CO_2 Emissions Profile of the U.S. Cement Industry

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ABSTRACT

Global carbon dioxide (CO_2) emissions from cement production were approximately 829 million metric tons of CO_2 ($MMTCO_2$) in 2000[1], about 3.4% of global CO_2 emissions from fossil fuel combustion and cement production. The United States is the world's third largest cement producer, with production occurring in 37 states.

Cement production is not only a source of combustion-related CO_2 emissions, but it is also one of the largest sources of industrial process-related emissions in the United States. Between 1990 and 2001, U.S. process-related emissions increased 24%, from 33.3 $TgCO_2$ to 41.4 $TgCO_2$[2]. National estimates of process-related emissions are calculated based on methodologies developed by the Intergovernmental Panel on Climate Change (IPCC)[3,4]. Combustion-related emissions from the U.S. cement industry were estimated at approximately 36 $TgCO_2$ in 2001,[5] accounting for approximately 3.7 percent of combustion-related emissions in the U.S. industrial sector.

This paper explores, on a more disaggregated level, the geographic location of CO_2 emissions sources from the U.S. cement industry. This paper begins by providing a brief overview of the U.S. cement industry, including national level estimates of energy use and carbon emissions. The focus of the paper is on the development of a cement industry profile for the United States. Based on facility-level capacity statistics, a bottom-up analysis was undertaken to identify sources of CO_2 emissions in the U.S. cement industry in order to gain a better understanding of the geographic scope and concentration of this emissions source.

INTRODUCTION

Globally, over 150 countries produce cement and/or clinker, the primary input to cement. In 2001, the United States was the world's third largest producer of cement (90 million metric tons (MMt)), behind China (661 MMt) and India (100 MMt).[6] The United States imported about 25 MMt of cement in 2001, primarily from Canada (20%), Thailand (16%) and China (13%). Less than 1% of domestic production was exported. The primary destinations for export were Canada (82%) and Mexico (6%).

Cement is often considered a key industry for a number of reasons. To begin with, cement is an essential input into the production of concrete, a primary building material for the construction industry. Due to the importance of cement for various construction-related activities such as highways, residential and commercial buildings, tunnels and dams, production trends tend to reflect general economic activity. Furthermore, because of the large demand for cement, the relatively high costs associated with transport of the high-density product, and the wide geographic distribution of limestone, the principal raw material used to produce cement, cement is produced across the United States.

Cement production also is a key source of CO_2 emissions, due in part to the significant reliance on coal and petroleum coke to fuel the kilns for clinker production. Globally, CO_2 emissions from cement production were estimated at 829 $MMTCO_2$ in 2000[7], approximately 3.4% of global CO_2 emissions from fossil fuel combustion and cement production. In addition to combustion-related emissions, cement production also is a source of process-related emissions resulting from the release of CO_2 during the calcination of limestone.

Annually, the United States submits a national inventory of GHG emissions to the United Nations Framework Convention on Climate Change (hereafter referred to as the Inventory). Emission estimates included in the Inventory are based on methodologies developed by the IPCC, as well as some country-specific methodologies consistent with the IPCC. The Inventory estimates U.S. process-related emissions from cement production to be 41.4 $TgCO_2$ in 2001[8]. Due to the nature of the IPCC Guidelines, as well as the way industrial sector emissions are estimated in the United States, combustion-related emissions resulting from the cement industry are not as well characterized. While combustion-related emissions from cement production are incorporated into the Inventory, they are aggregated and presented in the estimate of CO_2 emissions from fossil fuel combustion.

This paper highlights the results of research to explore more in-depth, process and combustion-related emissions from the U.S. cement industry as a whole and on a more disaggregated level. Developing such a profile of the cement industry is important for several reasons, including:

- Development of time-series estimates for combustion-related emissions
- Comparison of bottom-up analyses with publicly available national estimates as a useful quality assurance and quality control activity
- Identifying the structure of the industry. For example, are there relatively few large companies or facilities, or is the industry dispersed across the country? Are companies primarily U.S. or international?
- Identifying the array of technologies and processes utilized in various parts of the country, allowing "typical practice" to be identified and, subsequently, opportunities for achieving emissions reductions
- Identification of local resources available that may be consumed as alternative fuels in existing facilities.

This paper begins by briefly discussing the cement production process, the sources of energy consumed in the process, and the resulting CO_2 emissions. The focus of the paper is on the development of a cement industry profile for the United States. Based on facility-level capacity statistics, a bottom-up analysis was undertaken to identify sources of CO_2 emissions in the industry in order to gain a better understanding of the geographic scope and concentration of this emissions source.

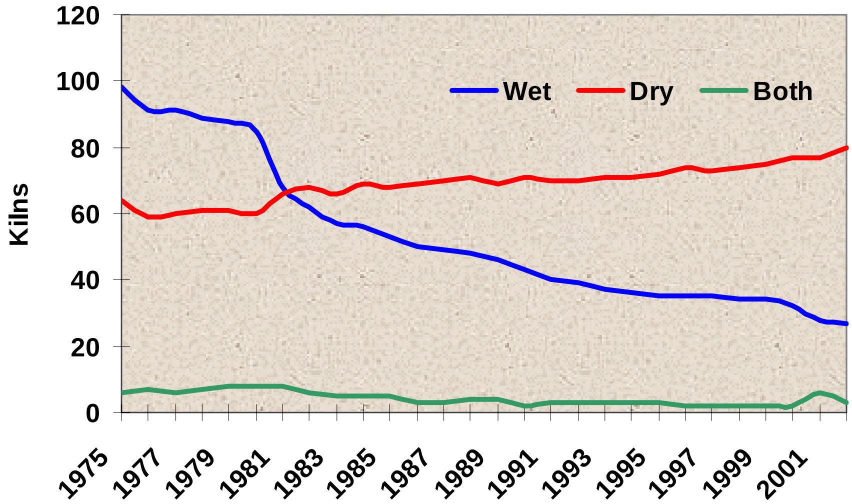
CEMENT PRODUCTION PROCESS

Cement's raw materials, calcium oxide and other minerals (such as silicon, aluminum and iron oxides) are taken from the earth through mining and quarrying. These minerals are crushed into a more manageable aggregate and transported for further processing. The manufacture of clinker and subsequently cement entails three major functions: kiln feed preparation, clinker production, and finish grinding[9].

1) *Kiln Feed Preparation*. Using dry or wet processes, mineral inputs are reduced to ground meal (powders or slurries, respectively) before they are sent to kilns for clinker production. The raw materials are first crushed to a maximum of 6 inches in diameter and then crushed a second time to a maximum of about 3 inches in diameter. In the "dry" process, the crushed

material is fed into the kiln. In the "wet" process, the ground materials are first mixed with water to form a slurry before being fed into the kiln. The use of the dry process for cement production has increased significantly in the last couple of decades (Figure 1), partially due to the lower fuel requirements for the dry process (discussed further below). In 1975, dry kilns comprised 38% of all kilns, whereas in 2001, dry kilns accounted for approximately 70% of all kilns[10].

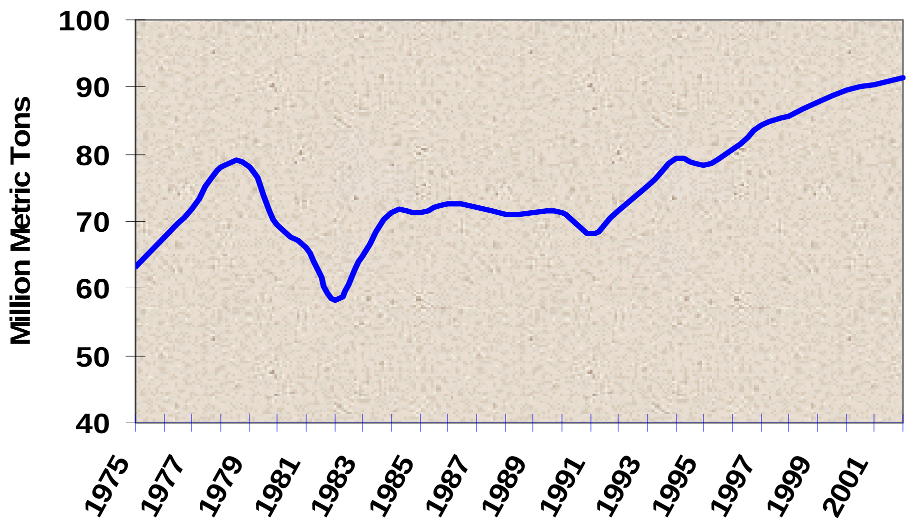
Figure 1. Number of Kilns by Process



Source: USGS Mineral Surveys (data from Surveys in 1975-2002)

This transition from the wet to the dry process coincided with a decrease in the total number of kilns in operation. Over the same time period production increased from 75 MMt in 1975 to 90 MMt in 2001[11] (Figure 2). The decrease in total number of kilns in operation (wet, dry and both), along with an increase in total production, illustrates that the average capacity of kilns has increased over time.

Figure 2. Total U.S. Cement Production: 1975-2002



Source:USGS. Various Years (1975-2002). Minerals Yearbook, Vol. 1. Metals and Minerals. U.S. Geological Survey. U.S. Department of the Interior.

2) *Clinker Production*. Clinker is produced in a kiln by pyro-processing the ground materials from Step 1 at approximately1500^{O}C. Kilns can be fueled by a range of energy sources, from fossil fuels to alternative fuels such as shredded tires and waste oils. Coal has been the primary source of fuel in the United States since the 1970s[12]. This step consumes over 90 percent of the industry's total energy.

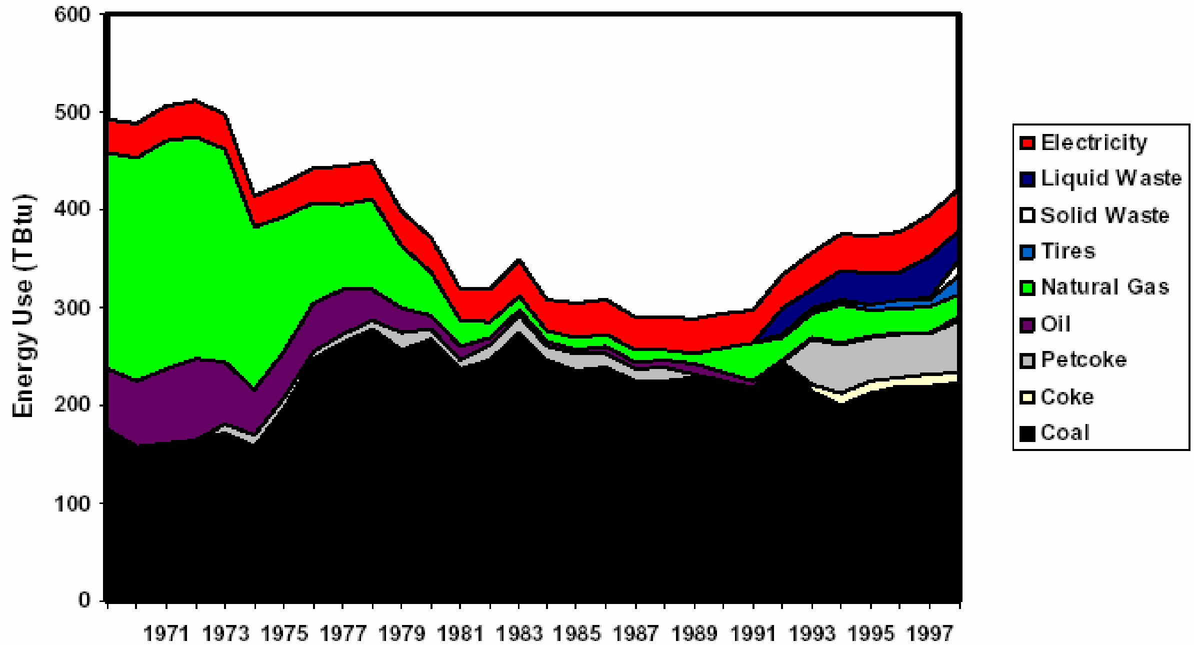
3) *Finish Grinding*. After the clinker is cooled, the clinker nodules are ground into a super-fine powder in a horizontal tube containing steel balls. During the finish grinding process, the type of cement is determined based upon the type and quantity of additives added. Cooled clinker can be mixed with a small quantity of gypsum to produce Portland cement or can be mixed with a greater quantity of lime to produce masonry cement.

ENERGY USE

Total energy consumption in the U.S. cement industry exhibited a decline between 1970 and the early 1990s, before showing an annual average increase of 4.5% between 1992 and 1999[13]. Some of the decrease in energy consumption through the early 1990s can be attributed to the conversion from the wet process of clinker making to the dry process. Although the actual process is more complex, dry kilns require more electricity to operate due to the need for fans and blowers; however, they consume significantly less energy. On average, the wet process has been estimated to require 6.3 Million Btu per short ton (MBtu/st) versus 5.5 MBtu/st for the dry process[14]. The increased energy consumption exhibited in the 1990s can be attributed to a number of factors, including general robust growth in the construction industry, sparked, in part, by low interest rates and increased funding for transportation infrastructure.

Due to the very high temperatures reached in cement kilns a large variety of fuel sources can be used to provide energy. Coal is responsible for the largest share of energy consumption at cement kilns, approximately 71% in 2001. Approximately 12% of energy consumption is derived from petroleum coke, 9% from liquid and solid waste fuels, 4% from natural gas, and the remainder from oil and coke[15]. Figure 3 illustrates the dominance of coal, in addition to the increasing reliance on waste fuels. The movement towards displacing fossil fuel consumption with waste fuels is expected to increase in the future as new waste streams are continuously tested for their suitability for use in cement kilns. Potential waste streams include carpets, plastics, paint residue and sewage sludge. Accounting for the CO_2 emissions attributed to these alternative fuels is a challenge.

Figure 3. Historical Mix of Fuels Consumed in the U.S. Cement Industry



Source: Worrell, E., and C. Galitsky. Energy Efficiency Improvement Opportunities for Cement Making: An ENERGY STAR Guide for Energy and Plant Managers. Environmental Technologies Division. Lawrence Berkeley National Laboratory. January 2004. LBNL-54036

GREENHOUSE GAS EMISSIONS

In cement manufacturing, CO_2 is emitted as a result of both fuel combustion and process-related emissions. Most combustion-related CO_2 emissions result from clinker production, and specifically the fuel used for pyro-processing. As mentioned above, fuel requirements, and subsequently carbon dioxide emissions depend partially on whether a wet process or dry process for clinker making is used, as well as the carbon intensity of the fuel inputs. Worrell and Galitsky estimate that the CO_2 intensity of the wet process averages 249 kgC/st, compared to 224.2 kgC/st for the dry process[16]. Combustion-related CO_2 emissions from cement production have increased 17 % between 1994 and 2001. It should be noted that these estimates include only CO_2. As mentioned above, various types of waste fuels are increasingly used as fuel sources. When waste fuels are combusted, methane (CH_4) and nitrous oxide (N_20), two GHGs more potent than CO_2, may also be emitted. However, due to the extremely high temperatures achieved in the kilns and the high combustion efficiency, these emissions may be minimal. Although non-CO_2 gases were not considered in this study, this could be an area for future work.

Process-related emissions from cement manufacture are created through a chemical reaction that converts limestone to calcium oxide and CO_2. The quantity of process-related emissions from cement production are proportional to the lime content of the clinker; therefore, emissions are calculated by applying an emissions factor in tons of CO_2 released per ton of clinker produced. This emissions factor does not account for the fact that some clinker precursor materials remain in the kiln in the form of cement kiln dust (CKD). The United States follows the recommendation of the IPCC that emissions from CKD are equal to 2% of total process-related CO_2 emissions.

CO_2 emissions from cement manufacture differ depending on the specific type of cement produced. In the United States, masonry cement accounts for approximately 4-5% of total production; the remainder is Portland cement. While the addition of gypsum for producing Portland cement does not result in additional CO_2 emissions, the addition of lime to produce masonry cement does result in additional emissions. These emissions are not included in the cement manufacturing sector of the Inventory; rather, they are included as part of the lime manufacturing sector, in accordance with the IPCC Guidelines. Table 1 illustrates total CO_2 emissions from cement manufacturing in the United States over the past 8 years. The table also illustrates the breakdown between combustion- and process-related emissions. For each ton of cement produced, approximately 54% of total emissions are process-related and 46% are combustion-related.

Table 1. Historical Trends in Combustion- and Process-related CO_2 Emissions from U.S. Cement Manufacturing ($MMTCO_2$)

	1994	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*
Combustion-related CO_2	30.6	31.3	31.6	32.1	32.9	36.1	36.5	35.5
Process-related CO_2 (incl. CKD)	36.1	36.8	37.1	38.3	39.2	40.0	41.2	41.4
Total CO_2	66.7	68.1	68.7	70.4	72.1	76.1	77.7	76.9

Source: Minerals Yearbook, Vol. 1, Metals and Minerals, 2002. U.S. Geological Survey. U.S. Department of the Interior. July 2003.
Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002. U.S. Environmental Protection Agency. February 2004.
ICF communications with Hendrick van Oss, USGS, 15 April 2004.

The information presented thus far provided an overall view of the U.S. cement industry. The remainder of this paper will take a more disaggregated look at the U.S. cement industry.

PROFILE OF THE U.S. CEMENT INDUSTRY

As discussed above, due to the nature of the IPCC Guidelines, as well as the way industrial sector emissions are estimated in the United States, process-related emissions have been more fully characterized than combustion-related emissions. This study attempted to develop a facility-level database for all clinker kilns and cement-grinding facilities in the United States, primarily using non-proprietary data available from the Portland Cement Association (PCA) and the Major Industrial Plant Database (MIPD), with the goal of analyzing both combustion and process-related emissions on a facility level.

Methodology

This paper presents the results of the preliminary analysis of CO_2 emissions from facility-level data. Total facility-level emissions were calculated as the sum of combustion- and process-related emissions, as well as emissions resulting from CKD. Process emissions and emissions from CKD were calculated in accordance with the IPCC Guidelines, based on clinker production data. Combustion-related emissions were estimated based on facility-level production data, with facility-level production estimated as the product of that facility's clinker or cement production capacity[17] and capacity utilization factors[18,19]. While capacity-level data are available on the facility-level, average capacity utilization rates were available at the state, and sometimes regional, level.

Production estimates were translated into combustion-related emissions based on average carbon dioxide intensity values available from Worrell and Galitsky for different process steps of the wet and dry cement manufacturing process[20]. The illustrations of geographic and trend data in the remainder of this paper are based upon these estimates.

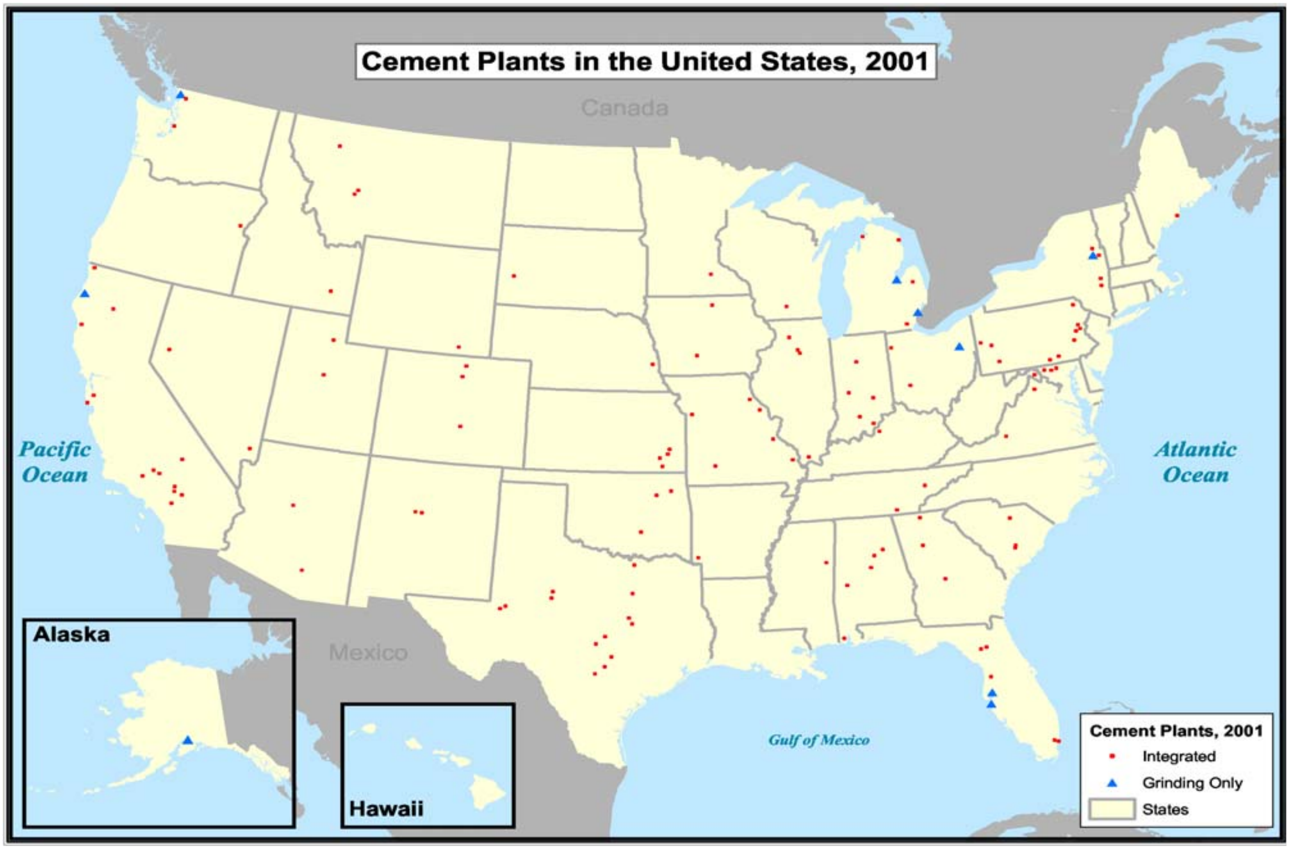
It is important to note that because of the methodology used in the subsequent analysis, the sum of state level data presented below may not equal the national level data presented above. The CO_2 estimates presented above were based on national level fuel consumption data. Ideally, facility level emissions estimates would be derived from facility-specific fuel consumption statistics and an appropriate emissions factor. Under these circumstances, the bottom-up and top-down analysis should produce the same emissions estimate. Data on fuel consumption at the facility level, however, are typically confidential.

As a first step to better characterizing the U.S. industry, we have estimated facility level emissions based on facility-specific capacity information and a national average emissions factor. A distinct emissions factor has been used for wet and dry facilities. Future analyses will attempt to refine these emissions estimates based on facility-specific fuel consumption. Trying to ascertain facility-specific fuel consumption will necessarily involve making assumptions, as many of the underlying data are confidential. The Energy Information Administration collects similar facility-level data for the Manufacturer's Energy Consumption Survey, however these data are confidential, with only aggregated results provided for public use.

Cement and Clinker Production

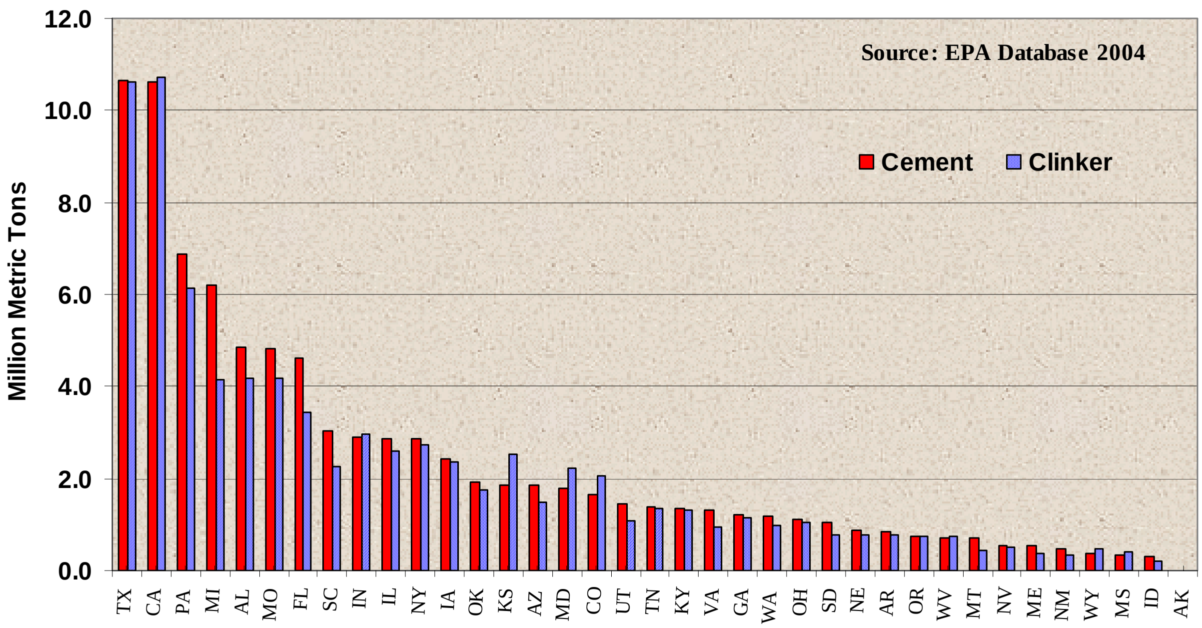
Cement industry operations in the United States are distributed across a majority of states. The widely distributed nature of the cement industry reflects two primary factors: the wide distribution of the primary raw material input of limestone, as well as the relatively high costs associated with the transport of high-density cement. In terms of cement manufacturing facilities, the database compiled by the U.S. Environmental Protection Agency (EPA) identified 130 unique production facilities located across 37 states. Figure 4 illustrates the relative distribution of these production facilities in the United States. The states with the highest number of production facilities, including integrated plants (plants that both produce clinker and grind cement) and grinding-only operations are, in decreasing order, California, Texas, Pennsylvania, Florida, Michigan, Missouri and Alabama. The majority of plants in the United States are integrated facilities, only 9 plants are grinding-only facilities.

Figure 4. Distribution of Cement Plants in the United States, 2001



States with the largest number of production facilities are typically also among those with the highest production capacities and actual production levels of clinker and cement. The states with the largest total production of cement are, in decreasing order, Texas, California, Pennsylvania, Michigan, Alabama, Missouri and Florida (Figure 5).

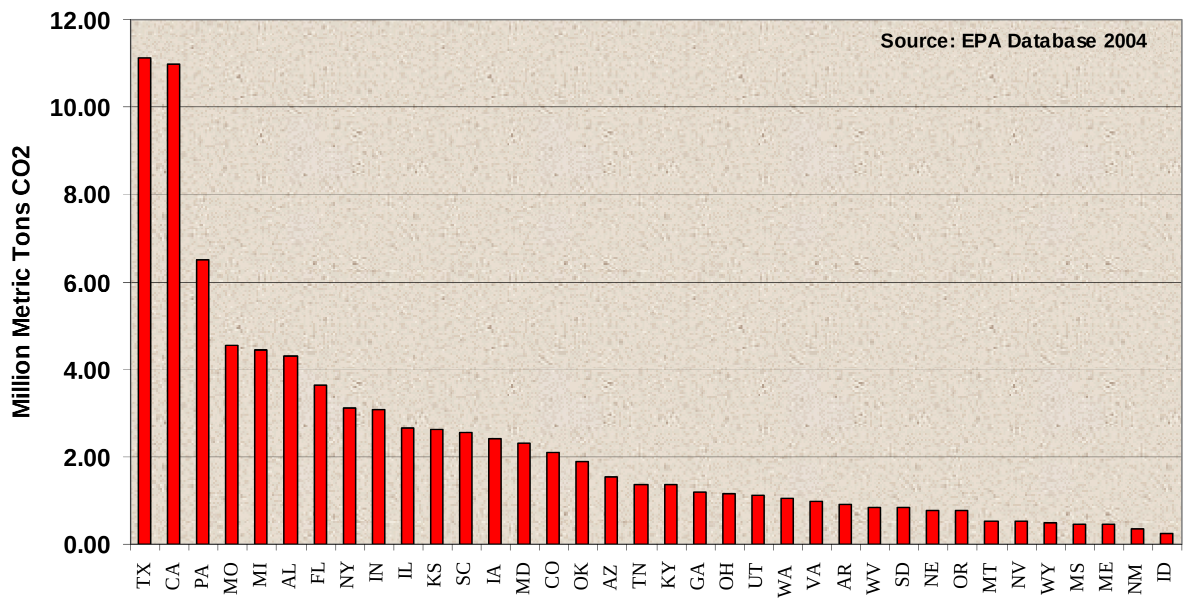
Figure 5. Estimated Annual Production, by State, 2001



State-level Greenhouse Gas Emissions

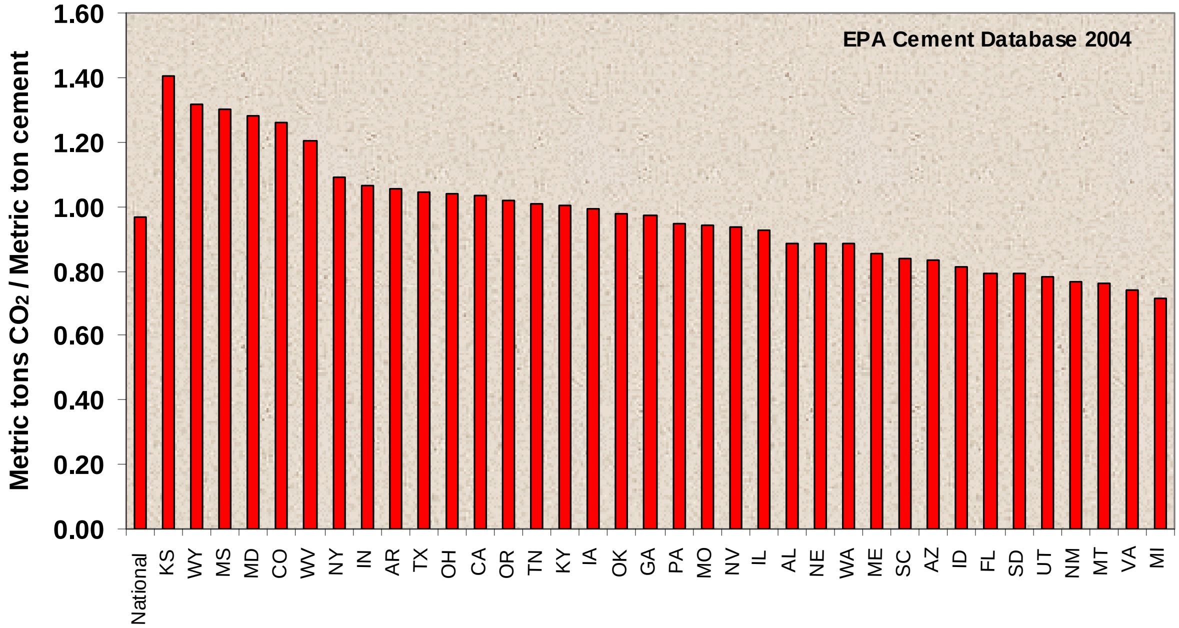
As might be expected, trends for state-level CO_2 emissions from cement manufacturing closely mirror the trends for state level production (Figure 6). Some of this may be an artifact of the methodology used to estimate facility-level CO_2 emissions (i.e., based on production and capacity utilization). This outcome may differ somewhat if the actual fuel consumption for each facility were used as opposed to a national average emissions factors for cement grinding, and wet and dry kilns. However, examining the Major Industrial Plant Database, which includes information on 101 facilities, it appears as though the various states consume a similar mix of fuels for cement manufacturing. With that said, the relative percentage of coal consumed for cement production, according to the MIPD, is less in some of those states designated as the top sources of CO_2, including Texas, California, Alabama and Florida.

Figure 6. Cement Industry Carbon Dioxide Emissions, 2001



Carbon dioxide intensity is presented as metric tons of CO_2 emitted per metric ton of cement produced. The range of intensities illustrated in Figure 6 primarily results from the relative share of wet versus dry facilities and the share of clinker versus grinding-only facilities. States with a relatively higher percentage of wet facilities and clinker kilns will have a higher intensity than states with only grinding facilities. The national weighted average carbon intensity for cement production was estimated at 0.97 ton CO_2/ton cement in 2001 (Figure 7). Kansas was the most carbon intensive producer of cement at 1.41 tons/ton, partially reflecting the fact that all cement plants are integrated facilities and the wet process is used at two facilities. Michigan's relatively low carbon intensity of 0.72 tons/ton partially reflects the fact that a number of facilities in Michigan are "grinding only" facilities, which have a comparatively lower carbon intensity than integrated facilities.

Figure 7. Cement Industry Carbon Dioxide Intensity, 2001



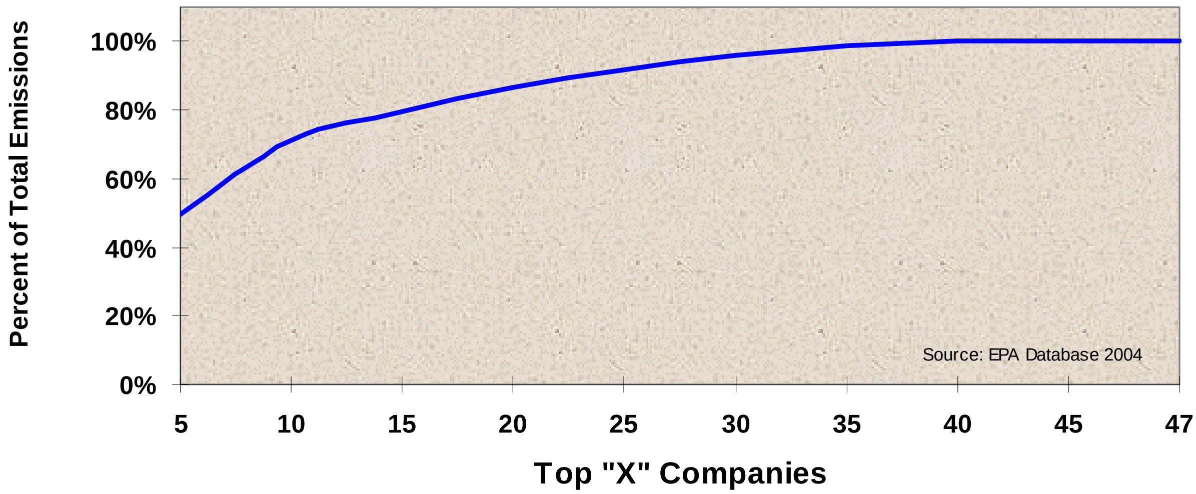
As mentioned above, it is a challenge to attribute carbon emissions, or carbon dioxide intensity, to a particular plant or a particular state due to the confidentiality of energy consumption data. The Portland Cement Association provides information on the primary fuel(s) consumed by various facilities, however, without knowing the exact percentage of each fuel consumed it is difficult to attribute carbon emissions to the facility level. The MIPD does provide some facility-specific fuel consumption data. The appropriateness of this database for estimating facility-specific carbon emissions will be investigated in future work.

Industry Concentration

The cement industry is becoming increasingly concentrated, with a few multinational cement companies assuming ownership of increasing shares of cement manufacturing plants. In 2001, five companies (54 facilities) produced approximately half of all domestic cement, while ten companies (78 facilities) were collectively responsible for more than three-quarters of all production. According to the USGS, if entities with the same parent company are combined under the larger parent company, and if joint ventures are apportioned, the top ten cement companies in 2001, in decreasing order were; Lafarge North America, Inc; Holcim (US) Inc.; CEMEX, S.A. de C.V.; Lehigh Cement Co.; Ash Grove Cement Co.; Essroc Cement Corp.; Lone Star Industries Inc.; RC Cement Co.; Texas Industries Inc. (TXI); and California Portland Cement Co[21].

A similar trend is exhibited for CO_2 emissions. According to preliminary estimates, five companies were responsible for roughly 50% of CO_2 emissions from the U.S. cement industry, whereas the top ten companies were responsible for nearly 70% of emissions.

Figure 8. Company Concentration of CO_2 Emissions



NEXT STEPS AND CONCLUSIONS

This analysis was a first step in examining the U.S. cement industry at a more disaggregated level than is achieved through the Inventory process. Currently, process-related emissions are estimated on the national level, while combustion-related emissions are not separately estimated, rather they are accounted for in the national estimate of CO_2 emissions from fossil fuel combustion.

This work was based on the use of a national average emissions factor for wet processing facilities and a separate national average emissions factor for dry processing facilities. This first step provides a clearer understanding of the concentration of emissions sources throughout the United States, as well as the relative carbon intensity of different regions of the country. Although a clearer picture of the industry has been developed, use of a national average emissions factor could "level the playing field". While the relative mix of fuels used for cement production may be similar throughout the country, the mix is not necessarily the same. An average emissions factor may introduce bias, particularly at the facility level. Further, it is difficult to identify and attribute emissions to the wide variety of solid waste materials used in kilns.

Future work will determine the availability of facility-specific fuel data. As mentioned above, there are a number of challenges with obtaining these data, most significantly perhaps, the fact that these data are typically confidential. Nevertheless, there are some sources available that contain facility-specific fuel data. These databases will be investigated further to determine the comprehensiveness, consistency, and accuracy of that data. If these data are deemed suitable the estimates presented in this study could be refined.

Cement is a key industry in the United States and globally, from both an economic and an environmental perspective. Although the cement industry is a relatively significant industrial source of CO_2 emissions there are a number of opportunities to achieve emissions reductions, including:

- Conversion from the wet process to the dry process,
- Substitution of lower carbon content fuels for coal, coke and petroleum coke,

- Testing different blends of cement, whereby clinker is replaced by various additives, and
- Capture and storage of CO_2 from the flue gases

All of these options require further analysis to determine feasibility, costs, environmental impacts, and the overall effect of the activity on the quality of cement produced. Use of waste fuels in particular, may have environmental effects that should be addressed. The availability of a profile of the U.S. cement industry, in addition to the benefits outlined throughout this paper, can serve as the foundation for such an analysis.

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