Efficiency Opportunities for the U.S. Cement Industry

Nathan Martin, Lawrence Berkeley National Laboratory
Ernst Worrell, Lawrence Berkeley National Laboratory
Lynn Price, Lawrence Berkeley National Laboratory

ABSTRACT

This paper reports on an in-depth analysis of the U.S. cement industry, identifying cost-effective energy efficiency measures and potentials. Between 1970 and 1997, primary physical energy intensity for cement production dropped 30%, from 7.9 GJ/t to 5.6 GJ/t[1], while specific carbon dioxide emissions due to fuel consumption and clinker calcination dropped 17%, from 0.29 tC/tonne to 0.24 tC/tonne. We examined 30 energy-efficient technologies and measures and estimated energy savings, carbon dioxide savings, and costs for each of the measures. We constructed an energy conservation supply curve for the U.S. cement industry which found a total cost-effective energy savings of 11% of 1994 energy use for cement making and a savings of 5% of total 1994 carbon dioxide emissions. Assuming the increased production of blended cement, the cost-effective potential would increase to 18% of total energy use, and carbon dioxide emissions would be reduced by 16%. This demonstrates that use of blended cements is a key cost-effective strategy for energy efficiency improvement and carbon dioxide emission reductions in the U.S. cement industry.

Introduction and Methodology

The production of cement is an energy-intensive process that results in the emission of carbon dioxide from both the consumption of fuels (primarily for the kiln) and from the calcination of limestone. We analyze the cement industry at the aggregate level (Standard Industrial Classification 324), which includes establishments engaged in manufacturing hydraulic cements, including portland, natural, masonry, and pozzolana cements.

Our analysis consists of three steps. First, we establish a 1994 baseline for energy and material use, using data from the last year for which detailed national energy statistics are available (EIA 1997; van Oss 1995). We then characterize energy-efficient technologies and determine the potential application and impact of these measures. We focus on retrofit measures using commercially available technologies. Finally, we assess the cost-effectiveness of the potential for energy efficiency improvement, using an energy conservation supply curve[2].

We subdivided energy use for each of the processes into the raw material preparation, clinker making and finish grinding (or cement making)[3]. Energy consumption data are based on data from the Portland Cement Association, United States Geological Survey and the

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[1] We use metric units throughout this paper. Note that 1 GJ = 0.95 Mbtu and 1 Metric Tonne (Mt) = 1.102 short tons.

[2] A detailed analysis of the technologies and measures can be found in (Martin et al. 1999) at http://eetd.lbl.gov/EAP/IEUA/Pubs.html.

[3] Throughout this paper, primary energy is calculated using a conversion rate from final to primary electricity of 3.08 (equivalent to a power generation efficiency of 32.5%), including transmission & distribution losses. Energy is expressed in higher heating value (HHV), as is common in U.S. energy statistics.

Manufacturing Energy Consumption Survey (EIA 1997; Portland Cement Association 1996; van Oss 1995). When data on specific sub-processes were not available, consumption estimates were based on process energy intensity estimates from available literature. CO_2 emissions from calcination are included in the emissions estimate.

For each technology or measure, we estimate costs and energy savings per tonne of cement produced in 1994. We then calculate carbon dioxide emissions reductions based on the fuels used at the process step to which the technology or measure is applied. Fuel and electricity savings for each efficiency measure were usually calculated as savings per tonne product. To convert savings from a per tonne product basis to a per tonne cement basis we multiplied the savings by the ratio of throughput (production from a specific process) to total cement. Operating and capital costs are also calculated on a cement basis according to the same methodology as fuel and electricity savings. Carbon dioxide emissions reductions for each measure were calculated based on a weighted average carbon dioxide emissions coefficient for each process step.

We then apply a conservation supply curves methodology to rank energy efficiency measures by their "cost of conserved energy" (CCE). The CCE accounts for both the costs associated with implementing and maintaining a particular technology or measure and the energy savings associated with that option over its lifetime. For our analysis, we used a 30% real discount rate, reflecting the cement industry's hurdle rate, and an industry average weighted fuel cost based on energy data provided by the Portland Cement Association, U.S. Geological Survey, and cost data from EIA (EIA 1997).

The CCEs are plotted in ascending order to create a conservation supply curve. This curve is a snapshot of the total annualized cost of investment for all of the efficiency measures being considered at that point in time. The advantage of using a conservation supply curve is that it provides a clear, easy-to-understand framework for summarizing complex information about energy efficiency technologies, their costs, and the potential for energy savings. There may, however, be additional energy efficiency measures or technologies that do not get included in an analysis, so savings may be underestimated. The costs of efficiency improvements (initial investment costs plus operation and maintenance costs) do not include all the transaction costs related to an efficiency investment, and there may be additional investment barriers as well that are not accounted for in the analysis. We therefore also include in our cost effectiveness analysis internal rate of return and simple payback for additional comparison.

Description of Cement Making Process

The U.S. cement industry is made up of clinker plants, which produce clinker, cement plants that grind clinker obtained elsewhere, or a combination of the two, an integrated plant. The production process consists of three main steps: raw material mining and preparation, clinker production, and finish grinding

Raw Material Mining and Preparation

The most common raw materials used for cement production are limestone, chalk and clay (Greer et al. 1992). The most common raw material, limestone or chalk, is generally extracted from a quarry near the plant. The collected raw materials are selected, crushed, ground, to obtain the desired fineness and composition.

Raw material preparation is an electricity-intensive production step. The grinding of raw material differs with the pyro-processing process used. In dry processing the materials are ground into a flowable powder in ball mills or in roller mills, and may be further dried from waste heat from the kiln exhaust before pyro-processing. The moisture content in the (dried) feed of the dry kiln is typically around 0.5% (0 - 0.7%). In the wet process raw materials are ground with the addition of water in a ball mill to produce a slurry typically containing 36% water (range of 24-48%).

Clinker Production (Pyro-Processing)

Clinker production is the most energy-intensive stage in cement production, accounting for over 90% of total energy use. Clinker is produced by pyro-processing in large kilns. These kiln systems evaporate the free water in the meal, calcine the carbonate constituents (calcination), and form portland cement minerals (clinkerization). The kiln type used in the U.S. is the large capacity rotary kiln. In these kilns a tube with a diameter up to 8 meters is installed at a 3-4 degree angle that rotates 1-3 times per minute. The ground raw material, fed into the top of the kiln, moves down the tube toward the flame. In the sintering (or clinkering) zone, the combustion gas reaches a temperature of 1800-2000°C.

In a wet rotary kiln, the water is first evaporated in the kiln in the low temperature zone. The evaporation step makes a long kiln necessary. Fuel use in a wet kiln can vary between 5.3 and 7.1 GJ/t clinker depending on the moisture content of the raw meal (Cowiconsult 1992; Van de Vleuten 1994).

In a dry kiln, feed material with much lower moisture content (0.5%) is used, thereby reducing the need for evaporation and reducing kiln length. The first development of the dry process took place in the U.S. and was a long dry kiln without preheating, or with one stage suspension preheating. Later developments have added multi-stage suspension preheaters (i.e. a cyclone) or shaft preheater. Additionally, pre-calciner technology was more recently developed in which a second combustion chamber has been added to a conventional pre-heater that allows for further reduction of kiln energy requirements. The typical fuel consumption of a dry kiln with 4/5-stage preheating can vary between 3.2 and 3.5 GJ/t clinker (Cowiconsult 1992) The most efficient pre-heater, pre-calciner kilns use approximately 2.9 GJ/t clinker (Anonymous, 1994, Steuch and Riley 1993; Somani and Kothari 1997; Su L-H TPI Polene 1997). Kiln dust (KD) bypass systems may be required in kilns in order to remove alkalis, sulfates, and chlorides. Such systems lead to additional energy losses since you are removing the sensible heat from the dust.

Once the clinker is formed it is cooled rapidly in order to ensure the maximum yield of alite (tricalcium silicate), an important component for the hardening properties of cement. The main cooling technologies are either the grate cooler or the tube or planetary cooler. The cooling air is used as combustion air for the kiln.

Finish Grinding

After cooling, the clinker is stored. To produce powdered cement, the nodules of cement clinker are ground. Grinding of cement clinker, together with additives (3-5%) to control the properties of the cement (gypsum and anhydrite) can be done in ball mills, roller mills, or roller presses (Alsop and Post 1995). Combinations of these milling techniques are often applied. Coarse material is separated in a classifier to be returned for additional grinding.

Electricity use for raw meal and finish grinding depends strongly on the hardness of the material (limestone, clinker, pozzolan extenders) and the desired fineness of the cement as well as the amount of additives. Traditionally, ball or tube mills are used in finish grinding, while many plants use vertical roller mills. Modern ball mills may use between 32 and 37 kWh/t (Cembureau, 1997; Seebach et al. 1996) for cements with a Blaine of 3,500.

Finished cement is stored, tested and filled into bags, or shipped in bulk. Additional power is consumed for conveyor belts and packing of cement.

Overview of U.S. Cement Industry: Production Trends and Energy Use

Portland and Masonry cements are the chief types produced in the United States. More than 90% of the cement produced in the U.S. in 1997 was portland cement, while masonry cement accounted for 4.4% of U.S. cement output in 1997 (van Oss 1997).

There were 119 operating cement plants in the U.S. in 1997, spread across 37 states and in Puerto Rico, owned by 42 companies. In that year Portland cement was produced at 118 plants in 1997, while clinker was produced at 108 plants. Clinker kiln capacity varies between 75 and 1550 kilotonnes per year (Research Triangle Institute, 1996; van Oss 1998). Production rates per plant vary between 0.5 and 3.1 million metric tons (Mt) per year. Total production of U.S. cement plants in 1997 was slightly over 82.5 Mt (van Oss 1998).

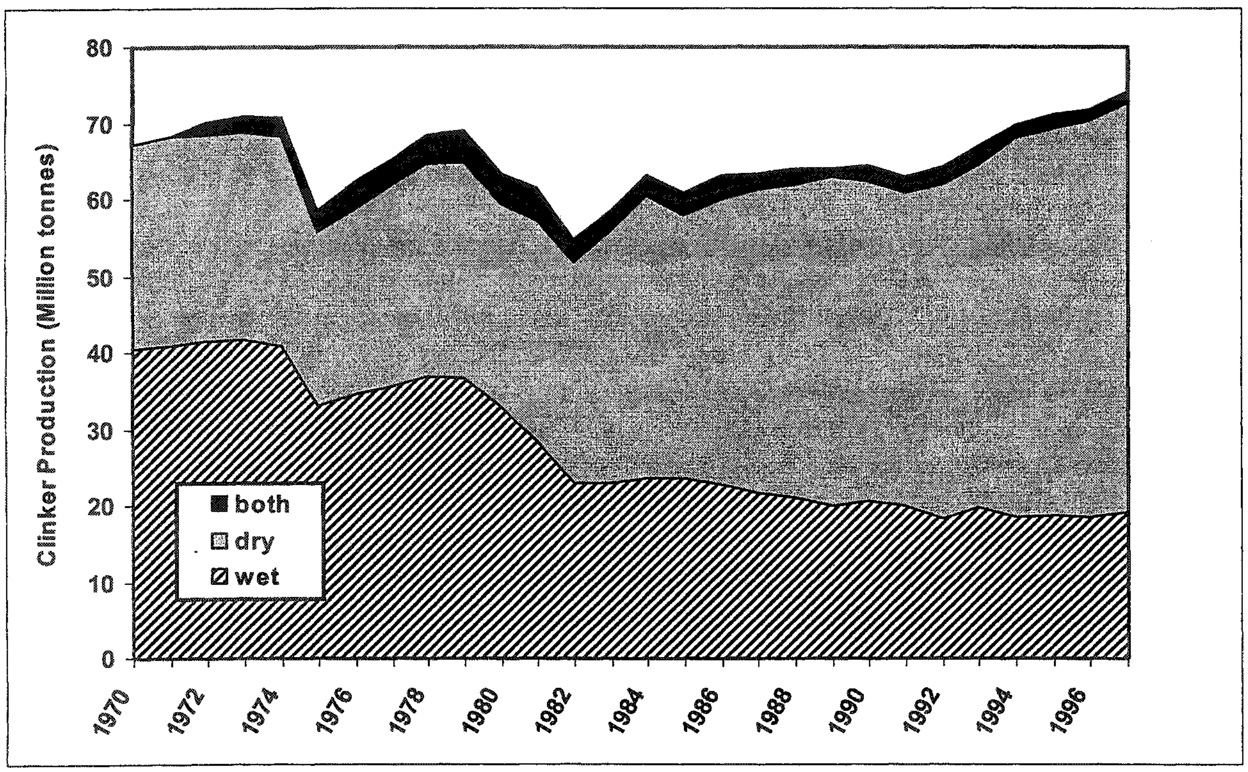

Figure 1. U.S. Clinker Production by Process, 1970-1997 (million Mt/year)

Figure 1 depicts historical clinker production in the industry between 1970 and 1997 by process type. As the figure indicates clinker produced with the wet process decreased at an average of –2.7% per year, falling from a 60% share of total clinker production in 1970 to a 26% share in 1997. During this same period cement production, increased at 0.7% per year rising from 69 Mt in 1970 to 84 Mt in 1997, at a rate slightly faster than clinker production due to increased use of additives and changes in clinker imports.

Although cement production increased between 1970 and 1997, primary energy consumption decreased at an average of –0.6% per year, from 550 PJ in 1970 to 470 PJ in 1997. During this period primary energy intensity, energy requirements per unit of cement produced, decreased at an average rate of –1.3% per year, from 7.9 GJ/t in 1970 to 5.6 GJ/t in 1997. Among the processes, the intensity of the dry process decreased at a rate of 1.0% per year, compared to 0.5% per year decline in the wet process. The intensity decreases were due to increased capacity of the more energy efficient dry process for clinkermaking, energy efficiency improvements and reduced clinker production per ton of cement produced (see figure 2).

Carbon dioxide emissions from fuel consumption in the cement industry decreased from 11.0 MtC in 1970 to 10.2 MtC in 1997, while emissions from clinker calcination increased from 9.3 MtC in 1970 to 10.2 MtC in 1997[4]. Total carbon dioxide emissions per

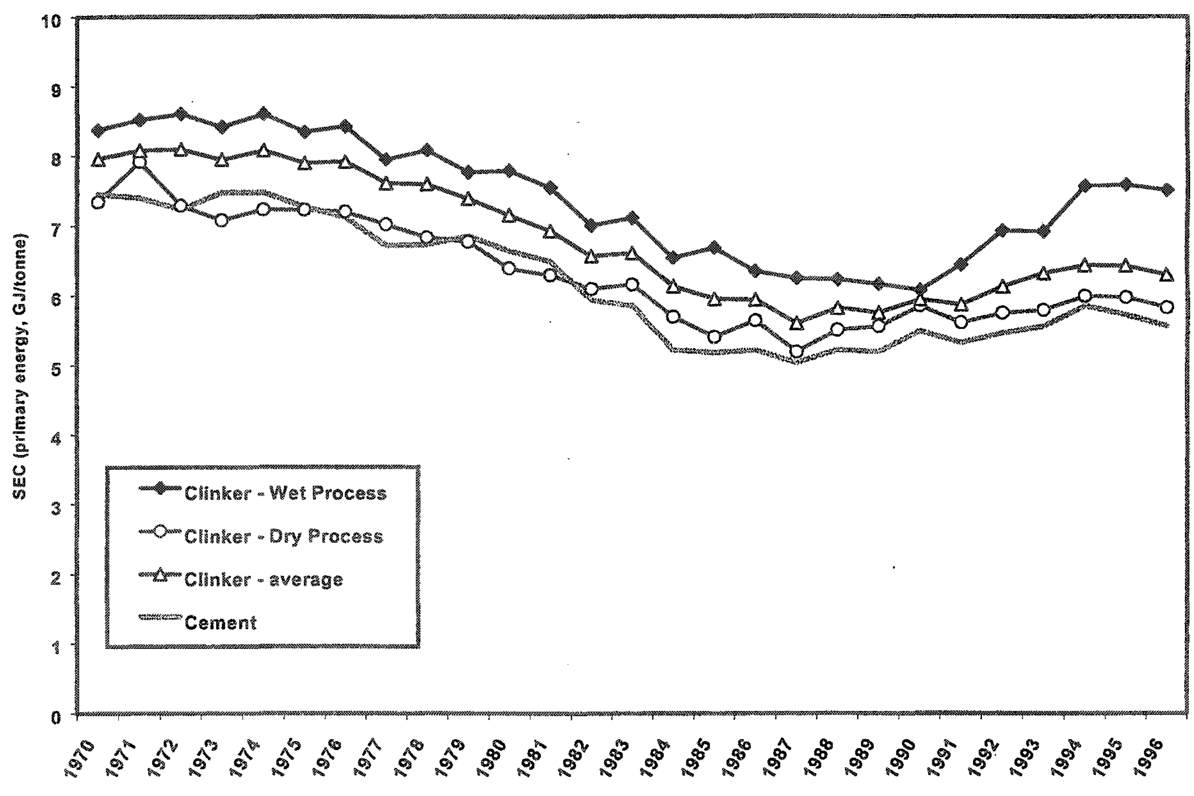

Figure 2. Primary Energy Intensity of US Cement, Clinker Production 1970-1997 (GJ/t)

[4] Carbon dioxide emissions are expressed in metric tons carbon. The carbon conversion factors used for calculating carbon emissions from energy consumption are taken from the Energy Information Administration and IPCC (EIA 1996; UNEP et al. 1996).

tonne cement decreased at 0.7% per year, on average, from 290 kg C/t cement in 1970 to 240 kg C/t cement in 1997. Overall, fuel mix trends were more than offset by energy intensity reductions, leading to an overall decrease in specific carbon dioxide emissions.

1994 Baseline Energy Use and Carbon Dioxide Emissions

In 1994, the U.S. cement industry consumed 366 PJ of final energy (about 2% of total U.S. manufacturing energy use) and emitted 19 MtC of carbon dioxide (about 4% of total U.S. manufacturing carbon emissions). Table 1 provides our estimate of 1994 U.S. baseline energy consumption by process.

In the calcination process we assume that 0.14 tonnes of carbon are emitted for every tonne of clinker produced (UNEP et al. 1996). We rely on the U.S. Energy Information Administration for 1994 carbon coefficients for the various commercial fuels, except we use the Intergovernmental Panel on Climate Change for coke and breeze (EIA 1997; UNEP et al. 1996). For electricity we use the 1994 average fuel mix for electricity generation in the U.S. The total 1994 carbon dioxide emission is estimated at 18.9 MtC, of which 9.5 due to the calcination process based on a production of 98.5 Mt of clinker in that year (Van Oss 1995).

Table 1. 1994 Energy Consumption and Carbon Dioxide emissions in the U.S. Cement Industry

Process Stage	Fuel (PJ)	Elec. (PJ)	Primary Energy (PJ)	Fuel SEC (GJ/t)	Elec. SEC (kWh/t)	Primary SEC (GJ/t)	Carbon Dioxide Emissions Energy Use (MtC)	Carbon Dioxide Emissions Calcination (MtC)
Wet Process								
Kiln Feed Preparation [a]	0	4	11	0.0	29	0.3	0.2	0.0
Clinker Production [b]	117	2	124	6.0	30	6.3	2.9	2.7
Finish Grinding [c]	0	4	13	0.0	57	0.6	0.2	0.0
Total Wet Process	*117*	*10*	*148*	*5.5*	*133*	*7.0*	*3.2*	*2.7*
Dry Process								
Kiln Feed Preparation [a]	0	11	33	0.0	34	0.4	0.5	0.0
Clinker Production [b]	211	6	230	4.3	35	4.7	5.3	6.8
Finish Grinding [c]	0	11	34	0.0	57	0.6	0.5	0.0
Total Dry Process	*211*	*28*	*296*	*4.0*	*145*	*5.6*	*6.2*	*6.8*
Total All Cement	328	38	444	4.4	142	6.0	9.5	9.5

Notes:

a) Raw Materials: In 1994, 123 Mt of raw materials were used in the cement industry (Van Oss 1995). We assume that 29% of raw materials were for the wet process kilns and 71% of raw materials were used for dry process kilns. Additionally we assume an electricity use of 29 kWh/t raw material preparation for wet kilns and 34 kWh/t for dry kilns due to the additional processing (Jaccard and Willis 1993; COWIconsult 1992).

b) Clinker Production: According to (Van Oss 1995), wet process clinker production was 18.6 Mt while dry process production was 49.3 Mt. Accounting for production from plants with both wet and dry processes on site, we estimate a total clinker production of 68.5 Mt in that year. We assume an average U.S. wet kiln fuel intensity in 1994 of 6.0 GJ/t clinker and an average dry kiln fuel intensity of 4.3 GJ/t (Holderbank consulting 1993; Jaccard and Willis 1993; Portland Cement Association 1996; Van Oss 1995). Electricity requirements of 30 kWh/t are assumed for fuel preparation and for operating the kiln, fans, and coolers for wet kilns and 35 kWh/t for dry kilns (COWIconsult 1992).

c) Finish Grinding: We assume that the amount of throughput for finish grinding is the same as the total amount of cement produced in 1994, 21.2 Mt for wet cement and 53.1 Mt for dry cement (Van Oss 1995). We estimate average energy requirements for finish grinding to be 57 kWh/t (52 kWh/short ton) (COWIconsult 1992).

Energy Efficiency Technologies and Measures for the U.S. Cement Industry

Table 2. Energy Savings, Costs, and CO_2 Emissions Reductions for Energy Efficient Technologies

Option	Production (Mtonne)	Fuel Savings (GJ/tonne)	Electricity Savings (GJ/tonne)	Primary Energy Savings (GJ/tonne)	Annual Operating Costs (US$/tonne)	Retrofit Capital Cost (US$/tonne)	Carbon Dioxide Emissions Reductions (kgC/t cement)	Share of Production Measure Applied (percent)
Raw Materials Preparation (wet process)								
Mechanical Transport Systems	34.9	0.0	0.01	0.02	0.00	3.00	0.53	46%
Raw Materials Preparation (dry process)								
Mechanical Transport System	87.6	0.00	0.01	0.02	0.00	3.00	0.53	19%
Raw Meal Blending System	87.6	0.00	0.01	0.01	0.00	3.70	0.26	20%
High Efficiency Roller Mills	87.6	0.00	0.03	0.08	0.00	5.30	1.85	72%
High Efficiency Classifiers	87.6	0.00	0.01	0.03	-0.07	2.00	0.71	70%
Clinker Production (wet process)								
Kiln Combustion Systems	19.5	0.20	0.00	0.24	0.00	0.98	10.30	5%
Kiln Shell Heat Loss Reduction	19.5	0.15	0.00	0.15	0.00	0.25	6.44	46%
Use of Waste Fuels	19.5	0.60	0.00	0.60	0.00	1.00	25.76	20%
Conversion to Grate Cooler	19.5	0.30	-0.01	0.30	0.10	0.40	13.74	6%
Conversion to Semi-Wet Process	19.5	1.26	-0.01	1.21	0.14	1.80	53.31	10%
Optimize Heat Recovery (Grate Cooler)	19.5	0.10	0.00	0.10	0.00	0.20	4.29	73%
Conversion to Precalciner Kiln	19.5	2.80	-0.04	2.69	-0.90	75.00	118.67	43%
Clinker Production (dry process)								
Kiln Combustion Systems	49.0	0.20	0.00	0.17	0.00	0.98	8.80	6%
Kiln Shell Heat Loss Reduction	49.0	0.20	0.00	0.15	0.00	0.25	7.67	17%
Use of Waste Fuels	49.0	0.60	0.00	0.60	0.00	1.00	30.70	8%
Conversion to Grate Cooler	49.0	0.30	-0.01	0.30	0.10	0.50	16.37	6%
Low Pressure-Drop Cyclones	49.0	0.00	0.01	0.04	0.00	3.10	0.74	31%
Heat Recovery for Power Generation	49.0	0.00	0.07	0.22	0.30	1.80	3.68	4%
Conversion to Multi-Stage Preheating	49.0	0.90	0.00	0.90	0.00	20.00	46.05	15%
Conversion to Pre-Calciner Kiln	49.0	0.40	0.00	0.40	-1.10	10.00	20.46	21%
Conversion to PH/PC-Kiln	49.0	1.30	0.00	1.30	0.00	28.00	66.51	8%
Optimize Heat Recovery (Grate Cooler)	49.0	0.10	0.00	0.10	0.00	0.20	5.12	65%
Finish Grinding								
Improved Grinding Media	74.3	0.00	0.01	0.02	0.00	0.70	0.32	25%
High-Pressure Roller Press	74.3	0.00	0.03	0.09	-0.20	2.50	1.28	19%
Roller Press/Horomill	74.3	0.00	0.10	0.30	-1.00	4.00	4.33	22%
High Efficiency Classifiers	74.3	0.00	0.01	0.03	-0.60	2.50	0.48	40%
General Measures								
Variable Speed Drives	74.3	0.00	0.03	0.10	0.00	0.95	1.68	24%
High-Efficiency Motors	74.3	0.00	0.02	0.06	0.00	0.20	0.93	50%
Process Control Systems	74.3	0.18	0.02	0.22	0.00	1.60	9.91	49%
Preventative Maintenance	74.3	0.05	0.01	0.08	0.02	0.01	2.94	100%
Product Changes								
Blended Cement	74.3	1.53	-0.05	1.36	0.00	0.70	76.31	29%
Higher Alkali Allowance	74.3	Only included in clinker production for blended cement (see blended cement)						
Reduced Fineness for Selected Uses	74.3	Not included in analysis, due to lack of available data on specific uses and markets for cement and concrete						

Table 2 above lists the energy efficiency technologies and measures that we consider in our analysis, their energy savings, costs, and share of production to which the measure is applied. The energy savings are expressed per tonne of product. To estimate savings per tonne of cement in the U.S. multiply the savings per tonne product with production of the specific product and the share to which the measure is applied. The applied share is an estimate of the potential capacity to which the measure can be applied as share of the production (second column) of the specific product. A complete technical description of all measures is outside the scope of this paper and the reader is referred to (Martin et al 1999) for further details on technical information. (Martin et al 1999) also provides information on some advanced technologies and measures not specifically included in the analysis.

The Importance of Blended Cements

The production of blended cements involves the intergrinding of clinker with one or more additives (fly ash, pozzolans, blast furnace slag, silica fume, volcanic ash) in various proportions. The use of blended cements is a particularly attractive efficiency option since the intergrinding of clinker with other additives not only allows for a reduction in the energy used (and carbon emissions) in clinker production, but also corresponds to a reduction in carbon dioxide emissions in calcination as well. Blended cements are very common in Europe, and blast furnace and pozzolanic cements account for about 12% of total cement production with portland composite cement accounting for an additional 44%. In the U.S., some of the most prevalent blending materials are fly ash and blast furnace slag.

A recent analysis of the U.S. situation cited an existing potential of producing 31 Mt of blended cement in 2000 using both fly ash and blast furnace slag, or 36% of U.S. capacity (Portland Cement Association, 1997). This analysis was based on estimates of the availability of intergrinding materials of feasible market penetration.

The blended cement produced would have, on average, a clinker/cement ratio of 65% and would result in a reduction in clinker production of 9.3 Mt. The reduction in clinker production corresponds to a specific fuel savings of 1.4 GJ/t after accounting for the counteracting effects of increased fuel use for drying blast furnace slags and decreased energy requirements due to reduced bypass of kiln exit gases (Alsop and Post 1995). The bypass savings are due to the fact that blended cements offer an additional advantage in that the interground materials also lower alkali-silica reactivity (ASR) thereby allowing a reduction in energy consumption needed to remove the high alkali content kiln dusts.

While blended cements is technically feasible, additional policy and legislative efforts are needed to realize this potential in the U.S. market, especially changes in product standards that would encourage the use of blended cements in its various end-use markets.

Energy Efficiency and CO_2 Emission Reduction Potential in the Cement Industry

Our analysis of the potential for energy efficiency improvement and CO_2 emission reduction is based on two scenarios. The first scenario assumes that there will be no changes in product standards (Scenario A) that would encourage blended cements, while the second scenario assumes that product standards will be changed, to allow the production of blended cement, as is common in most countries outside the U.S (Scenario B). This is a departure from the 1994 mix of raw materials and products, as less clinker will be needed to produce the same quantity of cement.

For scenario A we identified *cost-effective energy savings of 48 PJ and carbon emissions reductions of 1.0 MtC for cement making in 1994 which represents 11% of total U.S. cement industry's energy use and 5.4% of the total carbon emissions* (including calcination). The technical potential which includes measures whose cost of conserved energy is higher than the average weighted fuel price is much higher, 180 PJ, or 40% of primary energy use. Figure 3 ranks the energy efficiency measures in a conservation supply curve; the cost-effective measures are those which fall below the average weighted energy supply cost for 1994, and are therefore cost effective at 1994 energy prices using a discount rate of 30%. Table 3 provides a list of the measures ranked by their cost of conserved energy, internal rate of return, and their simple payback periods.

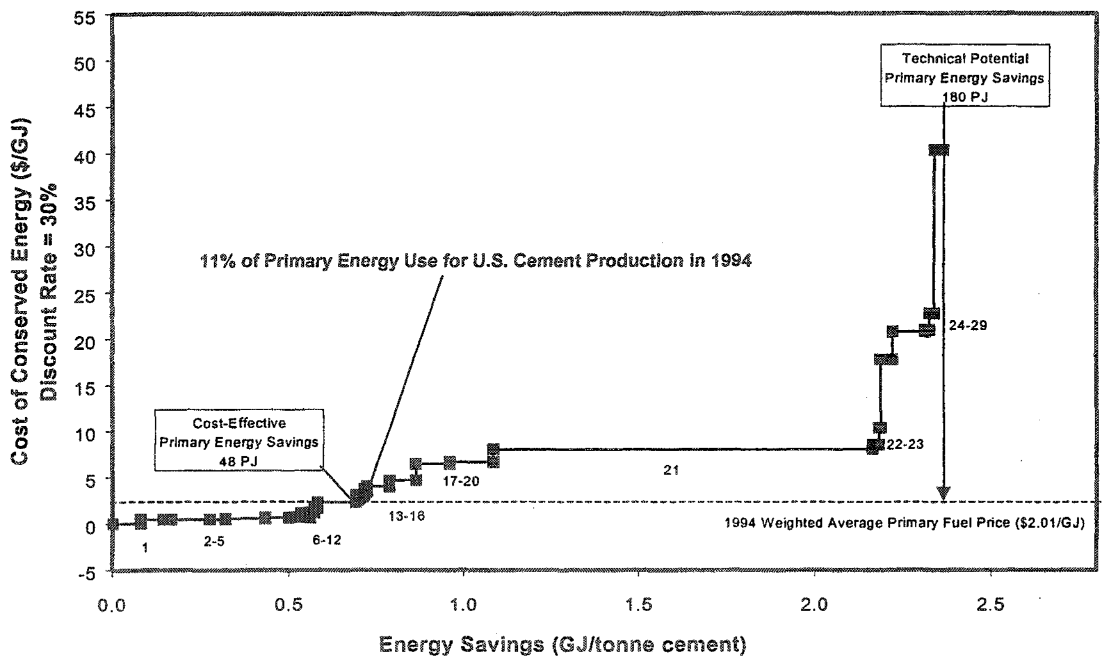

Figure 3. Energy Conservation Supply Curve for Energy Efficiency Measures in the U.S. Cement Industry (measures exclude the production of nlended cement-scenario A)

Many countries in the world produce blended cement that can reduce the energy intensity of cement considerably. Producing blended cements may have synergetic effects, as it can help to replace the most energy intensive kilns in a given region (depending on transport distances of resources, limestone reserves, and other conditions). In our analysis of scenario B, we assess the role of clinker replacement by cementious additives. We assume that the use of additives will reduce the total amount of clinker produced, maintaining the cement production level of 1994. The switch to the production of blended cement, replacing 15% of 1994 clinker production, does not significantly affect the technical potential for energy efficiency improvement. However, the *cost-effective potential increases from 11% to 18%.* The effects on carbon dioxide emissions are more profound, due to the reduced clinker production, which in turn reduces emissions from energy use and limestone calcination. *The total technical potential for carbon dioxide emissions is almost 5.3 MtC (or 28%)* and the cost-effective potential is estimated at 3.1 MtC (or 16%).

Table 3. Energy Efficiency Improvement Measures in the U.S. Cement Industry Ranked by the Cost of Conserved Energy (simple payback period and internal rate of return also given)

	Energy Efficiency Measure	Primary Energy Savings	Carbon Dioxide Emission Reduction	CCE Primary Energy	Internal rate of Return	Simple Payback Period
		(GJ/tonne)	(ktC)	($/GJ-saved)	(%)	(years)
1	Preventative maintenance	0.08	219	0.04	1254%	0.1
2	Kiln heat loss reduction (w)	0.06	58	0.50	107%	0.9
3	Kiln heat loss reduction (d)	0.02	62	0.50	107%	0.9
4	Use of waste fuels (w)	0.11	101	0.50	107%	0.9
5	Use of waste fuels (d)	0.04	120	0.50	107%	0.9
6	Conversion to semi-wet kiln	0.11	104	0.56	114%	0.9
7	Clinker cooler grate (w)	0.07	62	0.68	6%	1.3
8	Clinker cooler grate (d)	0.06	163	0.68	79%	1.3
9	Conversion to grate cooler (w)	0.02	16	0.76	102%	1.0
10	Conversion to grate cooler (d)	0.02	48	0.76	101%	1.0
11	High efficiency motors	0.03	35	1.17	33%	2.8
12	Kiln combustion system (w)	0.01	11	1.23	44%	2.3
13	Kiln combustion system (d)	0.01	25	1.72	31%	3.2
14	Process control system	0.11	361	2.32	20%	4.3
15	Variable speed drives	0.02	30	3.08	6%	7.3
16	Cogeneration (steam)	0.01	7	3.72	N/A	> 25
17	Roller press/Horomill	0.06	69	4.03	7%	10.3
18	Precalciner on preheater kiln	0.08	210	4.69	18%	5.4
19	Conversion to preheater kiln	0.10	261	6.46	8%	12.1
20	Conversion to precalciner kiln	0.12	338	6.67	8%	12.5
21	Wet to precalciner kiln conversion	1.08	1009	8.03	7%	13.0
22	Pre-grinding- HP roller mill	0.02	19	8.51	N/A	21.7
23	Improved grinding media	0.01	6	10.35	N/A	24.6
24	High efficiency classifiers (d)	0.03	44	17.77	N/A	18.8
25	High efficiency roller mill	0.09	117	20.74	N/A	> 25
26	Low pressured drop cyclones	0.01	11	20.94	N/A	> 25
27	High efficiency classifiers (w)	0.01	14	22.69	N/A	>25
28	Mechanical transport systems (d)	0.01	9	40.32	N/A	> 25
29	Mechanical transport systems (w)	0.02	9	40.32	N/A	> 25

Note: (d): applies to dry process kilns; (w): applies to wet process kilns. Also, the internal rate of return and simple payback period may vary by plant depending on local conditions.

For scenario B, we have assumed that both dry and wet process cement plants are taken out of production in equal shares. In practice, the introduction of blended cement may curb the production of the less efficient kilns, and may impact energy use more. Ready-mix producers are among the largest users of cement in the U.S. Ready-mix producers already use fly-ash in the production of concrete. Although ready-mix producers use additives, the intergrinding of additives at the cement plant may have additional benefits over use at the ready-mix producer. The use of additives at the cement plant may not affect the concrete production process, but additional research is needed to assess the potential impact and net impact on energy intensity for concrete-making.

We used 1994 as our analysis base year because that was the latest year for which energy data was available at a suitable aggregation level from the Department of Energy's Energy Information Administration. There have not been any dramatic changes in the industry since then, although a regular update of this study may be needed.

Conclusions

In this analysis we examined 30 energy-efficient technologies and measures and estimated energy savings, carbon dioxide savings, investment costs, and operation and maintenance costs for each of the measures. Based on the results of our technology assessment we constructed an energy conservation supply curve for U.S. cement industry which found a total cost-effective reduction of 0.6 GJ/tonne of cement, consisting of measures having a simple payback period of 3 years or less. This is equivalent to potential energy savings of 11% of 1994 energy use for cement making and a savings of 5% of total 1994 carbon dioxide emissions by the U.S. cement industry.

Assuming the increased production of blended cement in the U.S., as is common in many parts of the world, the the cost-effective potential would increase to 1.1 GJ/t cement or 18% of total energy use, and carbon dioxide emissions would be reduced by 16% due to the reduced clinker production. This demonstrates that use of blended cement is a key cost-effective strategy for energy efficiency improvement and carbon dioxide emission reductions in the U.S. cement industry. We believe that additional periodic technology assessment would be useful to continue to provide up to date assessments of the potential for this sector.

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