Title
INVENTORY OF ENERGY CONSERVATION POTENTIAL IN CALIFORNIA: THE CEMENT INDUSTRY

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Peter Kuhn, Kathleen Hudson, Carl Blumstein, and Carl York

April 1979
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Inventory of Energy Conservation Potential in California:
The Cement Industry

April 1979

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NOTE TO READERS

This is the first in a series of reports on energy conservation potential in California's manufacturing sector. The series is intended to provide a starting point for a complete inventory of energy conservation in California. The inventory's purpose is to assist the California Energy Commission (CEC) in establishing a system for organizing and analyzing information on energy conservation opportunities. This information is needed by the CEC to plan its conservation programs efficiently and to forecast the effect of all conservation activities, including CEC programs, on future energy requirements.

The reports we are preparing are largely intended to demonstrate the system for compiling the complete inventory. Drawing on existing literature as well as primary data collected by us and our colleagues at the CEC, these reports will provide estimates of energy conservation potential as well as information on the technical aspects, economic costs, and environmental considerations related to individual energy conservation measures. While a complete inventory covering the manufacturing sector, let alone the entire State's economy, is beyond the resources of this project, the reports we do prepare will be useful in: a) providing a model for the inventory system, and b) increasing the scope and coherence of the CEC's information on energy conservation potential.

We have taken two different approaches to estimating conservation potential in California's manufacturing sector. One approach is to consider equipment, such as boilers, that is used in many different manufacturing industries as part of their "systems" for the production of goods. The other approach focuses on systems, such as the cement industry, that involve many different types of equipment. This report provides an example of the latter approach; a planned report on boilers and other steam supply equipment will provide an example of the former approach.

The two approaches are necessary to achieve the project's goal of providing information on the full range of energy conservation potentials in California. The equipment-oriented approach yields the most detailed information on possible increases in the efficiency of specific energy-using devices, the costs of the improvements, and other pertinent considerations. The system-oriented approach,
on the other hand, can consider the effects of substitutions among devices, choice of feedstocks, cogeneration, and other measures that cannot be covered by the equipment-oriented approach.

In a more practical sense, the two approaches are made necessary by the limitations of available information. Information on the energy-using characteristics of some industries is too sketchy to permit them to be properly treated with the system-oriented approach; conservation potential for part of their energy use can be analyzed by the equipment-oriented approach. The opposite case is even more prevalent. Data on stocks of many types of equipment in California, including electric motors and pumps, is presently so inadequate that no estimate of energy conservation potential can be produced by the equipment-oriented approach. By considering the equipment as part of systems, however, conservation measures for the equipment can be evaluated in the context of the applications of that equipment in a particular system. A part of the conservation potential in electric motors, for example, would be captured in a study of the chemical industry, a major user of electric motors for pumps and fan drives.

The format of the inventory has been chosen to make it as useful as possible to planners. Each case study within the inventory will be organized into three levels of increasing detail. The first level is the overview data sheet, a report which summarizes information on conservation potential in the equipment or system, presents relevant data on equipment stocks and energy consumption, and briefly describes how the conservation potential could be achieved. The second level consists of individual data sheets on particular conservation measures that describe them in greater detail and show how savings can be calculated (where data permits) or estimated (where assumptions are necessary). The third level of detail is provided by sourcebooks that contain fairly comprehensive collections of literature on the subject. This report on the cement industry provides an example of an overview data sheet.

Within each overview or individual data sheet, the information has been organized into a format that makes it easier to find the different types of information (saving potentials, costs, technical descriptions, environmental effects, etc.) included in the inventory. Underlined headings divide each data sheet into the following sections:
• **Introduction/Summary** - identifies key issues and states most important conclusions.

• **Description of equipment of system** - describes the basic types and their uses and presents data on the stocks of the equipment or systems and on fuel and electricity consumption. This information provides a background for the discussion of energy conservation measures.

• **Energy savings opportunities** - describes conservation measures and their costs and gives estimates of potential fuel, electrical demand savings. The overview data sheet gives the estimate of total potential savings from all measures.

• **Calculation of savings** (individual data sheets only) - describes methods and assumptions for estimating or calculating potential savings from application of a measure.

• **Other considerations** - includes, as appropriate, estimates of potential overlaps between energy-saving measures, environmental effects of conservation, and second law analyses.

• **Information needs** - evaluates the completeness and reliability of available information and indicates where more information is most needed.

• **Technical notes** - presents actual calculations of savings potential and other relevant quantities.

• **References** - lists references referred to by number within the body of the data sheet.

The material on the following pages was compiled by the first author. The other project participants provided assistance in the study design and in reviewing and editing earlier drafts of the study. In addition to the project participants, the study was reviewed by Stanton Smith of LBL, by Prof. David Dornfeld of UC Berkeley, and by Hoke Garrett and James Murray of Kaiser Engineers. Their helpful comments are gratefully acknowledged. Most of the information on California's cement plants was obtained by telephone interviews and visits with plant managers and engineers. Special thanks are due to Paul Deutschmann, Rick Berby, and Gus Klemm (Kaiser Cement); Ron Evans (California Portland Cement Co.); Dave Maars and Satish Sheth (Lone Star Industries); Harry Banfield (General Portland); Don Holt (Monolith); W.W. Smith (Riverside Cement); Tom Meredith (Calaveras Cement); and John Goetz (Southwestern Portland). We also wish to
thank Cynthia Helmich, Bob McAver, and Steve Powlesland of the CEC for their support of and participation in the work of the inventory project.

Since we hope periodically to revise and update the material in this report, comments from readers regarding the information herein or its organization will be greatly appreciated.
Introduction/Summary

California's cement industry is a major energy consumer. In 1976 it consumed nearly 9 percent (44 trillion Btu) of the fuel and 3 percent (one billion kWh) of the electricity purchased by all California manufacturers (Ref. 16). Among manufacturing industries coded at the Standard Industrial Classification (SIC) three-digit level, only petroleum refining (SIC 291) surpassed hydraulic cement manufacture (SIC 324) in total energy consumption. Energy is a very significant factor in the cost of cement. Fuel (1976 average: 5.3 million Btu/ton) and purchased electricity (1976 average: 124 kWh/ton) can account for a third to a half of total production costs.

There are a number of opportunities for significant energy conservation in the cement industry. First, energy efficiency can be improved by modifying existing equipment (primarily to improve heat transfer) and by changing the procedures involved in materials preparation. Second, existing equipment can be replaced by new equipment incorporating the latest advances in energy-saving technology. Third, new types of equipment are now being developed which promise further dramatic improvements in energy efficiency. In addition to these changes in the methods of cement production, there appears to be some potential for cogeneration of electricity using waste heat, although there are significant technical and economic problems.

Because energy is such a major cost factor, California's cement manufacturers are very aware of energy conservation. Although there is still some potential to be realized by modifying existing equipment and improving operations, most plants have made efforts in these areas and many have realized significant savings. More importantly, a number of the companies have committed themselves to plans for replacement or expansion of their plants using efficient equipment. If these plans are carried through, average fuel consumption for cement production will be reduced to 4.4 million Btu/ton (see Tech. Note 1). The trend toward more efficient equipment is firmly established and it seems very likely that average consumption will fall below 3.8 million Btu/ton within the next twenty years.

Presently available energy-efficient technology does have somewhat higher electricity requirements. However, increased use of cogeneration can reduce the amount of purchased electricity required. One plant has been cogenerating since
1954; at least two other plants have plans to install cogenerating equipment. If these plans are carried through, average purchased electricity will be reduced to 115 kWh by 1982 in spite of the addition of equipment that is more electricity intensive (see Tech. Note 2). If the full technical potential of cogeneration can be realized, average purchased electricity requirements could fall to about 50 kWh/ton (see Tech. Note 3).

The most important factors that will affect the industry's progress in energy conservation are capital availability and air pollution control requirements. It is not at all certain that the growth of the cement market, which fluctuates with construction activity, will be sufficient to attract the capital necessary for installations of more energy efficient equipment planned for the next few years. These installations would add 20 percent more cement production capacity to the state and cost around $400 million. The current shortage of capacity is a major impetus for the plans, but the industry may reappraise its plans in light of its history of cyclic shortages and surpluses of capacity. More stringent air pollution regulations would favor installation of the more efficient equipment, which also tends to have lower emissions, but at the same time they could divert funds away from the installation plans as well as from energy-saving modifications of existing equipment. Further improvements in air pollution control at existing plants will be costly and will raise electricity requirements. Installations of the more efficient equipment will ease the industry's worst air pollution problems, particulates and nitrogen oxides, because this equipment has much lower emissions.

As the discussion above suggests, a cement plant's decision on whether or not to undertake an energy-conserving measure may be largely unrelated to energy considerations. Many of the plans for installation of new, more energy-efficient equipment, for example, appear to be motivated by the need to expand production capacity rather than by a need to cut fuel costs, as evidenced by indications that the equipment to be replaced is among the most fuel-efficient in the state (see fuel consumption rates in Tech. Note 1). Also, some equipment modifications that will result in reduced electricity consumption are being undertaken to increase plant reliability and improve quality control.

These observations can be placed in perspective by noting the place of energy conservation measures in the following overall objectives of cement plant management:
minimize the total cost of producing each ton of cement
maintain production to meet demand
meet air pollution regulations
meet product quality specifications concerning the chemical composition, setting time, and strength of the finished cement.

Energy conservation measures can directly contribute to the achievement of the cost-minimization objective, provided of course that the increase in capital and labor costs required for the measures are not greater than the reduction in fuel and electricity costs they provide. The indirect effects on the other objectives, however, can be equally or more important. Energy conservation measures can affect production rate through their effect, beneficial or adverse, on plant production capacity and reliability. Some measures save energy by increasing production relative to energy loss; others, such as cogeneration, can reduce reliability by adding another potential source of failure to the plant. Air pollution regulations are of especial concern in the planning of plant expansions; a new system that is only marginally justified on cost considerations may be chosen if it is the only way of meeting the regulations. Finally, product quality specifications are of great concern in considering energy conservation measures. Most plants have difficulty in meeting specification on chemical composition of the cement, especially those which limit the concentration of alkali (sodium and potassium). Some modifications to existing equipment which would increase fuel economy may be rejected because they would also increase alkali entrapment in the product.

The cement industry is rapidly switching to less costly, higher sulfur content fuels, which can usually be burned without violating air pollution regulations because about 80 percent of the sulfur is retained in the product. As a result of the priority system, natural gas is no longer burned as a primary fuel except in the manufacture of white (masonry) cement, a minor product. About half the state's capacity uses coal as its primary fuel, 40 percent uses residual oil, and 9 percent uses petroleum coke. Gas is still burned as an alternate fuel, but consumption is falling.
Description of the California Cement Plants and Cement Manufacture

There are twelve cement plants in California. They produce essentially the same product; there are minor variations in the specifications for chemical composition, strength, and setting time for the different types of cement, but one type of cement accounts for the bulk of production at all of the plants. Their combined production capacity is the highest of any state in the United States, as is cement consumption in California. Because of the relatively low value-to-weight ratio of cement, which now sells for a little over $40/ton, the plants usually serve a regional market. Figure 1 shows the locations of the plants in California; most of the plants are located in Southern California and they constitute the bulk of the production capacity. Capacity is usually measured by maximum production rate of cement clinker, an intermediate product that accounts for about 95 percent of the weight of the finished cement. This maximum is almost never achieved because of necessary downtime for maintenance and repairs. The most important part of the production process, also the site of almost all the fuel consumption, is the thermal processing, or "burning," of ground raw materials to form clinker, which is done in huge rotary kilns. The kiln operation must be continuous to prevent wastage and ensure product quality; the size of the rotating kilns places them among the largest, if not the largest moving equipment used in manufacturing. All of the plants follow the same basic steps in production (with minor variations in process and equipment that will be mentioned by plant name): quarrying of raw materials, grinding, burning in the kiln, and grinding the clinker with added gypsum to make finished cement. The technical aspects of these steps and the equipment used to accomplish them are very important to the consideration of energy-saving opportunities in the following section.

Figure 2 shows the basic steps of cement manufacture. Limestone rock (CaCO₃), which constitutes about 85 percent of the raw material, is quarried near the plant, crushed, and conveyed to storage. Additional raw materials are clay or shale, which may also be mined on-site or else purchased, and sand and iron ore to adjust the chemical composition of the raw material blend to the precise values required for different types of cement. The raw materials are ground in ball mills (shown in Fig. 2) in all the state's plants. The two
Fig. 1. Locations of Cement Plants in California

Source: Ref. 7, p. 4-51.
FIG. 2 Steps in the manufacture of portland cement.

1 Stone is first reduced to 5-in. size, then ¾-in., and stored.

2 Raw materials are ground to powder and blended, or

2 Raw materials are ground, mixed with water to form slurry, and blended.

3 Burning changes raw mix chemically into cement clinker.

4 Clinker with gypsum is ground into portland cement and shipped.

Source: Portland Cement Association (Ref. 3 p.23)
basic types of processes are shown in Fig. 2: the wet process, used by 46 percent of the state's production capacity, and the dry process. The difference is that water is added before grinding in the wet process and the slurry that is produced can be pumped around the plant and blended in storage basins. More precise control of blending and simplified equipment has been the main advantage of the wet process (Ref. 4). Ref. 1 notes that the wet process is mandatory for very wet raw materials,* but that does not appear to be a factor in California.

Dry process grinding includes drying when the raw materials contain moisture (note hot air furnace in illustration). The powder that is produced by the raw mills is conveyed by pneumatic pumps which force the powder into a blast of compressed air. Compressed air is also used to agitate the powder for mixing and blending in silos. Also note the dust collector (cyclone and baghouse) on the dry process mills. Because there is no water to aid in grinding in the dry process, and also because of additional electricity use in the dry process' air separators and dust collectors, electricity requirements are higher than in the wet process. The difference in raw grinding energy ranges from ten to twenty percent depending on the raw materials (some clays will disperse in water without grinding) and the equipment used. A "semi-dry" process (not shown in Figure 1) is used in one California plant. In this process, the raw materials are ground to a dry powder, as in the dry process, but then about 15 percent water is added so that the powder can be "pelletized." The pellets are dried and partially calcined with exhaust gases on a grate preceding the kiln.

The kiln is the heart of the manufacturing operation and consumes all but a tiny fraction of the fuel used in the plant. It is a brick-lined steel tube, usually over ten feet in diameter and hundreds of feet long. The end which receives the feed is slightly raised and the tube is rotated by electric motors. This causes the raw materials to travel down its length, sliding over and over to continually expose fresh surface to the flame and hot gases are drawn up the kiln by a huge fan. In effect, the kiln is a counter current heat exchanger, the arrangement that produces most efficient heat exchange. As the ground raw materials travel down the kiln, they are first dehydrated, which requires only 212°F for free moisture but over 900°F for water combined

*According to Hoke Garrett of Kaiser Engineers, the development of dry process systems for very wet raw materials has rendered this statement invalid.
in clay. The next step is decarbonization or calcining of the limestone, which requires the feed to be heated to about 1650°F and liberates about one-third of the feed's weight in carbon dioxide gas. Calcining is the major energy-consuming step of the operation if the wet process is not being used. After calcining, the oxides which remain in the feed are further heated to about 2700°F and partially fused into glassy nodules which are called clinker. Clinkering, which actually releases heat, takes place in the flame region of the kiln. The flame is about thirty feet long and its temperature is about 3700°F. In the coal-and-coke-burning plants, fuel is crushed, ground to a fine powder, and blown through the burner. Power for the equipment to accomplish this accounts for between 5 and 10 kWh/ton of clinker produced. Residual oil-fired plants heat the oil to about 250°F and atomize it in the burner using mechanical, steam, or air pressure. As the clinker moves further down, it is slightly cooled by in-rushing combustion air and then falls into the clinker cooler.

In all of the California plants, the cooler is a moving grate; the clinker forms a downward-moving bed through which air is blown upwards by fans. The cooler is in effect a heat exchanger returning part of the clinker's heat in air for combustion, especially in the dry process which requires less fuel and thus less air per ton of clinker produced. The excess air must be vented, wasting heat and requiring some electricity for particulate control. Figure 3 shows the three types of kiln systems in use in California--wet process, dry process and "semi-dry" process or grate pre-heater.

The kiln and cooler generate most of the dust that always accompanies cement manufacture. Particulate control on the California plants is provided by cyclones, gravel beds, and baghouses or precipitators. The exhaust of dry process kilns is very hot because of the absence of drying; temperatures can range from 1000°F to 1200°F.* Baghouses and precipitators generally require a much cooler gas stream temperature; the use of water sprays or air quenching increases the total gas volume and the power required by the fans. Cogeneration with waste heat boilers inserted between the kiln and the baghouse or precipitator is, of course, an alternative--which has been practiced at the Oro Grande plant since 1954. Dust emissions from the cooler at the Oro Grande plant have been completely eliminated by the installation of a heat exchanger.

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*Note this is not true of the newer kiln systems with suspension preheaters.
Figure 3: Kiln systems used in California (Source: Ref. 3)

WET PROCESS KILN SYSTEM

LONG DRY PROCESS KILN SYSTEM

GRATE PREHEATER KILN SYSTEM
to cool the excess air, which is then recirculated back to the cooler (Ref. 15). The device does not save fuel and actually increases electricity consumption, however, since the heat is not recuperated and the fan power requirements are higher than those of a baghouse dust collector. With present technology, particulate control accounts for 5 to 15 kWh per ton of clinker. The dust is usually returned to the kiln unless it is desirable to discard it to reduce the alkali content in the finished cement; alkaline compounds evaporate in the flame region and condense as the gas cools. Even if all the dust in the kiln exhaust is returned, the loss of heat can be substantial (Ref. 1).

After cooling, the clinker is conveyed to storage and from there to the finish grinding operation. Finish grinding accounts for the largest fraction of electricity consumption, about 40 percent of the total. Almost all of the cement produced is portland cement, 95 percent clinker plus 5 percent gypsum (CaSO₄) added to retard setting time. The clinker and gypsum must be ground to an extremely fine power, i.e., high surface area-to-weight ratio, to insure that the hydration responsible for the setting of the cement (and the strength of the concrete) will be complete. The ball mills used are essentially larger, higher-power versions of the ones used for dry-process raw grinding. After finish grinding, the cement is stored in silos and then shipped in bulk (now the largest fraction) or in bags.

Truck shipment accounts for the largest fraction in the U.S. Trucks require more fuel than rail cars (estimated at 1000-1500 Btu per ton-mile as compared to 225-600 Btu per ton-mile (Ref. 21)). However, rail shipment often necessitates truck shipment for a considerable portion of the distance because rails do not always serve the consumer. In these cases, the total fuel consumption in the rail and truck shipment, together with electricity consumption for transferring cement between railroad cars and trucks, can make rail shipment less desirable from an energy standpoint.

Figure 4 shows the breakdown of average U.S. energy consumption into pyroprocessing--fuel used in the kiln--and the various uses of electricity (valued at the average primary energy requirement of about 11,000 Btu per kWh) as well as the breakdown of average U.S. electricity consumption in wet and dry process plants. Table 1 gives the fuel and electricity consumption and clinker production figures for California in 1976.
Figure 4: Breakdown of U.S. average energy consumption in cement manufacture.

Note: electricity is valued in the above diagram at approximately 11,000 BtU/kWh.

Source: Portland Cement Association (Ref. 3 p. 163)
Table 1
Fuel and Electricity Consumption in California Cement Plants - 1976

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity (a)</th>
<th>Btu x 10^{12} (c)</th>
<th>Btu/ton of clinker (d)</th>
<th>kWh/ton of clinker (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>546,000 ST(b)</td>
<td>14.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residual Oil</td>
<td>2,400,000 bbl</td>
<td>15.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas</td>
<td>10.4 BLF</td>
<td>10.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Petroleum Coke</td>
<td>83,500 ST</td>
<td>2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distillate Oil</td>
<td>300,000 bbl(b)</td>
<td>1.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Purchased Fuel</td>
<td></td>
<td>44.0</td>
<td>5.57 x 10^6</td>
<td></td>
</tr>
<tr>
<td>Purchased Electricity</td>
<td>1.03 gWh</td>
<td>10.3</td>
<td></td>
<td>130.1</td>
</tr>
<tr>
<td>Purchased Fuel and Electricity</td>
<td></td>
<td>54.3</td>
<td>6.88 x 10^6</td>
<td></td>
</tr>
</tbody>
</table>

(a) From the Annual Survey of Manufacturers 1976 (Ref. 16).

(b) Coal and distillate consumption were not disclosed in the reference. The reference does disclose total fuel energy consumed, total expenditures on fuel, and average prices and energy content of all fuels. This information, together with the quantities of residual oil, natural gas, and coke consumed makes it possible to estimate coal and distillate using equations for the content of purchased fuels and expenditures on purchased fuels (i.e., two equations in two unknowns).

(c) Conversion factors are coal 26,194 MM Btu/ST, Coke 25,993 MM Btu/ST, residual 6,285 MM Btu/bbl, distillate 5.824 MM Btu/bbl, natural gas 1,024 Btu/SCF, electricity 10,000 Btu/kWh.

(d) Based on cement clinker production of 7,892,000 ST in 1976 as reported in the U.S. Bureau of Mines, 1976 Minerals Yearbook.
Table 2 lists the capacities, processes (wet, dry, or semi-dry) primary fuels, and other information on the plants. Note that over half the state's production capacity is in kilns which were installed over twenty years ago.

**Energy-Saving Opportunities**

Three categories of energy-saving measures will be discussed: 1) those which can reduce fuel and electricity consumption and control electric load at utility peak times in existing plants; 2) cogeneration in existing and new plants; and 3) new kiln and grinding systems. Energy and peak demand savings potentials have not been estimated for the first category of measures because their applicability, cost, and savings potential is critically dependent on the raw materials and equipment used by each plant. The plants which indicated they have undertaken the measures or plan to do so will be listed, and the technical problems which other plants face will be discussed. The full potential of cogeneration cannot be firmly established at this time because a new generation of technologies are just being commercialized and the technical aspects and economics of trading off heat recuperation for generation of electricity with waste heat have not been fully explored. In Technical Note 3, it is estimated that cogeneration could potentially supply over 60 percent of total electricity requirements, reducing purchased electricity requirements to about 50 kWh/ton of cement. The effect on the utilities' peak load would depend on the factors just mentioned as well as the possible coincidence of cogeneration system failures with utility peak loads. The potential energy savings from new kiln and grinding systems are apparent from a comparison of their energy consumption, as low as 3.2 million Btu's and 135 kWh per ton of clinker produced, with the current state average of 5.6 million Btu's and 130 kWh. In Technical Notes 1 and 2, it is estimated that the effect of currently-planned kiln, grinding, and cogeneration systems would be to reduce the state's average fuel and purchased electricity consumption to 4.7 million Btu's and 121 kWh per ton of clinker by 1982. The assumptions used in these estimates deserve careful examination. With further adoption of new kiln and grinding systems, it is very probable that average fuel consumption in the state could fall below 4 million Btu's per ton of clinker, or 3.8 million Btu's per ton of cement.
Table 2
Cement Plants in California (1979)

<table>
<thead>
<tr>
<th>Name/Owner</th>
<th>Capacity (10^6 t/yr. clinker)</th>
<th>Process</th>
<th># of Kilns</th>
<th>Date Built</th>
<th>Primary Fuel</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>COLTON/ California Portland Cement</td>
<td>850^a</td>
<td>DRY</td>
<td>2</td>
<td>1961</td>
<td>Coal w/oil back-up</td>
<td>Company-owned coal mines</td>
</tr>
<tr>
<td>DAVENPORT/ Lone Star Industries</td>
<td>360^b</td>
<td>SEMI-DRY</td>
<td>3</td>
<td>2 kilns built around 1940; one built 1950^c</td>
<td>Residual oil (average 1.7% S)</td>
<td>4.5 x 10^6 Btu and 150 kWh per ton clinker</td>
</tr>
<tr>
<td>LEBEC/ General Portland</td>
<td>567^a</td>
<td>DRY</td>
<td>1</td>
<td>1967</td>
<td>Petroleum coke w/oil or gas ignitor</td>
<td></td>
</tr>
<tr>
<td>LUCERNE VALLEY/ Kaiser Cement</td>
<td>1,105^a</td>
<td>WET</td>
<td>3</td>
<td>2 kilns built 1956; 1 built 1963</td>
<td>Residual oil</td>
<td></td>
</tr>
<tr>
<td>MOJAVE/ California Portland Cement</td>
<td>1,100^a</td>
<td>DRY</td>
<td>5</td>
<td>1955</td>
<td>Coal w/oil back-up</td>
<td>Company-owned coal mines</td>
</tr>
<tr>
<td>MONOLITH/ Monolith Portland Cement</td>
<td>700^a</td>
<td>WET</td>
<td>1</td>
<td>1974</td>
<td>Coke/coal blend</td>
<td></td>
</tr>
<tr>
<td>ORO GRANDE/ Riverside Cement</td>
<td>1,147^a</td>
<td>DRY</td>
<td>7, 5 with waste heat-boilers; also two fuel-fired boilers</td>
<td>5 in 1948 - 1952; 2 in 1960</td>
<td>Coal</td>
<td>Waste heat boilers installed 1954; generates 16 MWe</td>
</tr>
<tr>
<td>PERMANENTE/ Kaiser Cement</td>
<td>1,600^b</td>
<td>WET</td>
<td>6</td>
<td>5 in 1939 - 1941; 1 in 1956</td>
<td>Residual oil (1.2% S)</td>
<td>5.2 x 10^6 Btu and 110-120 kWh per ton of clinker</td>
</tr>
<tr>
<td>REDDING/ Calaveras Cement</td>
<td>282^a</td>
<td>DRY</td>
<td>1</td>
<td>1960^c</td>
<td>Coal</td>
<td></td>
</tr>
<tr>
<td>RIVERSIDE/ Riverside Cement</td>
<td>735^a</td>
<td>DRY</td>
<td>2</td>
<td>1963</td>
<td>Coal</td>
<td></td>
</tr>
<tr>
<td>RIVERSIDE/ Riverside Cement</td>
<td>132 (masonry cement only)</td>
<td>DRY</td>
<td>2 (total 4)</td>
<td>1958, 1963</td>
<td>Oil/Gas</td>
<td></td>
</tr>
<tr>
<td>SAN ANDREAS/ Calaveras Cement</td>
<td>590^b</td>
<td>WET</td>
<td>3</td>
<td>1954-1956</td>
<td>Coal and Wood Shavings</td>
<td>Quarry 26 mi. away with slurry pipeline</td>
</tr>
<tr>
<td>VICTORVILLE/ Southwestern Portland</td>
<td>500^b</td>
<td>DRY</td>
<td>1</td>
<td>1965</td>
<td>Residual Oil</td>
<td></td>
</tr>
<tr>
<td></td>
<td>800^b</td>
<td>WET</td>
<td>5</td>
<td>1965</td>
<td>Residual Oil</td>
<td></td>
</tr>
<tr>
<td>TOTAL &quot;CAPACITY&quot;</td>
<td>10,466</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTES:


^b Capacity data reported by plant manager or staff engineer.

^c These plants have announced plans to add new capacity (see Table 3).

^d Company official reported only that this plant had been the second most efficient wet process plant in the U.S. a few years ago. These fuel and electricity consumption rates are those reported in Ref. 1 for the second most efficient wet process plant in the U.S. in 1973.
Measures for existing plants. The objectives of these measures are to reduce waste heat and dust losses, electricity consumption in grinding mills and fans, and the plant's electric load at utility peak-time hours. These objectives can be achieved, however, only if the measures are compatible with the smooth operation of the plant system on its available raw materials (Ref. 12). Some of the measures, if improperly applied, could result in overloading of plant equipment or more frequent kiln upsets and shutdowns. More energy could be lost in stopping and restarting the plant or running at reduced capacity with higher heat losses per ton of production than would be saved by the changes. The alkali content of raw materials is an important consideration because of specifications which limit alkali in the finished cement. Measures which reduce the energy lost in dust collected from kiln exhaust and wasted, for example, tend to increase the cement's alkali content. The proper application of the measures can only be determined by an analysis of the entire plant system.

Electricity consumption in raw and finish grinding, which accounts for about 65 percent of total electricity consumption, can in many cases be reduced by simply readjusting the grinding mills. The objective of the adjustment is to produce a kiln feed with a narrower distribution of particle sizes, i.e., smaller percentages of both super-fine and very coarse particles. This will save raw grinding electricity (about 25 percent of total electricity) and save fuel as well by improving heat transfer at the kiln's feed end and reducing dust carry-out (highest in dry-process kilns) and its heat loss (Ref. 12). The savings, between 6 and 8 kWh per ton of cement, are possible only if the raw grinding mill circuits can produce a slightly coarser feed (65 percent passing a 80 mesh screen rather than the customary 80 to 85 percent) without too many large particles and if the kiln can produce sound clinker.

Coarser finish grinding can also save electricity without impairing product quality in many cases, provided that the customer will accept a lower fineness specification. Fineness is measured by surface area-to-weight ratio, expressed in cm$^2$/g. A reduction from 3600 to 3200 cm$^2$/g saves about 7 kWh/ton of cement and is usually consistent with cement strength and setting-time specifications (Ref. 3). Proper adjustment and maintenance of mills and classifiers (when used) is crucial to obtaining good grinding efficiency regardless of whether coarser grinding is desirable or not. Without proper attention, the balls
can be rendered ineffective by a coating of fine particles and the classifiers can return fine particles to the mill for unnecessary regrinding (Ref. 3). The efficiency of finish grinding mills can be further increased by adding dry-dispersal agents, called grinding aids, to the mill feed to prevent agglomeration of fine particles.

Most of the plants indicated that they had made no changes in grinding. Permanente, however, reduced its raw and finish grinding for a savings in grinding energy of up to 15 percent. The Lebec plant, whose near-term objectives focus on plant reliability more than on energy conservation, is planning modifications to its grinding circuits that will improve efficiency.

Electricity demand during the peak-load times of the utilities (which now costs the plants more per kW) can be reduced by rescheduling operations. (The plants' peak demands average about 16 kW per thousand tons of annual production capacity.) Raw grinding is the area where plants are likeliest to have excess capacity and accounts for a large proportion of the load. Permanente, Victorville, and Redding run their raw-mills during the off-peak and partial-peak hours. Colton, Lebec, Lucerne Valley, Mojave, and San Andreas indicated that they have little excess capacity available but try not to schedule grinding during the peak-time periods. Start-up, which creates the highest load, is almost always delayed until the off-peak hours.

Wet-process plants can save up to 10 percent on fuel by using a slurry thinner to reduce the water content of their kiln feed. The thinner, a surface-active reagent, allows pumping of slurry with less water (Ref. 3). A reduction from 36 to 30 percent water in the slurry saves about 0.5 million Btu's per ton of cement. Permanente and San Andreas are both using slurry thinners and their kiln feed's water content is about 30 percent. The Victorville plant indicated that it uses slurry thinners only when they are compatible with the chemistry of the cement being produced.

In dry-process plants, a major area for conservation is reduction of heat loss in kiln exhaust, which ranges from 1000°F to 1200°F and carries up to 20 percent of the product as dust (Ref. 1). Some of the lost heat can be recaptured by installing chains, lifters, crosses, or partitions to increase heat transfer from the exhaust gases to the feed. In some cases, however, installation of these devices can result in excessive gas flow restriction, increased dust carry-out, and greater entrapment of alkali compounds (which volatize in the flame region and condense upon cooling). The last effect is
a particularly important problem because of specifications which limit alkali content of the finished cement to 0.6 percent. Most of the plants have problems meeting these specifications. The installation of chains and other waste heat recovery devices could make it impossible to meet these specifications if they increase the percentage of alkali retained in the clinker. If they increase the alkali content of dust collected from the kiln exhaust, they could lead to increased overall fuel consumption by requiring the wasting of a larger percentage of the dust. Among the dry-process plants, only Victorville indicated that it had recently changed its chain configuration, resulting in lower exhaust gas temperatures. Note that cogeneration is an alternative to exhaust heat recuperation; high exhaust gas temperatures assure good generation efficiency. Oro Grande, which cogenerates, does not use chains for this reason but would install them (after installation of the two additional waste heat boilers which are planned) if it has too much steam for its turbines.

Wet process plants, which all use chains, can save fuel by increasing the chain weight and trying new configurations for better heat transfer (Ref. 1). Some wet process plants may be unable to further reduce their kiln exhaust temperatures, however, because the resultant lower temperatures in the kiln exhaust dust collectors would lead to corrosion from condensation of sulfuric acid mist. The cost of installing chains in a kiln is around $500,000 (Ref. 1). Permanente replaced the chains in all six kilns in 1977. San Andreas rechained in 1975. Victorville reported that it had tried changing the chain configuration in its kilns. (Monolith's kiln was installed in 1974 and the chains probably have not been changed since then.)

Improved kiln insulation can save fuel, especially in dry-process kilns, by reducing radiation and convection from the kiln surface. These heat losses account for 5-8 percent of total fuel consumption in wet-process kilns and 10-15 percent in dry process kilns (Ref. 1). Refractories with better insulation properties, however, cost more and usually do not last as long; they are usually only applied in the low-wear section of the kiln between the chain section and burning zone (Ref 3, pp. 168-177).

Heat recuperation from the clinker to the combustion air can be increased to save fuel in all types of plants. The easiest way to do this is to limit the amount of outside air entering the kiln, thereby increasing the proportion of combustion air receiving heat from the clinker. Outside air enters the
kiln by infiltration at the firing end and as primary air supplied directly to the burner. Infiltration can be reduced by installation or proper adjustment of seals between the kiln and firing hood and by elimination of unnecessary openings in the firing hood, such as gaps between the burner gun and the hood or open portholes. Primary air is necessary for proper combustion of coal, coke, and oil, but can be reduced if the fuel's velocity at the burner tip can be increased; a reduction of primary air from 21 percent to 15 percent of total air will save 1 percent of fuel (Ref. 12). A more difficult way to increase heat recuperation is to modify the cooler so that it quenches the clinker with less air, thereby increasing the temperature of air supplied by the cooler. Leaks around the clinker bed in the cooler must be eliminated and the hottest section of the cooler may have to be narrowed or run at slower speed. In plants where non-uniform thickness of the bed of clinker on the grate allows air leakage, similar results can be obtained with operational changes or less costly modifications. The Davenport plant indicated that it plans to install a variable-speed drive on its cooler next year.

Oxygen enrichment of combustion air has been tried at several U.S. plants, mainly as a method of increasing production capacity (Ref. 1). In most cases, however, total energy consumption (including energy required to produce the oxygen) has been reduced. The source of energy savings is the reduction in the volume of gases that must be heated to the temperature (2700°F) required for clinkering.

All of the plants can, in principle, manufacture pozzolanic cements to save energy, but only Permanente indicated that it did this. Pozzolanic cement is a blend of portland cement and other materials, such as expanded shale, that do not require kiln processing but still contribute strength, albeit less than provided by portland cement, to the finished product. Most of the other plants indicated that either demand for the products or the availability and price of pozzolanic raw materials was not sufficient to manufacture.

Cogeneration. Cement plants always have a surplus of heat that can be used to generate electricity with waste heat boilers and steam or vapor turbines. Kiln exhaust from existing dry process plants is the most economic source of waste heat for cogeneration because of its large volume and high temperature.
(1000°F to 1200°F in most California plants). The exhaust from the new suspension preheater kilns (700°F) could also be utilized; this application has been proposed. The use of this exhaust for cogeneration, however, is impractical if it is already necessary as a heat source for drying of raw materials.

In existing dry-process plants, steam boilers and turbines can be used. The Oro Grande plant has been cogenerating since 1954. Waste heat boilers are installed on five of its seven dry kilns, supplemented by two fuel fired boilers to provide steam for condensing turbines. The generators presently provide up to 16.5 MW of electricity to a separate electric system. Next year the plant will be fully interconnected to the utility and the two remaining kilns will have waste heat boilers installed. Colton is now considering the installation of 9 MW of steam cogeneration capability at its plant.

Victorville is investigating the use of organic vapor turbines to generate 5 to 8 MW. Organic fluids such as toluene or fluorinol have several advantages over steam at temperatures lower than 800°F. First, the size of heat exchangers, a major cost component, is reduced because organic fluids have better heat transfer properties. Second, the cycle is simplified by not having to reheat steam to avoid condensation in the turbine; most organic vapors superheat as they cool from the turbine inlet temperature. Third, turbine design is simplified; less turbine stages and more easily manufactured turbine blades will achieve comparable efficiency (between 20 percent and 25 percent at peak temperatures near 600°F) in an organic vapor turbine.

Balanced against these advantages are the higher cost and toxicity, and in many cases the flammability, of organic fluids. Peak cycle temperatures are limited by the thermal stability of the organic fluids. Furthermore, steam-electric generation equipment can presently be purchased off-the-shelf or as surplus, while most organic fluid equipment bears an added cost for development and special engineering.

Thermo-Electron has proposed a 2.6 MW steam-cycle cogeneration system on the exhaust of a suspension preheater dry-process kiln (Ref. 17). There is very little difference in exhaust steam temperature and dust loading of these kilns and the types planned for installation in California. The Thermo-Electron system is reported to have a simple payback time of three years (capital cost of $1.46 million, cost of purchased electricity 3¢/kWh, 7,000 hr/yr. operation, $60,000/yr. operating costs), which makes this system seem promising for the new kiln installations.
The particulate emissions and locations of cement plants constitute important technical problems for cogeneration in cement plants. Dust in kiln exhaust can foul the less-costly finned-tube boilers which are usually preferred for waste heat recovery. Excessive dust in the air around the plant could foul water used in cooling towers. The availability of water is a potential problem for the large number of plants located in the desert of Southern California; most of these plants depend on their own wells for their current requirements (Ref. 19).

The full potential of cogeneration cannot be firmly established at this time, partly because cogeneration technologies and kiln systems are separately undergoing development. While development of cogeneration technologies may increase their efficiencies and lower their cost, development of new kiln systems reduces the amount of waste heat available for use in generating electricity. The trend in kiln and grinding systems development seems to be toward utilization of as much high-temperature heat as possible for preheating and drying of raw materials and coal, thus pre-empting most of the heat suitable for generation of electricity.

It is possible, however, that a reappraisal of the total cost of cement production might encourage development of systems which include cogeneration, particularly if the cost of electricity substantially increases relative to the cost of fuels. The consequences of such a scenario are estimated in Technical Note 3, in which it is assumed that both cogeneration and efficient kiln and grinding systems are extensively introduced into the state's cement industry. With efficient cogeneration systems (25 percent efficiency) utilizing a large proportion (40 percent) of all the waste heat produced by the industry's kiln systems, it is estimated that cogeneration could supply over 60% of the industry's electricity needs. As noted in the comments on the assumptions in Technical Note 3, this would require extensive recovery of waste heat from kiln shells and kiln exhaust, as well as improvement in cogeneration technology.

New Kiln and Grinding Systems. This topic includes conversion from wet to dry process as well as expansion or modernization of existing plants. Two of the wet-process plants, Lucerne Valley and Permanente, are converting to dry-process by replacing most of their plants. The Monolith plant,
which installed a wet-process kiln in 1974, intended to convert the kiln to dry-process by overhauling its raw grinding department, according to a 1973 California Air Resources Board report (Ref. 5). According to a recent economic analysis (Ref. 9), current fuel costs do not justify conversions from reasonably efficient (i.e., less than 6.5 million Btu's per ton of clinker) wet-process to semi-wet processes that involve pressing water from the slurry or drying it before sending it to the kiln. Until fuel costs rise dramatically—above $2.00 per million Btu—the only economic conversion for the California plants appears to be complete conversion to dry-grinding and an efficient dry-process kiln.

The wet-process San Andreas plant, however, faces a formidable obstacle to complete conversion. A 26-mile slurry pipeline links the plant's limestone quarry and grinding mills to its plant. Unless the pipeline is abandoned, the plant must either remain on wet-process or convert to semi-wet process. The latter course will probably not be adopted unless there is a large increase in the cost of its present fuel supply (75-80 percent Utah coal plus 20-25 percent wood shavings).

The kiln systems scheduled for installation by five plants to expand or modernize their plants are dry-process with suspension preheaters and pre-calciner furnaces like the one shown in Figure 5. The suspension preheater is a string of cyclones that swirl the incoming feed with kiln exhaust gases to increase heat transfer. The pre-calciner or "flash" furnace supplies low-temperature heat (1800°F in the system shown in Fig. 5) to almost completely calcine or decarbonize the feed before it enters the kiln. The advantages of adding the pre-calciner furnace are not so much fuel economy, which is not greatly affected, but rather allowing use of a smaller kiln for the same production rate and reducing the heat penalty incurred when part of the kiln exhaust must be by-passed around the preheater for alkali removal. Between 50 percent and 60 percent of the fuel, residual oil or pulverized coke or coal, is burned in the precalciner furnace, whose combustion air can be separately ducted from the clinker cooker as shown in the diagram. Separate ducting reduces the volume of gases flowing through the kiln, resulting in lower nitrogen oxides emissions because less air is heated to the high temperatures at which nitrogen oxides form in large quantities.
Fig. 5. Schematic Diagram of Suspension Preheater Kiln with Precalciner ("Flash") Furnace

Source: Ref. 1, p. 87.
Table 3 lists the plants which are planning or considering installation of new kilns and grinding systems. The new kilns, whose capacities range from 0.5 to 1.6 million tons of clinker per year, will be larger than most of the existing kilns. This contributes to improved fuel economy because many heat losses become a smaller fraction of heat input as kiln size increases. Expected fuel consumption rates for the new kilns are between 3.2 and 3.4 million Btus per ton of clinker, varying with the amount of kiln exhaust bypass to be used as well as with kiln size. The Redding plant plans to use a planetary cooler on its new kiln, a type of cooler which limits cooling air to the amount necessary for combustion, but no efficiency improvement is foreseen since the clinker will exit at a higher temperature and lose heat to the ambient air. The Lebec plant, whose plans have been deferred pending overhaul of the existing plant, is now only considering the addition of a suspension preheater and shortening its kiln.

Roller mills (Fig. 6) can grind some raw materials with less electricity than ball mills. The feed, which requires less previous crushing than feed to ball mills, is carried by a rotating table beneath stationary wheels. Hot kiln exhaust dries the feed and carries fine particles through the roller mill's internal classifier. Electricity savings, when compared to the consumption of ball mill systems, are typically 5 percent to 15 percent, but they can reach 50 percent when grinding easily crushable limestone rock (Ref. 1). When the plant's raw materials contain abrasive components such as quartzite, the cost of maintenance and replacement of worn parts quickly outweighs the savings. Oro Grande indicated that it would not use roller mills for this reason and Lucerne Valley and Permanente do not expect to install them in their new plants. The new kilns at Davenport and Mojave will have roller mills, and Redding is considering it.

The cost of an entirely new plant with a suspension preheater kiln and roller mill was estimated at $80 per ton of annual production capacity in 1975 (Ref. 1); Table 4 shows the estimated cost breakdown. The cost of converting an existing plant, retaining part of the grinding facilities as well as quarrying, shipping, etc., is about $50 per ton; this is the current cost reported by the Davenport plant for its new kiln, coal-handling equipment, and partial replacement of grinding facilities.

Kiln systems, and to a lesser extent grinding systems, are still being developed and improved and some further reductions in fuel and electricity consumption may be expected. At least nine separate precalciner systems are
Table 3  
Cement Plant Installations Planned in California (1979)

<table>
<thead>
<tr>
<th>Location</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Davenport</td>
<td>(Scheduled for completion by end of 1980)</td>
</tr>
<tr>
<td></td>
<td>Retire present kilns and raw grind department; add $750 \times 10^3$ t/yr. coal-fired suspension preheater kiln with precalciner furnace (SP + PC) and roller mill; also add new 2500hp finish mill.</td>
</tr>
<tr>
<td>Lucerne Valley</td>
<td>(Scheduled for completion in 1981)</td>
</tr>
<tr>
<td></td>
<td>Retire present kilns and raw grind department; add $1,600 \times 10^3$ t/yr. coal-fired SP + PC kiln; do not expect to use roller mill.</td>
</tr>
<tr>
<td>Mojave</td>
<td>(Under construction)</td>
</tr>
<tr>
<td></td>
<td>Retain present plant; add $1,000 \times 10^3$ t/yr. coal-fired SP + PC kiln with roller mill.</td>
</tr>
<tr>
<td>Permanente</td>
<td>(Scheduled for completion by 1981)</td>
</tr>
<tr>
<td></td>
<td>Retire all of plant except quarry, crushers, cement storage, shipping; add $1,600 \times 10^3$ t/yr. SP + PC kiln; no roller mill; probably will operate on residual oil until coal-firing becomes economic.</td>
</tr>
<tr>
<td>Redding</td>
<td>(Scheduled for completion by 1981)</td>
</tr>
<tr>
<td></td>
<td>Replace existing kiln with $500 \times 10^3$ t/yr. coal-fired SP + PC kiln; may use roller mill; kiln will have a planetary cooler rather than traveling grate used in other new kilns.</td>
</tr>
<tr>
<td>Lebec</td>
<td>(No scheduled construction start--only preliminary study done and plans are on the back burner)</td>
</tr>
<tr>
<td></td>
<td>Shorten present kiln and add a suspension preheater; capacity would increase from present $567 \times 10^3$ t/yr.*</td>
</tr>
</tbody>
</table>

*A doubling of capacity can be expected (Ref. 9).
Fig. 6. Roller Mill

Source: Ref. 1, p. 59.
Table 4

Estimated Cost of Constructing a 725,000 Ton per Year Dry Process Suspender Preheater Plant in Thousands of 1975 Dollars

<table>
<thead>
<tr>
<th>Department</th>
<th>Equipment</th>
<th>Installation</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarry Equipment</td>
<td>$4,000</td>
<td>$300</td>
<td>$4,300</td>
</tr>
<tr>
<td>Limestone Crushing</td>
<td>400</td>
<td>900</td>
<td>1,300</td>
</tr>
<tr>
<td>Limestone Storage</td>
<td>500</td>
<td>1,150</td>
<td>1,650</td>
</tr>
<tr>
<td>Raw Grinding (Roller Mill)</td>
<td>2,250</td>
<td>5,200</td>
<td>7,450</td>
</tr>
<tr>
<td>Additive and Clay Handling</td>
<td>600</td>
<td>1,400</td>
<td>2,000</td>
</tr>
<tr>
<td>Blending and Feed Storage</td>
<td>600</td>
<td>1,400</td>
<td>2,000</td>
</tr>
<tr>
<td>Calcining and Kiln System</td>
<td>4,150</td>
<td>9,550</td>
<td>13,700</td>
</tr>
<tr>
<td>Clinker Grinding and Gypsum Handling</td>
<td>1,700</td>
<td>3,900</td>
<td>5,600</td>
</tr>
<tr>
<td>Loading and Packing Cement</td>
<td>600</td>
<td>1,400</td>
<td>2,000</td>
</tr>
<tr>
<td>Electrical Distribution and Central Process Control</td>
<td>1,600</td>
<td>3,700</td>
<td>5,300</td>
</tr>
<tr>
<td>Electric Motors</td>
<td>1,200</td>
<td>2,750</td>
<td>3,950</td>
</tr>
<tr>
<td>Land (640 Acres)</td>
<td>1,000</td>
<td></td>
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</tr>
<tr>
<td>Storage Facilities</td>
<td>1,000</td>
<td>3,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Land Improvements</td>
<td>1,000</td>
<td></td>
<td>1,000</td>
</tr>
<tr>
<td>Coal Equipment and Handling</td>
<td>1,250</td>
<td>1,250</td>
<td>2,500</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$21,850</td>
<td>$35,900</td>
<td>$57,750</td>
</tr>
</tbody>
</table>

Cost Per Ton of Capacity .................................. $80

Source: Portland Cement Association (Ref. 1)
being developed and/or operated elsewhere in the world, many of which have fuel consumption rates below 3 million Btus per ton of clinker (Ref. 20). Fluidized bed systems to replace the conventional rotary kiln are being developed, but they have not yet achieved fuel economy comparable to the rotary kilns with suspension preheaters (Ref. 1). Grinding systems are also being perfected, mostly by fine-tuning and increase in capacity rather than by changes from the basic ball and roller mill technologies, and many of the newest plants elsewhere in the world have electricity consumption rates of about 100 kWh per ton of cement (Ref. 20).

Improvements in operation may help reduce electricity consumption in the state's new cement plants, according to an article included in Ref. 20 ("Comparison of Microstructure of Cement Clinker Throughout the World", by Eric R. Hansen). The U.S.'s new, more efficient kilns tend to produce a clinker that is harder to grind than that produced by the U.S.'s older kilns, while the same types of new kilns in Europe and Japan produce a more easily ground clinker. The article suggests that the new U.S. plants could reduce grinding energy requirements by following the apparently different operating techniques practiced in Europe and Japan; this is being investigated.

Looking to the California cement industry's future one can anticipate improvements beyond those expected from currently planned installations. There will be further replacements of existing kiln and grinding systems, and both the equipment and the techniques for its operation will be somewhat improved. Some existing plants will remain in operation for more than twenty years from now, however, since cement plants have a thirty to fifty year life. Also, some of the new plants will not achieve the highest possible efficiency due to difficulties with raw material or other technical problems. Therefore, the most realistic average fuel and electricity consumption rate that can be expected from the state's industry twenty years from now would have to be somewhat higher than consumption rates of the most efficient kiln and grinding systems. It seems probable that average fuel consumption will fall below 4 million Btus per ton of clinker and that total electricity requirements, including the portion
supplied by cogeneration, will fall to 125 kWh per ton of clinker, given the current state of technology.

Other Considerations

Environmental: Air pollution is the most serious problem associated with cement manufacture. All of the plants have particulate control equipment installed, but particulate emissions will continue to be a problem because of the large amounts of dust generated. Dust from quarrying and trucking operations is usually controlled by water-spraying of roads and truck trailers. Dust generated at conveyor transfer points can be collected through duct-work to baghouses. Kiln and cooler vent exhaust carries the largest volume of dust and gas. Even with the best precipitators and baghouses, it is difficult to meet stack exhaust capacity requirements and nearly impossible to control the finest, potentially most hazardous particulates. The pressure drop through these devices requires a sizable expenditure of energy in fans; when the exhaust must be cooled with added air or water sprays to meet temperature limitations in the control equipment, the increase in exhaust volume raises fan power requirements. Electricity requirements for dust control are now about 5 to 10 percent of the total (Ref. 1). The Oro Grande plant has opted for a system that recirculates excess clinker cooling through a heat exchanger rather than venting it through dust control apparatus (Ref. 15). The Permanente plant plans to install a clinker-to-air indirect heat exchanger that will receive clinker from a grate cooler and effect the final cooling without using much excess cooler air. These arrangements do not increase heat recuperation to the kiln and thus add to electricity consumption by increasing fan power requirements. The Redding plant will have a planetary cooler on its new kiln, which sends all cooling air to the kiln and limits the volume of air to that required for combustion. The new preheater and precalciner kilns are more suitable for achieving lower particulate emissions due to the better trapping of dust in the preheaters, lack of dust-generating chains, and the smaller total volume of gases passing through the system.

Nitrogen oxide emissions are inevitable due to the high temperatures employed in the kiln. Use of the separate precalcining furnace will reduce these emissions if air from the cooler is separately ducted to the precalciner furnace for combustion air, which results in only half the gas volume passing through the kiln. In existing kilns, nitrogen oxides can be controlled by limiting combustion air to the amount necessary for complete combustion,
thus lowering fuel consumption and the amount of oxygen that can combine with nitrogen. Unfortunately, a slight oxygen surplus (between 2 percent and 4 percent oxygen in the stack gas) is usually necessary to prevent unsafe fuel-rich conditions and to ensure retention of sulfur compounds in the clinker so as to reduce sulfur oxides emissions when burning high-sulfur fuels (Ref. 1). There is thus a potential trade-off between sulfur and nitrogen oxides emissions.

Sulfur oxides emissions are not presently an important problem due to the product's ability to absorb about 80 percent of the sulfur in the fuel. Plants burning high-sulfur fuels, such as residual oil from California's heavy-oil deposits and high-sulfur coke, report no problems in reducing stack emissions to 200ppm. If further control is necessary, the most practicable route is to install precalciner kilns and treat the kiln exhaust, which constitutes about half of the total gases in the kiln system and carries most of the volatized sulfur compounds (Ref. 3, pp. 177-8).

Cement plants could help reduce environmental problems by serving as incinerators for hazardous or polluting wastes. The high temperatures in the kiln can dissociate many compounds into less hazardous products. PCB's and waste-oils, for example, have been successfully incinerated in cement kilns (Ref. 18). Liability for accidents, however, is an unresolved issue that is stymying further application.

Fuel-switching: As noted previously, all but one of the plants, which makes only white cement and thus cannot use the "dirtier" fuels, no longer use natural gas as a primary fuel. Fifty percent of the capacity is now coal-fired and 70 percent will use coal after 1981 if all scheduled installations occur. The exact trend in coal use is difficult to predict due to uncertainty in the relative economics of the fuels. The cheapest fuels on a per-million Btu basis are petroleum coke and coal, but handling equipment is far more expensive and adds up to 10 kWh per ton of finished cement (Ref. 1). In 1976, coke cost the cement plants about fifty cents per million Btu (Ref. 16). Cost figures for the cement industry's coal, part of which comes from company-owned mines, are not available, but the average cost to all California manufacturing plants in 1976 was $.98 per million Btu (Ref. 16). The average cost of residual oil to cement plants in 1976, by comparison, was $1.53 per million Btu or $9.60 per barrel (Ref. 16). The future supply of coal depends on western mines development, while that of coke depends on increases in production of gasoline and other light products that yield
coke as a by-product. Natural gas and oil will still be used at coal-
and coke-fired plants as a back-up fuel in case of main fuel supply failure
and for start-up of kilns, since the coal and coke grinding mills require
hot kiln exhaust for drying.

First and Second Law Considerations: All cement plants have a surplus
of waste heat due to their (first law) inefficiencies. The theoretical heat
requirement, excluding grinding energy and other necessary work inputs,
for producing one ton of clinker is, on the average, about 1.5 million Btus,
varying slightly with the composition of raw materials (Refs. 1, 4). Even
the best kiln systems in the world, with thermal energy consumption rates
of 2.4 million Btu/ton (Ref. 1), have a high proportion of heat loss.

Increases in the (first-law) efficiency of utilization of thermal
energy, however, are not necessarily the most desirable objective of
energy conservation. Since cement manufacture requires mechanical
energy as well as thermal energy, it would be optimal to supply the
mechanical energy from the kiln's fuel input. This would result in an
increase in the second-law efficiency of total energy input (kiln fuel
plus powerplant fuel) into cement manufacture. An available energy analysis,
which takes second-law considerations into account, of a fairly efficient
kiln system concluded that second-law efficiencies were lower than the first-
law efficiencies, from which it was inferred that "substantial process in-
efficiencies would remain even if all heat losses were eliminated and the
enthalpy (above ambient) of all waste streams recovered." (Ref. 8). In
other words, even a kiln that required only the theoretical thermal energy
input would still be under-utilizing the potential of its fuel to supply
high-quality energy such as the work required for grinding. The obvious
route to increased second-law efficiency is cogeneration of electricity.
The most efficient method would be to use the high-temperature heat from
combustion of fossil fuels and from the exothermic clinkering process for
electricity generation and use rejected heat and lower-grade fuels to
supply the lower temperature for calcining and drying. The most practica-
ble cogeneration method is to install waste heat boilers on the exhaust of
dry kilns without preheaters, which results in lower efficiency of electricity
generation due to the lower temperature of the heat input. This is practiced
at the Oro Grande plant and being considered at Colton and Victorville. It
may also be possible to use by-passed kiln exhaust (1500°F) from the preheater kilns to generate electricity with high efficiency, but the technical and economic feasibility has not yet been established.

International Comparisons of Energy Use in Cement Manufacture: In comparison to the cement industries of Japan and Western Europe, the California industry appears extremely inefficient. Three factors can explain most of the difference in average fuel and electricity consumption per ton of clinker produced. First, the industries in Europe and Japan are younger, faster-growing, and face higher fuel costs. Thus they have newer, more efficient kilns. Second, California plants serve a smaller market than in more densely-populated Japan and Europe, which dictates smaller and thus less efficient kilns. Lastly, European plants, especially those in Germany, produce cement with a higher alkali content and lower finish grind "fineness" than is required by the specifications of most California customers. Since finish grinding constitutes the largest requirement for electricity, this has a dramatic effect on electricity requirements.

Institutional Factors

Changes in the specification for cement, particularly those related to alkali content and finish grind fineness as well as the acceptability of pozzolanic cements, could make significant energy savings possible. To bring about the necessary revisions in cement specifications, consumer protection laws would have to be changed to facilitate the use of less energy-intensive cement in applications which do not require the qualities of the cement which is conventionally used. The U. S. Army Corps of Engineers, a major user of cement, could take the lead in changing specifications.

Information Needs

Information on the plans of the California plants should be periodically updated. While it appears that currently scheduled installations would accomplish a great deal toward energy conservation, plans could be deferred or abandoned if the cement market does not grow to support the planned capacity.

Also cogeneration in cement plants should be further investigated to determine the potential of the technologies being commercialized and the economics of heat recuperation relative to cogeneration.
Technical Note 1: Estimate of Average Fuel Consumption if All Presently Planned Kiln Constructions and Retirements Occur.

Assumptions

1. The following plants install suspension preheater with precalciner furnaces by the end of 1981 as planned (capacities in tons of clinker/yr. in parentheses): Redding (500 x 10^3), Lucerne Valley (1600 x 10^3), Permanente (1600 x 10^3), Davenport (750 x 10^3), and Mojave (1000 x 10^3). Total capacity is 5450 x 10^3 t/yr.

2. The average fuel consumption of the new plants will be 3.2 x 10^6 Btu/ton of clinker.

3. The following plants retire kilns as planned (capacities in parentheses): Lucerne Valley (1105 x 10^3), Permanente (1600 x 10^3), Redding (282 x 10^3), and Davenport (360 x 10^3). Total capacity is 3347 x 10^3 t/yr.

4. Production as a fraction of capacity will be equal among all plants, i.e., the more efficient new plants will not be more heavily used nor suffer breakdowns, etc.

5. The fuel consumption and production figures for California cement plants in 1976 given by the Annual Survey of Manufacturers and the Bureau of Mines (44.0 x 10^12 Btu and 7.9 x 10^6 tons of clinker) are correct. Average fuel consumption for the state in 1976 is then 5.57 x 10^6 Btu/ton of clinker.

6. 1976 production as a fraction of capacity was equal among all plants.

7. The average 1976 fuel consumption per ton of clinker of the kilns to be retired as follows: Lucerne Valley: 5.0 x 10^6 Btu/t, Permanente: 5.2 x 10^6 Btu/t, Redding: 4.5 x 10^6 Btu/t, Davenport: 4.5 x 10^6 Btu/t. (Except for Lucerne Valley and Redding, all figures are from the plant operators.)

8. 1976 total capacity was 10,466 x 10^6 t/yr.

Calculations

With the above assumptions, average fuel consumption rates can be calculated by summing the (capacity in thousands of tons per year) times (fuel consumption rate in millions of Btus per ton) for each of the plants and dividing by (sum of capacities in thousands of tons per year), i.e.:

\[ f = \frac{\sum_{i} f_i C_i}{\sum_{i} C_i} \]

where \( i \) = plant index, \( f = \) fuel consumption, 10^6 Btu/ton, \( C = \) capacity, 10^3 t/yr.

1. Average fuel consumption rate of plants to be retired:

\[ \frac{(1105 \times 5.0) + (1600 \times 5.2) + (282 \times 4.5) + (360 \times 4.5)}{3347} \]

\[ = 5.0 \times 10^6 \text{ Btu/t.} \]

2. Average fuel consumption (X) of existing plants which will not be retired (capacity of 10,466 - 3347 = 7119 x 10^3 t/yr.):
Technical Note 1 (continued)

\[
(7119 \times X) + (3347 \times 5.0) = (10,466 \times 5.57);
\]

\[
X = \frac{(10,466 \times 5.57) - (3347 \times 5.0)}{7119} = 5.8 \times 10^6 \text{ Btu/t}
\]

3. Average fuel consumption of plants after 1981 (7,119 \times 10^3 \text{ t/yr. of plants existing in 1976 and 5,450 \times 10^3 \text{ t/yr. of new plants})}:

\[
\frac{(7,119 \times 5.80) + (5450 \times 3.2)}{7119 + 5450} = 4.7 \times 10^6 \text{ Btu/t clinker} = 4.4 \times 10^6 \text{ Btu/t cement}
\]
Technical Note 2: Estimate of Average Purchased Electricity Consumption Rate if All Presently Planned Kiln Constructions and Retirements Occur.

Assumptions

1. The following plants will install roller mills and suspension preheater with precalciner furnace (SP+FC) kilns by the end of 1981 as planned (capacities in tons of clinker per year in parentheses): Redding (500 x 10^3), Davenport (750 x 10^3), Mojave (1000 x 10^3).

2. The average electricity requirements of the above new kiln systems will be 135 kWh/ton of clinker.

3. The following plants will install SP+FC kilns (no roller mill) by the end of 1981: Permanente (1600 x 10^3) and Lucerne Valley (1600 x 10^3).

4. Electricity consumption at the new Permanente and Lucerne Valley plants will be 140 kWh/ton of clinker.

5. The following plants will be replaced (capacities in parentheses): Lucerne Valley (1105 x 10^3 t/yr), Davenport (360 x 10^3 t/yr), Permanente (1600 x 10^3 t/yr) and Redding (282 x 10^3 t/yr).

6. Average 1976 electricity consumption per ton of clinker produced in the kilns to be retired was: Lucerne Valley and Permanente - 120 kWh, Redding and Davenport - 150 kWh.

7. Oro Grande (1147 x 10^3 t/yr) will install additional cogeneration capacity to reduce its purchased electricity requirements from an assumed 22 kWh/ton in 1976 to 5 kWh/ton in 1982 and Colton (850 x 10^3 t/yr) and Victorville (dry kiln only, 500 x 10^3 t/yr) will install cogeneration to reduced purchased requirements from an assumed 145 kWh in 1976 to 30 kWh/ton in 1982.

8. The 1976 purchased electricity consumption (1.0264 x 10^9 kWh) reported by the Annual Survey of Manufacturers and the 1976 cement clinker production (7.892 x 10^6 short tons) reported by the Bureau of Mines are correct. Average 1976 electricity consumption then is 130.1 kWh per ton of clinker.

9. 1976 production as a fraction of capacity was equal among all plants.

10. 1982 production as a fraction of capacity will be equal among all plants.

Calculations

With the above assumptions, average electricity consumption rates can be calculated by summing the (capacity in thousands of tons per year) times (electricity consumption rate in kWh per ton) for each of the plants and dividing by (sum of capacities in thousands of tons per year), i.e.:

\[ \tilde{e} = \frac{\sum C_i e_i}{\sum C_i} \]

where \( i \) = plant index, \( e \) = electricity consumption, kWh/t, and \( C \) = capacity, 10^3 t/yr.
Technical Note 2 (continued)

a) Average electricity consumption rate of all plants to be retired:

\[
\frac{(1105 \times 120) + (1600 \times 120) + (282 \times 150) + (360 \times 150)}{3347} = 126 \text{ kWh/ton}
\]

b) Average 1976 purchased electricity consumption rate of plants which will install cogeneration facilities by 1982:

\[
\frac{(1147 \times 22) + (850 \times 145) + (500 \times 145)}{2497} = 88.5 \text{ kWh/ton}
\]

c) Average electricity consumption rate \(x\) of existing plants that will not be retired or be cogenerating (capacity of 10,466 - 3347 - 2497 = 4622 x 10^3 t/yr):

\[
x = \frac{(10,466 \times 130) - (2497 \times 86.5) - (3347 \times 126)}{4622} = 156 \text{ kWh/ton of clinker}
\]

d) Average 1982 electricity consumption of new SP+FC kilns with roller mills (2250 x 10^3 t/yr), new SP+FC kilns without roller mills (3200 x 10^3 t/yr), cogenerating plants (1147 x 10^3 t/yr purchasing 5 kWh/ton and 1350 x 10^3 t/yr purchasing 30 kWh/ton), and remaining plants (4622 x 10^3 t/yr):

\[
\frac{(2250 \times 135) + (3200 \times 140) + (1147 \times 5) + (1350 \times 30) + (4622 \times 156)}{12,569} = 121 \text{ kWh/ton of clinker}
\]

\[
= 115 \text{ kWh/ton of cement}
\]
Technical Note 3: Estimate of Cogeneration's Potential for Reducing Requirements for Purchased Electricity

Assumptions

1. Average fuel consumption rate could fall to 4 million Btus/ton clinker.
2. Average total (purchased and self-generated) electricity requirements could fall to 125 kWh/ton clinker.
3. An average of 40 percent of waste heat could be used for cogeneration.
4. Average cogeneration cycle efficiency would be 25 percent.

Comments on Assumptions

1, 2: These average fuel and electricity consumption rates could be realized after widespread replacement of existing kiln and grinding systems with more efficient, larger-scale units such as SP + PC kilns and roller mills.

3: This average percentage assumes that not all waste heat in kiln preheater exhaust is needed for drying, that some precalciner kiln bypass gas could be used for cogeneration, and that heat could be collected from kiln shells. The total amount of heat available from these sources is larger (see heat balances in Ref. 1) than the amount assumed available for cogeneration.

4: This cycle efficiency assumes some improvement in cogeneration technology and an average waste heat temperature of at least 600°F.

Calculations

1. The waste heat output is equal to the average fuel consumption minus the theoretical minimum, $1.5 \times 10^6$ Btu/ton clinker. That is,

   $$2.5 \times 10^6 \text{ Btu waste heat/ton clinker}$$

2. The cogenerated electricity is equal to (total waste heat output) x (kWh per Btu) x (fraction used for cogeneration) x (efficiency)

   $$= 2.5 \times 10^6 \text{ Btu/ton clinker} \times 1 \text{ kWh/3412 Btu} \times 0.4 \times 0.25$$

   $$= 73.3 \text{ kWh/ton clinker}.$$

3. Purchased electricity requirement is the difference between total electricity requirements and cogenerated electricity.

   $$125 \text{ kWh/ton clinker} - 73.3 \text{ kWh/ton clinker}$$

   $$= 51.7 \text{ kWh/ton clinker (49.1 kWh/ton cement).}$$
REFERENCES


References (continued)


20. Selected Material from the Cement Process and Technology Seminar presented by Kaiser Engineers.

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