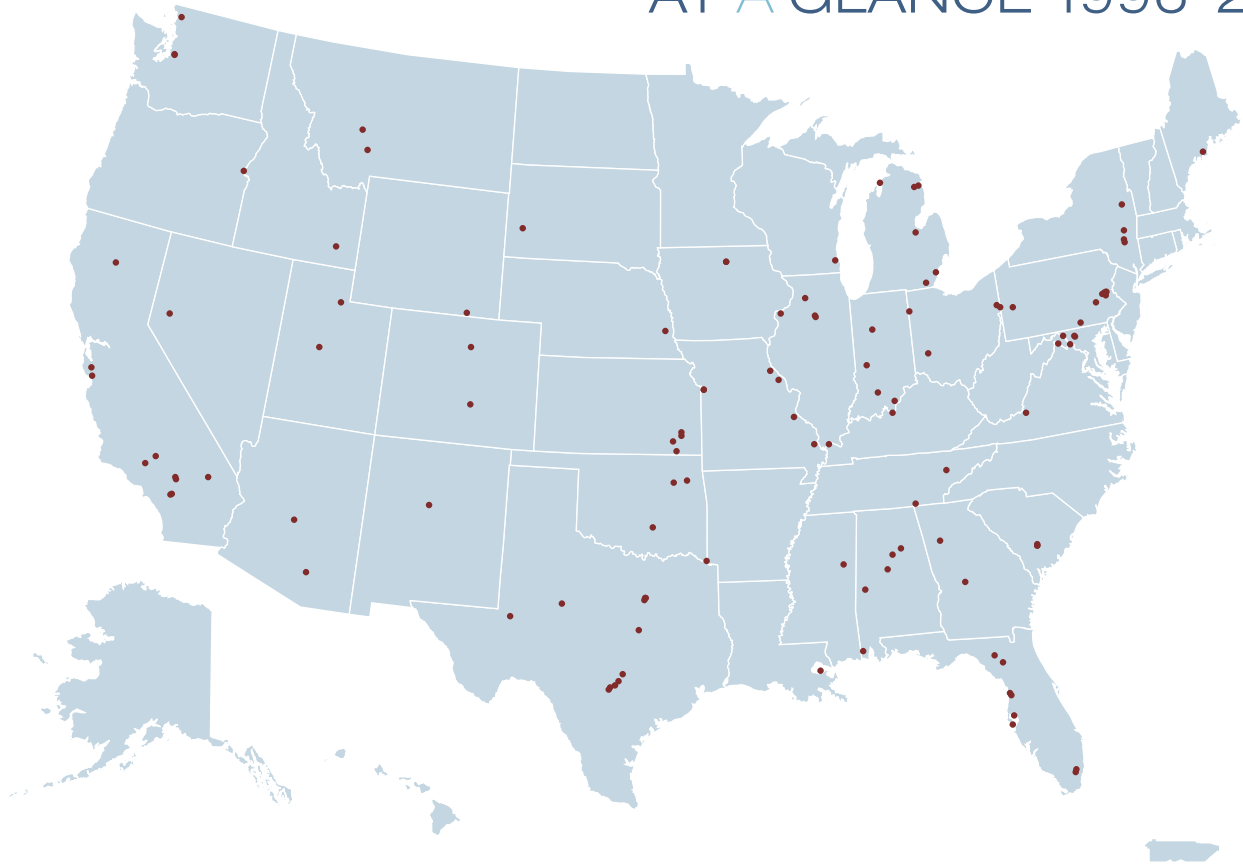




CEMENT MANUFACTURING

AT A GLANCE 1996-2005¹



115 facilities — 115 ▲ 0%

13,800 employees — 13,800 ▲ 0%

70.4 million metric tons of clinker produced — 87.4 million ▲ 24%

Latest Environmental Statistics²

Energy Use: 410.8 trillion Btu

Emissions of Criteria Air Pollutants: 576,000 tons

Releases of Chemicals Reported to TRI: 13.5 million lbs.

Air Emissions: 10.6 million lbs.

Water Discharges: 3,300 lbs.

Waste Disposals: 2.9 million lbs.

Recycling, Energy Recovery, or Treatment: 412 million lbs.

Hazardous Waste Generated: 17,000 tons

Hazardous Waste Managed: 31,000 tons

The data discussed in this report are drawn from multiple public and private sources. See the Data Guide and the Data Sources, Methodologies, and Considerations chapter for important information and qualifications about how data are generated, synthesized, and presented.

Profile

The Cement Manufacturing sector produces Portland cement, a binding agent that when mixed with water, sand, and gravel or crushed stone forms the rock-like mass known as concrete. Concrete, in turn, serves highway, commercial, and residential construction projects.

Limestone is the key ingredient to manufacture cement. Limestone and other ingredients, including material that is aluminous, ferrous, and siliceous, are placed into a kiln where a thermochemical process occurs to make cement clinker. The cement clinker is mixed with additives (e.g., gypsum) to make Portland cement.

The U.S. Cement Manufacturing sector is concentrated among a relatively small number of companies; many U.S. cement plants are owned by or are subsidiaries of foreign companies. Together, 10 companies accounted for about 80% of total U.S. cement production in 2005.³

California, Texas, Pennsylvania, Florida, and Alabama are the five leading cement-producing states and accounted for about 48% of recent U.S. production.⁴

Although production, imports, sales volumes, and prices of cement all reached record high levels in 2005, cement consumption is expected to decline in the near future.⁵

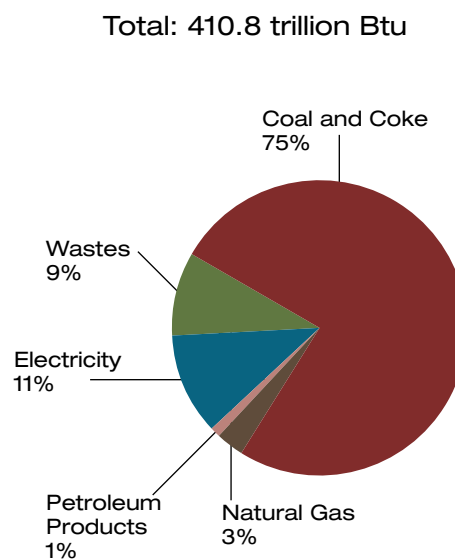
Energy Use

Cement Manufacturing is an energy-intensive industry. The thermochemical production process requires very high temperatures; grinding and crushing operations also use energy. On average, producing one metric ton of cement requires 4.7 million Btu.⁶ Between 2000 and 2006, the sector's energy consumption, when normalized by clinker production, decreased about 7%.⁷

To make cement, the manufacturer places limestone and other ingredients into the upper end of a rotary kiln. At the lower end of the inclined kiln, a burner pipe emits a large flame, providing the intense heat required for the thermochemical process. The limestone and other materials go through several chemical processes that require temperatures reaching almost 1,500 degrees Centigrade (C). During the process, the raw materials, fuel molecules, and the air inside the kiln break apart. The limestone becomes calcium oxide and carbon dioxide (CO₂). Calcium oxide and silicates bond to form the principal compounds that cool into solid pellets called clinker. The manufacturer grinds clinker with gypsum and smaller amounts of other ingredients to create Portland cement.

Kilns employ either a wet or dry process. The wet process uses raw materials ground with water to create a slurry material to be fed into the kiln, while the dry process uses dry materials in a powder-like input to the kiln. The wet process was initially used to improve the chemical uniformity of raw materials being processed; however, it

FIGURE 1
Fuel Use for Energy 2006



Source: Portland Cement Association



requires 32% more energy per ton of clinker production than the average for dry processes.⁸ Technological improvements have allowed cement makers to utilize the dry process without quality deficiencies, and no new wet kilns have been built in the United States since 1975.⁹ Some existing plants are switching from the wet to the dry process.¹⁰ About 85% of U.S. cement production capacity now relies on the dry process technology.¹¹

As shown in Figure 1, Cement makers are able to utilize a variety of fuels to maintain high temperatures within kilns, such as coal, petroleum coke, distillate and residual fuel oils, natural gas, used tires, and solid and liquid wastes. The significant quantity of fuel and raw materials needed to manufacture cement provides an opportunity for the sector to consume alternative fuels and raw materials generated as byproducts from other industries.

Many plants meet 20–70% of their energy requirements with alternative fuels.¹² These fuels include scrap tires, waste oil, refinery wastes, and other solid and liquid wastes that have fuel value. Cement kilns burn hotter, have longer gas residence times, and are much larger than most commercial thermal treatment facilities (e.g., hazardous waste incinerators), making them ideal for reclaiming such materials when properly managed.

Air Emissions

Air emissions from the sector include criteria air pollutants (CAPs), greenhouse gases (GHGs), and a number of chemicals reported to EPA's Toxics Release Inventory (TRI). CAPs and GHGs also are generated as byproducts from onsite combustion of fuels in cement kilns.

Air emissions from the kiln system are the primary environmental concern in cement manufacturing. More than 99% of the exit gases are composed of nitrogen, water vapor, and CO₂, while less than 1% is nitrogen oxide (NO_x), sulfur dioxide (SO₂), and even smaller quantities of organic compounds and heavy metals.¹³

The major processes in making Portland cement that cause air emissions are fuel combustion, the thermochemical process of making clinker, and crushing and grinding operations. The intense heat of the combustion process

separates the fuel into organic and inorganic components. The organic components are consumed as fuel, while the various inorganic components become either part of the cement product or are collected in a plant's air pollution control device (e.g., electrostatic precipitator or baghouse).

Raw materials, particularly clay, may contain ammonia, which is partially roasted off during material preheating. Smaller amounts may come from loss of ammonia when used in selective non-catalytic reduction (SNCR) NO_x control devices. Benzene and ethylene are found in both conventional and alternative raw materials and are partially roasted off during material preheating.

Chlorine may be present in raw materials as well as in alternative fuels (e.g., spent solvents, plastics). Much of the chlorine becomes bound in the clinker. Emissions can result if inputs exceed the capacity of the clinker to absorb inbound chlorine, in which case the chlorine combines with hydrogen to produce hydrochloric acid.

Metals are found in all cement input materials, including limestone, clay, coal, and cement kiln dust (CKD). Semi-volatile and volatile metals evaporate and condense on the fine dust fraction of material recovered in air pollution control equipment. Reduction controls for most heavy metals include efficient dedusting equipment (baghouses and electrostatic precipitators) and limits to inputs in feed materials (currently the primary control method for mercury).

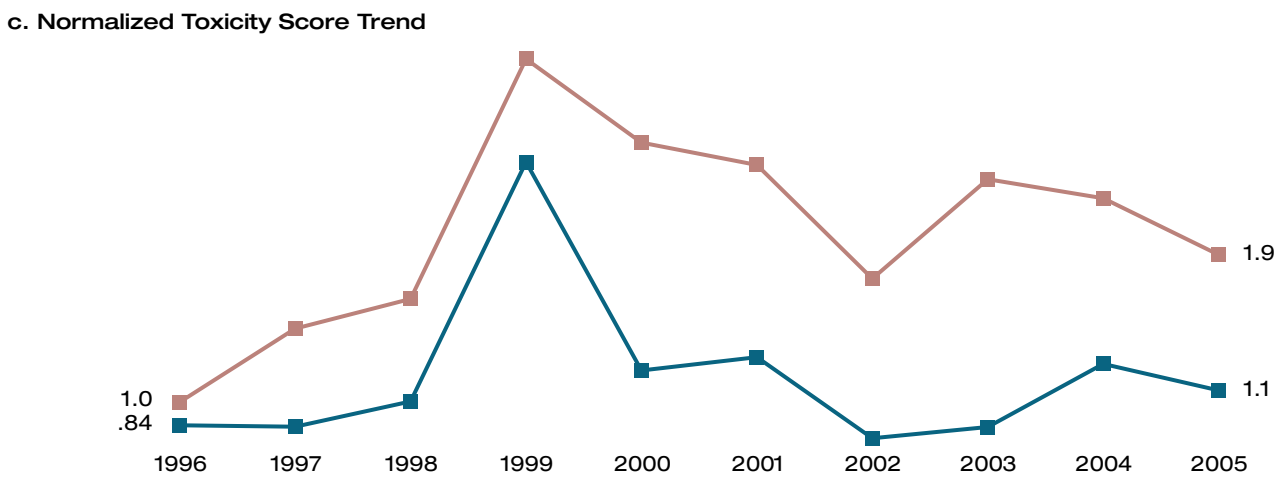
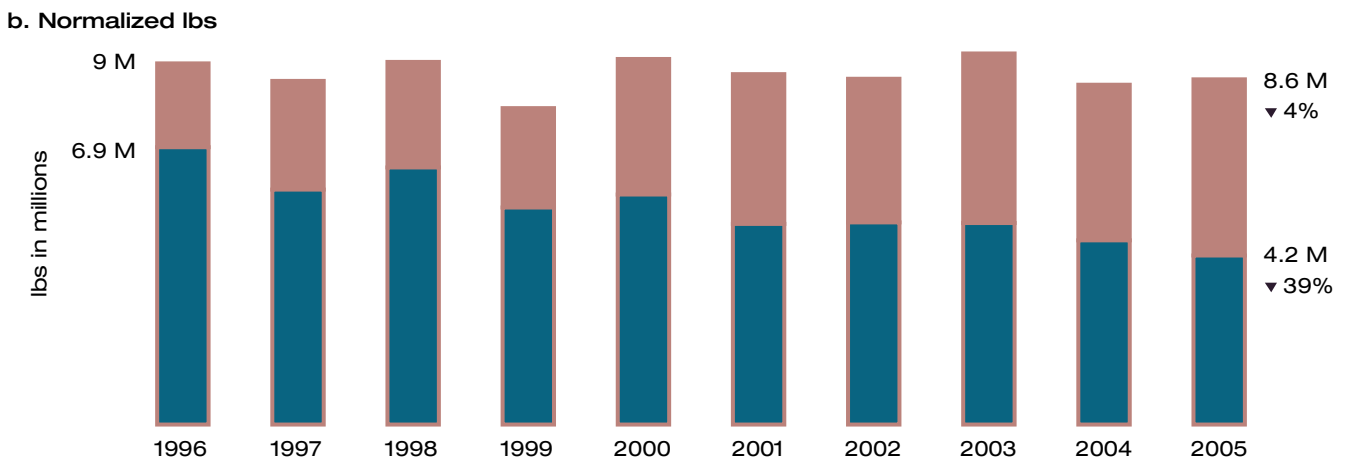
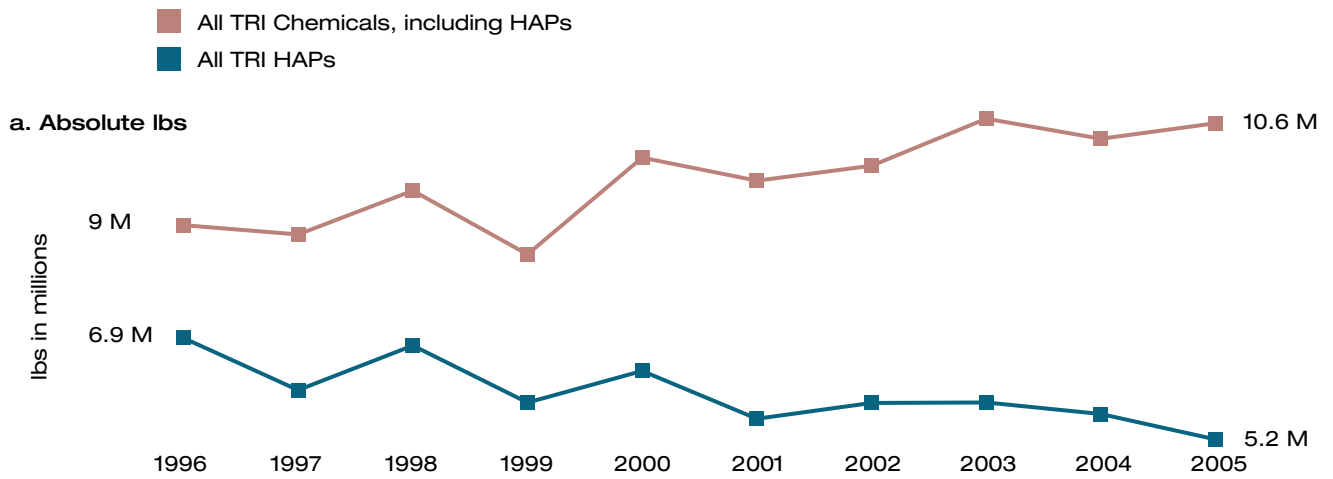
Air Emissions Reported to TRI

In 2005, 109 facilities in the sector reported 10.6 million absolute lbs. of air emissions to EPA's TRI.¹⁴ The TRI list of toxic chemicals includes all but six of the hazardous air pollutants (HAPs) regulated under the Clean Air Act. The absolute pounds emitted annually increased nearly 19% from 1996 to 2005, as shown in Figure 2a, but when normalized by annual clinker production, the sector's TRI air emissions decreased by 4% over the same period, as shown in Figure 2b.¹⁵

To consider toxicity of air emissions, EPA's Risk-Screening Environmental Indicators (RSEI) model assigns every TRI chemical a relative toxicity weight, then multiplies the pounds of media-specific releases (e.g., pounds of mercury released to air) by a chemical-specific toxicity weight to calculate a relative Toxicity Score. RSEI methodological considerations are discussed in greater detail in the Data Guide, which explains the underlying assumptions and important limitations of RSEI.

Data are not reported to TRI in sufficient detail to distinguish which forms of certain chemicals within a chemical category are being emitted. For chemical categories such as chromium, the toxicity model conservatively assumes that chemicals are emitted in the form with the highest toxicity weight (e.g., hexavalent chromium); thus, Toxicity Scores are overestimated for some chemical categories.

FIGURE 2
Air Emissions Reported to TRI 1996–2005



Note:
Normalized by annual clinker production.
Sources: U.S. Environmental Protection Agency, U.S. Geological Survey

Summing the Toxicity Scores for all of the air emissions reported to TRI by the sector produces the trend illustrated in Figure 2c. The sector's Toxicity Scores fluctuated from 1996 to 2005, with an overall increase of 98%, when normalized by clinker production. Fluctuations in emissions of sulfuric acid and chromium caused reciprocal fluctuations in the sector's overall Toxicity Score. Fluctuations in sulfuric acid, which is released as a byproduct from burning coal during clinker manufacturing, were driven by changes in pounds reported by only a few cement plants. Changes in chromium results were due to naturally occurring variations in the level of chromium in limestone.¹⁶ The apparent spike in 1999 was due, among other things, to changes in methodologies used to calculate releases, and to changes in TRI reporting requirements. In absolute pounds, HAPs accounted for 49% of the sector's air emissions reported to TRI in 2005, and 54% of the overall Toxicity Score.

Table 1 presents the sector's top TRI-reported air emissions based on three indicators.

TABLE 1
Top TRI Air Emissions 2005

Chemical	Absolute Pounds Reported ¹	Percentage of Toxicity Score	Number of Facilities Reporting ²
Ammonia	1,469,000 ³	<1%	15
Benzene ⁴	599,000	1%	14
Chlorine	50,000	7%	1
Chromium	10,000	14% ⁵	63
Dioxin and Dioxin-Like Compounds	<1	<1%	74
Ethylene	1,811,000	<1%	1
Hydrochloric Acid	3,900,000	6%	35
Lead	15,000	2%	107
Manganese	34,000	19%	34
Mercury	11,000	1%	104
Sulfuric Acid	1,580,000	45%	11
Percentage of Sector Total	89% ⁶	95% ⁷	100% ⁸

Notes:

- Total sector air releases: 10.6 million lbs.
- 109 total TRI reporters in the sector.
- Red indicates that the chemical is one of the top five chemicals reported in the given category.
- Italics* indicate a hazardous air pollutant under section 112 of Clean Air Act.
- Calculation of Toxicity Score for chromium conservatively assumed that all chromium emissions were hexavalent chromium, the most toxic form, with significantly higher toxicity weights than trivalent chromium. However, hexavalent chromium may not constitute a majority of the sector's chromium releases. Thus, RSEI analyses may overestimate the relative harmfulness of chromium emissions.
- Chemicals in this list represent 89% of the sector's air emissions.
- Chemicals in this list represent 95% of the sector's Toxicity Score.
- 100% of facilities reported emitting one or more chemicals in this list.

Source: U.S. Environmental Protection Agency

- 1) Absolute Pounds Reported. Hydrochloric acid and ethylene were the highest-ranking chemicals based on the pounds of each chemical emitted to air in 2005, although ethylene was largely reported by a single facility.
- 2) Percentage of Toxicity Score. Sulfuric acid and metals—manganese and chromium—dominated top chemicals based on Toxicity Score. Manganese and other metals can occur naturally in limestone.
- 3) Number of Facilities Reporting. Lead and mercury were the most frequently reported chemicals, with almost all of the TRI filers in the sector reporting these chemical emissions.

Criteria Air Pollutants

At 219,000 tons in 2002, NO_x were the largest CAP emissions from cement making, as shown in Table 2.¹⁷ NO_x formation is an inevitable consequence of high temperature combustion. Called "Thermal NO_x," it is produced in the main flame of all cement kilns and is formed during combustion of air. Some NO_x may result from combustion of fuels.¹⁸ Control strategies include low-NO_x burners and SNCR technologies.

TABLE 2
Criteria Air Pollutant and VOC Emissions 2002

	Tons
SO ₂	161,000
NO _x	219,000
PM ₁₀	37,000
PM _{2.5}	17,000
CO	150,000
VOCs	9,000

Notes:

1. PM₁₀ includes PM_{2.5} emissions.

Source: U.S. Environmental Protection Agency

SO₂ results from volatilization of sulfur from raw materials roasted off during material preheating. The range of emissions depends on the content of volatile sulfur compounds in the raw materials. Control strategies include the addition of hydrated lime to the kiln feed and the use of wet sulfur scrubbers. Volatile organic compounds (VOCs) result from volatilization of organics in raw materials (limestone and shale) that are roasted off at material preheating. The range of emissions depends upon the content of the raw materials mined. Carbon monoxide (CO) is formed either because of incomplete combustion or the rapid cooling of combustion products below the ignition temperature of 610°C.

At the end of the thermal treatment process, gases and pulverized materials must be separated again. Incomplete separation gives rise to dust emissions from the kiln/raw mill main stack, the clinker cooler stack, cement mill stacks, or material transfer point dedusting air outlets. Bag filters and electrostatic precipitators are emission reduction techniques typically used.

The fine dust generated from the kiln line, collectively labeled cement kiln dust, includes particulates representing the raw mix at various stages of burning, particles of clinker, and even particles from the eroded refractory brick linings of the kiln tube. Most U.S. plants have reduced CKD air emissions to small amounts by using dust scrubbers—either electrostatic precipitators or filtration baghouses.

In general, the introduction of newer kiln technology and improved process controls by the sector has led to overall reductions of CAP emissions. Process controls stabilize kiln operations by improving energy efficiency, reducing heat consumption, improving clinker quality, and reducing emissions.

Greenhouse Gases

Cement manufacturers directly emit GHGs from their consumption of raw materials and combustion of fuels. The chemical reaction creating cement emits large amounts of CO₂ as limestone breaks down into calcium oxide. Noncombustion cement production processes emitted 45.9 million metric tons of CO₂ equivalent in 2005.¹⁹ The combustion of fuels in cement kilns and generation of electricity purchased by the sector also emit GHGs.

Figures published by major cement corporations provide some insight into the CO₂ emissions that cement companies have

Reducing Greenhouse Gas Footprint

The California Portland Cement company signed a 25-year contract with a wind energy company that ensures a large portion of the power consumed at the plant located in Mojave, CA, will be renewable energy. This helped reduce the company's indirect GHG emissions in 2006 by 31,247 metric tons over 2005.²¹

Reducing Direct GHG Emissions

Buzzi Unicem's Signal Mountain plant in Chattanooga, TN, reduced its CO₂ emissions 51.3% after completing a \$140 million upgrade to convert to a dry manufacturing process. The plant received a Green Industry Award from the Greater Chattanooga Chamber of Commerce.²²

identified. Three reports from 2005 and 2006 from cement companies estimated CO₂ emissions in the range from 658 to 670 kilograms (kg) per metric ton of cement produced.²⁰

The sector has various options for reducing GHG emissions, including using alternative sources of calcium oxide, such as steel slag, and upgrading to more efficient clinker production technologies, such as dry—rather than wet—process kilns. Under the U.S. Department of Energy's (DOE) voluntary Climate VISION program, the Portland Cement Association (PCA) adopted a voluntary goal to reduce CO₂ emissions by 10% per ton of cement product produced or sold by 2020, from a 1990 baseline.²³

Water Use and Discharges

Cement plants generate little wastewater. The water used in wet process plants evaporates in the kiln. While 109 facilities reported air emissions to TRI in 2005, just 16 reported water discharges. These facilities reported 3,300 lbs. of TRI chemicals discharged to water.²⁴ There are currently no aggregate data available on the quantity of water used by the Cement Manufacturing sector.

Discharges to surface water also can result from stormwater runoff. Plant operators generally channel stormwater into holding ponds so the solid particles can be removed. Cement makers can discharge the water in compliance with permits or recycle the water to cool equipment.

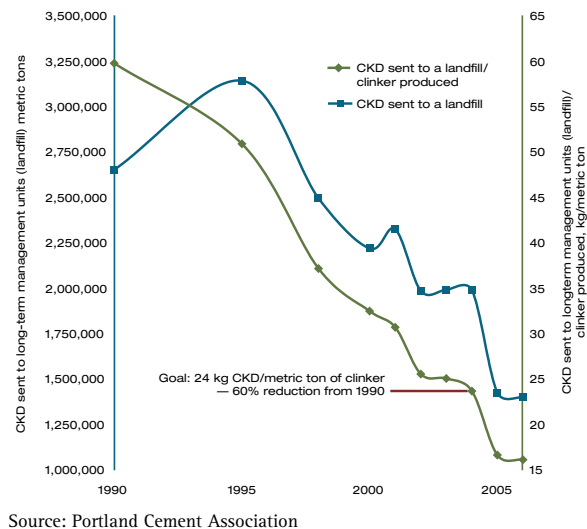
Waste Generation and Management

Of the solid wastes generated in a kiln, CKD is a major issue. The tumbling and grinding of materials within a kiln produce a great deal of dust. CKD consists of the ash and other tiny particles remaining from the burnt limestone and other products. It can contain metals and materials remaining from the hazardous wastes sometimes used as supplemental fuel within a kiln. CKD is removed from the kiln exhaust gases by pollution-control devices such as baghouses and electrostatic precipitators.

CKD is a valuable commodity to the industry. Recycling CKD into the cement kiln offsets the use of limestone and other raw virgin materials and reduces fuel usage. More than 75% of CKD is now fed directly back into the kiln. When not recycled to the kiln, because of contaminant build-up and quality-control concerns (e.g., alkalis), CKD can sometimes be used as a soil conditioner (liming agent), as a somewhat cementitious material for roadfill, and occasionally as a filler or cementitious extender for finished cement.

As illustrated by Figure 3, the cement industry has used process improvements to reduce the amount of CKD disposed. PCA adopted a voluntary target for its member companies of a 60% reduction (from a 1990 baseline) of

FIGURE 3
Cement Kiln Dust Disposal Rates
With Reduction Goal



CKD disposed per ton of clinker produced—a goal of 24 kg CKD disposed of per metric ton of clinker produced. PCA members achieved this goal in 2004.²⁵

EPA has categorized CKD as a special waste temporarily exempted from federal hazardous waste regulations under the Resource Conservation and Recovery Act (RCRA). EPA is developing standards for management of CKD and has published a set of proposed Subtitle D (concerning nonhazardous solid waste) regulations to govern CKD management.

Alternative materials from other sectors can be used to make cement. These materials include byproducts from other industrial processes, such as used foundry sand from the Metal Casting sector, mill scale from the Iron & Steel sector, or fly ash from electric utilities. These materials can replace corresponding raw materials that would have to be mined.

Burning wastes as fuel can reduce the need for virgin fuels to run the kiln, can treat hazardous waste, and can reduce the quantity of wastes buried in landfills, incinerated, or otherwise disposed. The practice can also reduce plant operating costs, improving competitiveness.

Hazardous Waste Management

In 2005, cement plants reported to EPA's *National Biennial RCRA Hazardous Waste Report (BR)* generating 17,000 tons of hazardous waste. However, only 18 of 115 facilities in the sector reported to BR, so the data may present an incomplete picture of the sector's generation of hazardous waste. For instance, 1 facility generated 32% of the sector's reported RCRA hazardous wastes, while 4 of the 18 generated almost 86% of the reported wastes.²⁶ Most of the generated hazardous waste reported was from pollution control and hazardous waste management activities.²⁷



The sector tends to manage more wastes than it generates because some facilities receive hazardous waste from offsite for use as fuel. The sector reported managing 31,000 tons of hazardous waste in 2005. A majority of the waste was managed through reclamation and recovery activities, almost all of which was through energy recovery.

Some cement companies have subsidiaries that operate as fuel blenders that accept, store, and process (e.g., fuel blending) hazardous waste. Estimating the flow of hazardous waste into and out of these subsidiaries and into and out of individual cement facilities is difficult to do but may be examined in future reports.

Waste Management Reported to TRI

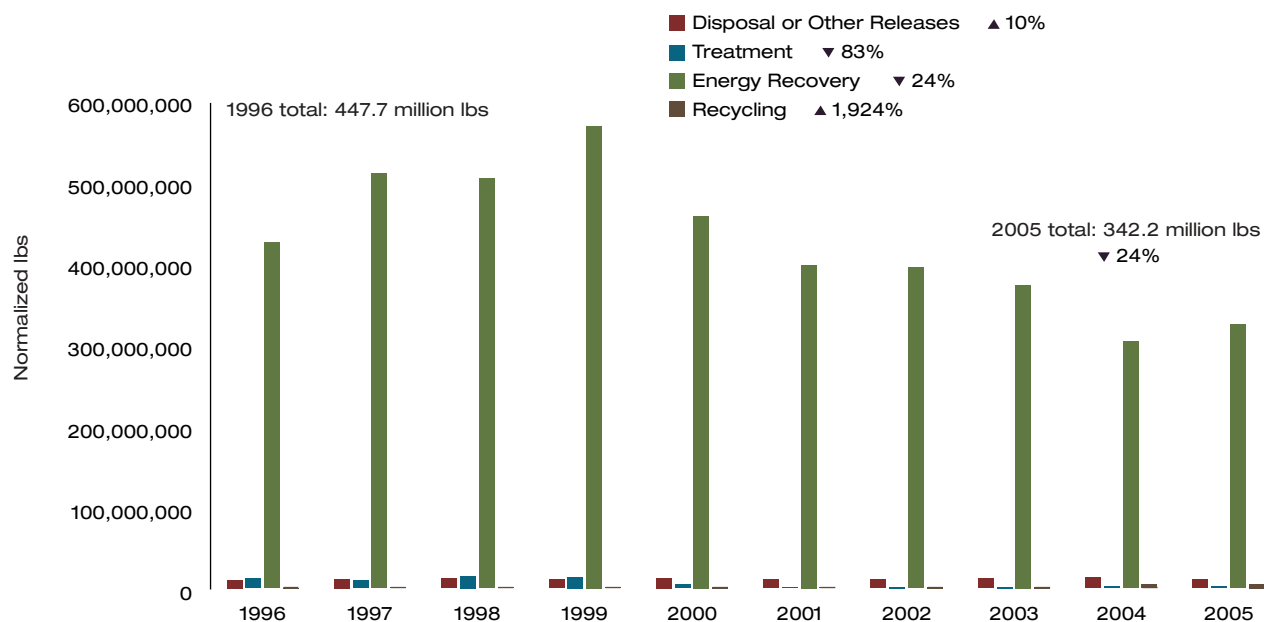
In 2005, the Cement Manufacturing sector reported managing 425 million absolute lbs. of TRI chemicals as waste. As shown in Figure 4, when normalized by annual clinker production, this quantity represented a 24% reduction since 1996. The downward trend indicates that less waste was generated per ton of clinker in the sector in 2005. In 2005, 3% of TRI-reported waste was disposed or released, while 95% was used for energy recovery. The remaining 2% was recycled or treated.²⁸

In 2005, the sector reported disposing 2.9 million lbs. of TRI chemicals to land or transferring the chemicals to offsite locations for disposal. As shown in Table 3, metals dominated the sector's TRI disposals. Major sources of these disposals are metals in CKD collected in air pollution particulate control systems. Metals from raw materials or fuels are usually bound to the clinker product, except for metals that are partly or completely volatilized in the kiln system (such as mercury, thallium, or cadmium).

Additional Environmental Management Activities

PCA set four performance measure goals regarding: CO₂, CKD, environmental management systems (EMS), and energy efficiency.

FIGURE 4
TRI Waste Management 1996–2005



Notes:

1. Normalized by annual clinker production.
2. Disposal or other releases include air releases, water discharges, and land disposals.

Sources: U.S. Environmental Protection Agency, U.S. Geological Survey

TABLE 3
Top TRI Disposals 2005

Chemical	Absolute Pounds Reported ¹	Number of Facilities Reporting ²
Barium	173,500 ³	14
Chromium	97,500	32
Lead	620,200	49
Manganese	974,700	18
Mercury	1,500	39
Nickel	55,900	15
Zinc	711,700	11
Percentage of Sector Total	90% ⁴	48% ⁵

Notes:

1. 2.9 million lbs. total sector disposals.
2. 109 total TRI reporters in the sector.
3. Red indicates that the chemical is one of the top five chemicals reported in the given category.
4. Chemicals in this list represent 90% of the sector's disposals.
5. 48% of facilities reported disposals of one or more chemicals in this list.

Source: U.S. Environmental Protection Agency

As noted above, PCA member companies achieved their CKD disposal goal in 2004. Pursuant to the goal to reduce CO₂ emissions, PCA introduced guidelines for greater use of limestone as a raw material that could reduce CO₂ generation by more than 2.5 million tons per year. The guidelines recommend upgrading facilities with efficient, lower-emitting equipment, improving product formulation to reduce energy and natural resource needs, and conducting new research and development into cement and concrete applications that are more energy efficient and durable.²⁹

An EMS is a set of processes and practices that enable an organization to reduce its environmental impacts and increase its operating efficiency. PCA adopted a target to have at least 75% of U.S. cement plants use an auditable and verifiable EMS by the end of 2010 and 90% by the end of 2020.

For the energy efficiency performance measure, PCA adopted a year 2020 voluntary target of 20% improvement (from 1990 baseline) in energy efficiency. This is measured by total Btu-equivalent per unit of cementitious product.