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Multimedia Assessment and Environmental Research Needs of the Cement Industry

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May 1979

MULTIMEDIA ASSESSMENT AND ENVIRONMENTAL RESEARCH NEEDS OF THE CEMENT INDUSTRY

by

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INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
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U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report provides a comprehensive assessment of the cement industry, its economic characteristics and its environmental research needs. Through this publication, it is hoped that a coordinated research effort of maximum applicability to the industry will be encouraged. The Industrial Pollution Control Division should be contacted for further information on this subject.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

This project was initiated to obtain a comprehensive assessment of the cement industry and its environmental research needs. Specific areas of concern were: pollution problems encountered by the industry; all alternatives for pollution reduction; and, identification of possible research efforts to be conducted by EPA's Office of Research and Development.

In this project, a literature search was undertaken and contacts were made with various cement manufacturers and the cement industry trade association. This organization was identified as a key source of R&D efforts for the U.S. cement industry.

This report contains a profile of the U.S. cement industry; an analysis of the cement manufacturing processes; a discussion of waste stream characteristics and controls; and an assessment of the U.S. cement industry's environmental research needs, the steps taken toward addressing these needs, and the sufficiency of these steps.

Recommendations for areas of further investigation were proposed. These areas are: Waste Kiln Dust Management, Nitrogen Oxides Control, Use of Cement Kilns as Waste Incinerators, and Sulfur Oxides Control.

This report was submitted in fulfillment of 68-03-2586, Work Directive No. 1 by A. T. Kearney, Inc., under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from June to September, 1978, and work was completed as of October 1, 1978.

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ACKNOWLEDGMENTS

The Portland Cement Association provided considerable information and support in the conduct of this study. Mr. Cleve Schneeberger, Vice President for Public Affairs, contributed general information on the nature of the industry and helped establish contact with industry personnel. Mr. N. R. Greening, Director of the Chemical/Physical Research Department, supplied valuable information on process technology and industrial research programs. Mr. T. R. O'Connor, Director of the Economic Research Department, provided economic and financial data, and, finally, Mr. R. F. Gebhardt, Environmental Affairs Subcommittee Chairman, contributed to our understanding of waste characteristics and pollution control technology in the industry.

The following cement manufacturing companies were most cooperative in supplying technical information:

Alpha Portland Cement Company
Citadel Cement Corporation
Martin Marietta Cement
Universal Atlas Cement Division of U.S. Steel

SECTION 1

INTRODUCTION

STUDY OBJECTIVES

Cement manufacturing involves the inherent generation of air pollutants, water pollutants, and potentially hazardous solid wastes. Some of these pollutants, such as particulate emissions, are currently regulated by the U.S. Environmental Protection Agency (EPA) and by various state pollution control agencies. Federal regulations on other cement industry pollutants (e.g., kiln dust, nitrogen oxides) may be forthcoming.

The objectives of this study are to:

1. Characterize the cement manufacturing industry as well as the nature and extent of its pollution problems.

2. Determine the status of pollution control programs in the industry.

3. Identify the environmental research needs of the industry.

REPORT CONTENTS

This introductory section offers a description of cement. It is followed by conclusions and recommendations from the study. The next two sections deal with the cement industry and cement manufacturing process. Waste stream characteristics and controls are then discussed. Finally, environmental research programs and future needs are presented.

WHAT IS CEMENT?

Hydraulic cement is the basic binding agent in concrete and masonry construction. There are several types of cement in use:

1. Portland cement
2. Pozzolan cement
3. High alumina cement
4. Special or corrosion-resisting cements and mortars
5. Controlled cement
6. Slag cements*

Roughly 95 percent of cement production in the United States is portland cement. Portland cement is produced by the high temperature burning of calcareous material (e.g., limestone, oyster shells), argillaceous material (e.g., clay), and siliceous materials (e.g., sand, shale) to produce clinker. According to ASTM Specification C 150-60 and C 175-61, portland cement is "the product obtained by pulverizing clinker consisting essentially of hydraulic calcium silicates, to which no additions have been made subsequent to calcination other than water and/or untreated calcium sulfate (gypsum) except that additions not to exceed 1.0 percent of other materials may be interground with the clinker at the option of the manufacturer." There are five basic types of portland cement. Type I is "regular" portland cement which is used in general construction, and is produced in the largest quantities relative to the other types of cement. Type II portland cement is formulated for moderate heat-of-hardening and moderate sulfate-resisting applications. Type III is high-early-strength (HES) cement. Roads constructed of HES cement can be put in service faster than roads constructed from ordinary Type I cement. Type IV portland cement has a 15-35 percent lower heat of hydration than other types of cement. Finally, Type V portland cement is highly sulfate-resistant.[1]

Air-entraining agents (e.g., resinous materials, greases) can be added to portland cements in minute quantities. Air-entrainment increases the resistance of hardened concrete to scaling caused by alternate freezing and thawing and the use of de-icing salts. Air-entraining cements are classified as Type IA, IIA, etc.[1]

The 1975 production of various types of portland cement is shown in Table 1. It can be seen that Type I and Type II are by far the most commonly manufactured cement types.

Special cements such as pozzolan, high alumina, corrosion-resisting, and controlled cements are manufactured in relatively small amounts and are not covered in this report.

* Note: According to the Bureau of Mines, no slag cement has been produced in the United States since 1972.

The standard unit of measure used by the cement industry is the short ton. For this reason, short tons and similar English units are used in presenting data in this report.

TABLE 1. PORTLAND CEMENT PRODUCTION IN 1975

Type	Quantity (thousand short tons)	Percent of Total
General Use and Moderate Heat (Types I & II)	62,816	92.7
High Early Strength (Type III)	2,107	3.1
Special (including Type IV)	2,507	3.7
Sulfate-Resisting (Type V)	346	0.5
Total	67,776	100.0

Source: Mineral Facts and Problems. 1975 Edition. Bureau of Mines, Washington.

SECTION 2

CONCLUSIONS

In conducting this program for EPA's Industrial Environmental Research Laboratory, the contractor reached the following major conclusions:

1. Research efforts in the U.S. cement industry are limited. The industry's trade association and equipment suppliers are relied upon for research. Foreign technological developments, particularly in Japan and Germany, are also implemented by the cement industry in this country.

2. The low emphasis on R&D by cement manufacturers is primarily due to the ongoing activities of other organizations, and the currently poor financial position of the industry.

3. New cement plants will probably implement the dry process with suspension preheaters and some type of direct lime precalcining system.

4. Air pollution control for particulate emissions can be effected using conventional technology. This includes electrostatic precipitators or baghouse collectors for kiln exhaust gas and baghouse collectors for the various storage and material transfer stations throughout cement plants.

5. The most significant pollution control problem facing the industry is waste kiln dust management. Some sources of this dust could be hazardous wastes as defined in EPA regulations currently being developed pursuant to the Resource Conservation and Recovery Act.

6. Nitrogen oxides emissions in kiln exhaust gas have not been sufficiently characterized so that the significance of NO_x emissions from cement plants can be determined.

7. Since sulfur compounds are absorbed by calcareous materials in the kiln to a large extent, SO_x emissions from cement plants probably do not pose a serious problem despite the fairly rapid conversion by the industry to the use of coal.

8. Point-source water pollution is not considered a serious problem in the industry. Non-point-source water pollution (e.g., run-off from coal piles and raw material storage areas) is a problem in some cement plants.

9. Fugitive dust emissions on or near the plant site are a nuisance. Dust control on plant roads is particularly troublesome since water is ineffective and oil is environmentally unacceptable, especially if plant run-off must be collected.

10. Land use issues regarding quarries adjacent to cement plants are not as yet defined since legislation pertaining to this subject is pending in Congress.

SECTION 3

RECOMMENDATIONS

The contractor's review identified a number of areas of pressing concern for environmental research in the cement industry. These areas are described in detail in Section 7 of this report. Essentially, an environmental research program is needed to address the most significant pollution problems affecting the cement industry. The following are suggestions for specific projects.

1. Kiln Dust. Waste kiln dust would be characterized and environmentally sound methods to dispose, recycle, and reuse this material (as generated in various locations) would be identified.

2. Nitrogen Oxides. A characterization of NO_x generation would be run and methods of control -- both process controls and external systems -- investigated. This could include a demonstration program for one or more NO_x control technologies.

3. Use of Cement Kilns as Waste Incinerators. Tests have been conducted to demonstrate the technical feasibility of burning certain organic wastes such as PCB's and waste oil in cement kilns. The feasibility of more widespread use of cement kilns should be ascertained. This would include not only technical factors, but regulatory, economic, social, and institutional factors as well.

4. Sulfur Oxides Control. In view of the capability of calcareous materials in the kiln to remove sulfur oxides from combustion gases, the extent and feasibility of burning high-sulfur coals in cement plants without compromising product quality or air pollution control regulations should be investigated. This should include a determination of whether such plants can meet state air pollution control regulations promulgated to help achieve National Ambient Air Quality Standards (NAAQS).

SECTION 4

CEMENT INDUSTRY DESCRIPTION

INTRODUCTION

Cement production is both capital- and energy-intensive. The product itself is relatively undifferentiated among manufacturers and production technology is widely diffused.

Cement has an extremely low value relative to weight. As a result, transportation costs are high, limiting market areas which can profitably be served by individual production facilities. Manufacturing establishments are therefore widely dispersed, and markets tend to be regionally isolated. Transportation cost barriers permit regional production surpluses and deficits to coexist.

Demand for hydraulic cement is derived from construction requirements, which provide the ultimate consumption source for nearly all domestic cement production. Widespread availability of raw materials and the significance of transportation costs, together with the dependence of production on construction activity, result in a locational distribution of production facilities which conforms to areas of regional population concentration.

Supply and demand factors influencing distribution costs have historically limited the market range and production capacity of individual establishments. However, the increasing importance of economies of scale in production and in pollution control have resulted in a tendency toward construction of larger, more capital-intensive facilities serving somewhat larger markets. Despite this tendency toward increased scale of operations, transportation cost barriers remain a major limiting factor in the size and location of production facilities.

Pollution control costs tend to be relatively higher for smaller, older establishments. Industry investment in pollution control amounts to roughly 10-15 percent of total capital investment. Competitive and regulatory pressures for investment in both productive and non-productive capital have resulted in recent closures among marginal facilities, typically older, smaller plants situated in declining markets.

Market power in the cement industry appears to be widely dispersed at the national level. However on a regional basis, the industry is highly concentrated. The industry is also characterized by a significant degree of vertical integration, often extending from extraction through distribution to intermediate or end-users. Recent years have witnessed the diversification of cement manufacturers into more lucrative markets, both related and unrelated to construction materials. At the same time, a number of conglomerates previously inactive in this market have chosen to diversify into cement production.

Cement industry profitability is dependent upon several major factors. These include demand-capacity relationships; construction activity; and manufacturing costs, most notably energy and labor costs.[2] Since the industry is highly capital-intensive, fixed costs are extremely high, constituting 70 to 75 percent of total costs at full capacity. Industry financial performance is therefore quite sensitive to operating rates, which in turn depend directly on construction activity. Cyclical movements in construction activity tend to be reflected in cement industry profit performance.

Cement industry profits have consistently fallen short of the standard for manufacturing industries since the early 1960's, although the industry's profit record has improved in recent years. The industry's poor performance in the 1960's can largely be attributed to over investment in production capacity toward the close of the post-war construction boom.

Market projections for the cement industry assume increasing market penetration and a healthy construction industry, resulting in a generally favorable outlook for cement. Continued improvement in cement industry financial performance is anticipated. Regional capacity shortages may be increasingly evident as near-capacity operating levels are approached. Regional production shortfalls are most likely in areas where new capital investment has lagged in response to market or regulatory pressures. Energy conservation and pollution control will continue to exert demands for new capital investment beyond that required for additions to production capacity.

Research and development in the cement industry has originated largely from the industry's trade association; equipment manufacturers; and foreign industry sources. The primary thrust of industry R&D in recent years has been in the area of energy conservation. For example, four countries, including the United States, are jointly funding a $1.5 million study through the International Energy Agency of energy conservation possibilities in cement manufacture.* Cement manufacturing is highly energy-intensive, and production costs are extremely sensitive to changes in energy input requirements. Profit motives provide strong incentive for research and development in this area. These incentives are much less evident in pollution control technology, although efficiency and cost considerations are of interest in situtations where competitive advantage is sensitive to pollution control regulations. Future research and development efforts within the industry are likely to remain strongly biased toward energy conservation and production technology, where potential cost savings justify continued investment.

FACTORS OF PRODUCTION

Raw Materials

Raw materials must provide, in suitable form and proportions, compounds containing lime, silica, and alumina. Natural calcareous deposits such as limestone and shell beds, are common sources of lime. Natural argillaceous desposits, such as clay, shale, and slate, supply both silica and alumina. Natural deposits of limestone or marl (a calcareous clay) can occasionally supply all three basic ingredients at the correct proportion for the manufacture of "natural cement". Usually, however, it is necessary to combine raw materials to produce the desired mix. As a general rule, approximately 1.8 tons of raw materials are required to produce one ton of cement. Table 2 lists the types and relative quantities of different materials used to achieve the proper blend of mineral components for the industry as a whole.

Table 2 shows that the calcareous component, particularly limestone, is the largest constituent in cement. Limestone and clay are abundant all over the world. Limestone is generally quarried at or near the cement plant since the low value-to-weight ratio results in high transportation costs. Underwater deposits of materials are excavated by barge-mounted dredging. Material is pumped or loaded onto barges and moved by tugboats to cement plants. Although a few limestone and gypsum deposits are mined underground by room-and-pillar methods, most raw materials for the cement industry are quarried using surface mining methods.

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* News items Chemical Engineering Magazine August 28, 1978.

TABLE 2. RAW MATERIALS USED IN PORTLAND CEMENT IN 1975

Raw Material	Quantity (thousand tons)	Percent of Total
Calcareous:		84.6
Limestone	76,414	
Cement rock (including marl)	17,869	
Oystershell	3,006	
Argillaceous:		9.0
Clay	6,659	
Shale	3,447	
Other	208	
Siliceous:		2.1
Sand	1,813	
Sandstone and quartz	582	
Ferrous:		0.7
Iron ore, pyrites, millscale, and other material	772	
Other:		3.6
Gypsum and anhydrite	3,527	
Blast furnace slag	465	
Fly ash	180	
Miscellaneous other	2	
Total	114,944	100.0

Source: Mineral Facts and Problems. 1975 Edition. Bureau of Mines, Washington.

Capital and Labor Requirements

The cement industry is highly capital-intensive. Recent estimates[2] of the rates of capital required per dollar of revenue are in the range of 3:1. In 1971, a ratio of $7 capital to $4 revenue was cited in an EPA study.[3] Increased cost for energy has been a significant portion of the higher capital to revenue ratios.

In 1973, new construction costs for a medium-sized cement plant were $53 per ton of annual operation capacity.[3] By 1974, this figure had increased to $70 per ton.[4] Interviews with industry personnel during plant site visits indicate that in 1977-78 between $90 and $110 are required per ton of annual capacity.

Due to these increasingly high costs, established cement manufacturers are the most important entrants into new cement markets. They enter new markets by building new plants, expanding cement capacity or through market extension mergers. Since the cement industry is among the most capital-intensive, it is difficult for newly formed firms to successfully enter the industry. In addition, market share tends to be relatively stable, difficult to change, and closely related to capacity share. Historical supplier relationships tend to be build up over the years, with major customers limiting significant purchases to several sources of supply.

Labor requirements in a cement plant are a function of plant size and design. In 1974, the total number of employees per cement plant ranged from 94 to 292, with an average of 180 employees per plant.[5] As of 1975, there were almost 29,000 employees in the cement industry, of which roughly 22,000 were production workers.

If a plant is of a sufficiently large size, the designer has the option of labor-capital substitutions. Capital investment in plant modernization was the primary reason for the 30 percent drop in total employment between 1958 and 1971 that is shown in Table 3. During the same period, output rose by 31 percent. It is apparent that improving technology has led to consistent gains in labor productivity in the cement industry over recent years. In 1975, production per man-hour was 40 percent higher than in 1960. Between 1958 and 1971, production employment fell from 34,800 workers to 23,200 workers. Production workers' wages accounted for about 14 percent of value added by manufacturer in 1975, and total labor costs (all employees) amounted to 40 percent of value added to manufacture and 22 percent of the value of 1975 shipments. Average hourly earnings of cement production workers increased 148 percent in the period 1960-1975 while average mill prices of portland cement increased 14 percent in the same period.

TABLE 3. CEMENT INDUSTRY EMPLOYMENT

Year	Total Number of Employees (thousands)	Number of Production Employees (thousands)	Total Wages ($ million)
1958	41.1	34.8	$170.2
1959	41.1	35.0	183.0
1960	39.4	33.2	180.2
1961	36.4	30.5	170.6
1962	35.5	29.7	171.1
1963	34.9	28.7	173.9
1964	34.7	28.0	176.9
1965	34.6	27.9	181.5
1966	33.6	26.9	186.1
1967	32.6	26.2	184.4
1968	30.8	24.9	190.5
1969	30.4	24.6	211.3
1970	30.2	24.3	224.7
1971	28.8	23.2	233.9

Source: U.S. Department of Commerce, The Hydraulic Cement Industry in the United States: A State-of-the-Art Review, 1976.

Energy Requirements

Cement manufacture has been identified as one of the six most energy-intensive industries by the U.S. Department of Commerce, ranked by the energy required to produce one ton of product. Energy amounts to 35 percent to 40 percent of the total cement manufacturing cost. As a result, the conversion of plants to coal firing is proceeding rapidly. In 1972, approximately 39% of cement production was manufactured with coal or coke as the kiln fuel. By 1976, this increased to 55 percent. In the same year cement producers used 24 percent more coal, 41 percent less natural gas, and 30 percent less oil than in 1972. It is expected that by 1980 about 90 percent of cement production capacity can be fueled by coal. The Table 4 summarizes fuel-use capabilities of the U.S. cement industry as of January 1, 1977.

TABLE 4. SUMMARY OF FUEL USE CAPABILITIES OF THE U.S. CEMENT INDUSTRY AS OF JANUARY 1, 1977

Fuel Type or Combination	Number of Plants	Clinker Capacity (Thousand Tons)	Percent of Total Capacity
Coal	44	25,665	29
Oil	6	1,704	2
Natural Gas	10	2,669	3
Coal, Oil	16	11,828	13
Coal, Natural Gas	41	20,301	23
Oil, Natural Gas	18	11,161	13
Coal, Oil, Natural Gas	23	14,825	17
TOTAL	158	88,153	100

Source: Portland Cement Association, Economic Research Department.

In addition to conserving oil and gas through a greater reliance on coal, the cement industry has made significant progress in overall energy conservation through the implementation of technological improvements (e.g., the installation of steel chains as heat recuperative systems in kilns, conversion from wet to dry process, use of preheaters and precalciners, and adjustment of chemical proportions of raw materials used). From 1950 through 1976 energy consumption per ton of production was reduced from 7.75 million BTU to 6.30 million BTU, a 19 percent increase in energy efficiency. U.S. industry conversion from the wet process has been slow due to the capital restraints cited earlier. However, industry experience shows that conversion to the dry process is desirable because of the energy usage savings and will probably proceed as plant expansions and modernizations are required.

MARKET STRUCTURE AND PERFORMANCE

Fifty-three companies operating 160 plants in 40 states comprise the cement industry in the United States. Appendix A lists the companies by the location and the production capacity of each plant. Figure 1 illustrates the geographic distribution of these cement plants throughout the United States. Total demand for cement may vary independently from local demand due to divergent local trends in construction activity. It is not unusual for shortages in one region to persist while surpluses are evident elsewhere. Transportation costs limit the possibilities for exchange between surplus and deficit regions. As a result, and in order to minimize risk, cement manufacturers serve many markets through the development of a network of geographically scattered plants. The ten leading cement-producing states, listed in Table 5, account for 63 percent of the country's total cement production capacity.

Concentration

The structure of the hydraulic cement industry can be characterized as oligopolistic -- a market in which the number of competitors is small, yet a single firm has enough power and initiative to work independently of the others. Concentration ratios (the percentage of total market sales accounted for by the largest sellers in an industry) are commonly used to indicate the degree of competition in a particular market. In the cement industry, the eight leading companies account for about 47 percent of total industry sales. This concentration ratio indicates that the U.S. cement market, viewed as a whole, is fairly competitive and is not dominated by several large producers.

However, cement manufacture is a regional industry. Due to the low value-to-weight ratio of the product, cement plants tend to be located within 200 miles of their principal markets. Since cement manufacturers generally serve local markets, regional concentration levels (as opposed to the national level shown above) are more representative of true market conditions. Using total company production capacity as an indication of relative market share, Table 5 shows concentration ratios for the ten largest cement producing states.

These figures show relatively high concentration levels in many of these states, even where the presence of several companies would indicate a more competitive market. Reviewed from a regional or state-by-state perspective, competition in the cement industry appears to be limited by the presence of large dominating firms.

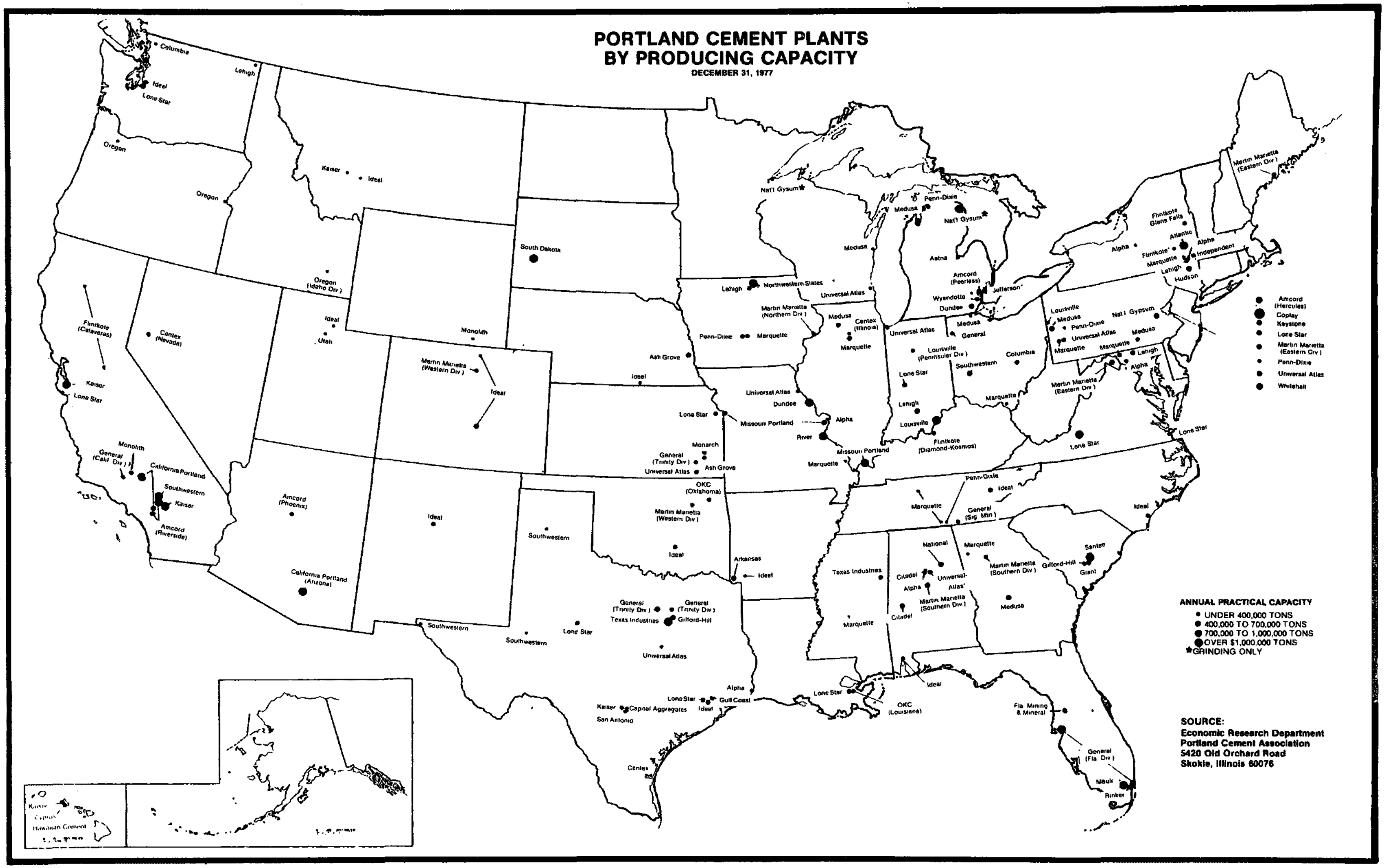
PORTLAND CEMENT PLANTS
BY PRODUCING CAPACITY
DECEMBER 31, 1977
ANNUAL PRACTICAL CAPACITY
UNDER 400,000 TONS
400,000 TO 700,000 TONS
700,000 TO 1,000,000 TONS
OVER $1,000,000 TONS
GRINDING ONLY
SOURCE:
Economic Research Department
Portland Cement Association
5420 Old Orchard Road
Skokie, Illinois 60076

TABLE 5. RELATIVE COMPANY CAPACITIES
OF THE TEN LARGEST CEMENT PRODUCING STATES

Rank	State	Number of Companies	Number of Plants	Total State Capacity	% Capacity of Largest	% Capacity 2 Largest	% Capacity 3 Largest
1	California	8	12	10,108	25.6	45.8	64.8
2	Pennsylvania	12	18	9,373	14.2	27.5	37.1
3	Texas	13	21	8,607	14.0	27.1	39.6
4	Michigan	8	8	6,785	35.1	49.8	61.2
5	New York	6	7	5,634	27.4	42.6	55.9
6	Missouri	6	7	5,016	26.2	51.3	75.3
7	Alabama	6	7	4,119	25.5	45.4	64.8
8	Florida	4	15	3,918	41.8	72.4	86.7
9	Indiana	4	5	3,866	45.8	65.2	84.6
10	Iowa	5	5	3,074	34.1	53.8	70.5

Source: Portland Cement Association, "U.S. Portland Cement Industry: Plant Information Summary"; 1977.

Company Diversification

Companies in the cement industry are highly diversified; only 18 percent of all the companies are solely involved in cement. Five percent are diversified to include construction-related products. Activities of divisions or subsidiaries of the enterprises comprising the remaining 77 percent include construction, real estate, transportation, aerospace, oil and gas, mining and chemicals.

Capacity

Historically, increases in cement production capacity have closely paralleled increases in cement demand, with the industry operating at an average capacity utilization rate of approximately 80 percent. As of 1977, the total production capacity of the industry was approximately 97.1 million tons per year. Appendix A lists the estimated capacities of individual plants and companies. During the late 1950's, when industry profitability was above average, production capacity increased significantly. However, when the post-war boom ended, the industry found itself with excess capacity and low utilization factors. When EPA air and water pollution control regulation for the cement industry were implemented in the early 1970's, large amounts of capacity were shut down because it was not considered economical to invest in pollution equipment for plants which were felt to be obsolete. In spite of these reductions, the industry has continued in an overcapacity situation, except for brief periods. Table 6 illustrates the trend in capacity utilization since 1960, and Table 7 documents cement plant closing over the past eleven years. While 19 plants with about 7.5 million tons of annual capacity have been closed down by the industry, the Portland Cement Association estimates conservatively that an additional 18 plants having roughly 6.5 million tons of capacity will close during the next ten years.* However, it is believed that the rate of closings will decrease in the next few years because the heavy environment/energy conversion costs of the past are not expected to reoccur, and most of the less efficient plants have already closed.

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* Letter from T. R. O'Connor, Portland Cement Association, to J. E. Levin, A. T. Kearney, Inc., August 4, 1978.

TABLE 6. U. S. PORTLAND CEMENT PRODUCTION CAPACITY AND CAPACITY UTILIZATION

Year	Production (Million Tons)	Apparent Capacity (Million Tons)	Percent Capacity Utilization
1960	59.0	72.6	81
1961	59.8	74.0	81
1962	62.1	78.4	79
1963	64.9	80.0	81
1964	67.8	80.2	85
1965	68.5	80.6	85
1966	70.8	82.8	86
1967	68.0	84.5	80
1968	72.6	84.7	86
1969	73.4	84.4	87
1970	71.4	85.6	83
1971	75.0	87.7	86
1972	78.8	87.8	90
1973	81.5	88.6	92
1974	77.5	93.6	83
1975	65.2	93.4	70
1976	70.8	93.4	76

Source: Portland Cement Association, "The U.S. Cement Industry: An Economic Report", 1978.

TABLE 7. CEMENT PLANT CLOSINGS

Year	Number of Closures	Capacity (Thousand Tons)
1968	4	1,675
1969	0	0
1970	0	0
1971	1	696
1972	2	676
1973	2	593
1974	0	0
1975	4	1,467
1976	5	1,930
1977	1	450
1978	0	0

Source: Letter from T. R. O'Connor, Portland Cement Association, to J. E. Levin, A. T. Kearney, Inc., August 4, 1978.

Since the cost of opening a new plant is estimated at $85 to $120 per ton of annual capacity, few companies are seriously considering building in the present economic environment. However, as conditions improve, there is a possibility that some plants may be constructed in markets where the long term outlook appears relatively attractive and/or to protect market share in existing markets. It is estimated that producers, proceeding cautiously, will add four to five million tons of capacity by 1981. Therefore, it appears that the most significant changes in future capacity will come about through modernization and conversion of existing facilities.

Plant Size and Age Distribution

The U.S. Cement Industry exhibits a relatively advanced age structure, with 80 to 90 percent of its production facilities constructed prior to 1965. Table 8 presents the number of current plants in various age brackets and each bracket's percentage of the total.

TABLE 8. KILN DISTRIBUTION BY AGE

Year Built	No. of Kilns Wet	No. of Kilns Dry	Total Kilns	Percent of Total
1976-	0	9	9	2%
1971-1975	14	20	34	9%
1966-1970	24	10	34	9%
1961-1965	24	23	47	13%
1956-1960	48	32	80	23%
1951-1955	26	29	55	15%
1946-1950	24	9	33	9%
1941-1945	7	2	9	2%
1936-1940	5	2	7	2%
1931-1935	2	4	6	2%
Before 1931	33	20	53	14%
Total	207	160	367	100%

Source: Portland Cement Association, U.S. Portland Cement Industry: Plant Information Summary, December 31, 1977.

A sharp trend toward larger plant size has developed over the past three decades. In 1950, the average cement plant capacity was 335,000 tons/year. In contrast, today's average plant capacity is 563,000 tons/year. This is primarily due to two factors: 1) production costs are less for larger plants; and 2) increasing current plant capacity is the most viable way of increasing regional market share. Plant size may vary extremely, depending on the number of kilns in operation, and each kiln's clinker capacity. However, based on PCA data, there does not appear to be an appreciable difference in capacity between wet-process kilns and dry-process kilns. Examples of the range are given below.

TABLE 9. EXAMPLES OF PLANT (KILN) SIZE DISTRIBUTION

	Process	# of Kilns	Clinker Capacity Per Kiln (Thousand Tons)	Cement Plant Capacity (Thousand Tons)
Plant A	Wet	3	120	300
Plant B	Dry	1	640	660

Source: PCA, U.S. Portland Cement Industry: Plant Information Summary, December 31, 1976.

Transportation & Methods of Distribution

Transportation is a significant factor in the delivered cost of cement because of low value-to-weight ratio of cement. On the average, freight costs appear to be approximately 25 percent of the total cost of cement. For inland plants, the market is regional, usually within a radius of 200 miles (see Table 10). Beyond this distance, overland transportation costs become excessive in relation to the value of the product. Plants on waterways may have terminals in market areas at distances 1,000 miles or more, but these distribution centers must be located on navigable waterways. Waterborne shipping is becoming increasingly important because of its significant cost advantages and energy efficiency. The relative cost of shipping by barge was in the magnitude of 0.3 cent per ton-mile compared with 1.5 cents per ton-mile by rail and 6.0 cents per ton-mile by truck.

This disparity is pointed up in the current (Summer, 1978) cement shortages in the midwest. The shortage in the Chicago area was aggravated by the fact that locks on the Illinois River, a major cement transportation route for Chicago producers, were closed for repairs. Local concrete producers were forced to have cement shipped in by truck from St. Louis, at a cost of $20 more per ton than by barge.

TABLE 10. DISTANCE OF CEMENT SHIPMENTS COMPARED WITH ALL MANUFACTURED PRODUCTS (1972)

Distance Shipped (miles)	Percentage of Cement Shipped	Percentage of All Manufactured Products
0 - 99	57.5%	28.7%
100 - 299	37.6%	28.6%
300 - 499	3.5%	13.7%
500 - 999	1.2%	16.4%
1,000 or more	0.2%	12.6%
	100.0%	100.0%

Source: Portland Cement Association, "The U.S. Cement Industry: An Economic Report," 1978.

Significant changes in the way cement is distributed have accompanied growth of cement capacity and production in the post-war years. The general effect of these changes has been to provide faster and more convenient service to the customers. Changes in cement packaging illustrate the above point. Cement can be shipped in bulk or in containers (bags). The use of bag shipments has declined from 70 percent of all cement shipped in 1946 to 8 percent in 1973. Bulk shipments provide greater cost savings to customers because the cost of the bags is eliminated and because loading and unloading costs are substantially reduced.

Equally significant changes have been made in the modes of transportation used to ship cement to the consumer. Table 11 illustrates the transition from rail to truck shipments in the last 25 years.

TABLE 11. TRENDS IN MODE OF TRANSPORTATION FOR CEMENT SHIPMENT

	Percent of Shipments in 1950	Percent of Shipments in 1975
Rail	75	13
Water	1	1
Truck	24	86
Total	100	100

Source: Portland Cement Association, "The U.S. Cement Industry: An Economic Report," 1978.

Purchases and End Uses

Virtually all portland cement is sold for use in concrete for construction. Producers of ready-mix concrete are the primary customers and the remainder is purchased by concrete products manufacturers, highway contractors, building materials dealers and government agencies. Table 12 lists these customers and their relative share of total cement consumption.

TABLE 12. CEMENT USE BY CUSTOMER CATEGORIES

Customer	Percent of Total Purchases
Ready Mixed Concrete Producers	63.0
Concrete Products Manufacturers	13.0
Highway Contractors	8.0
Building Material Dealers	8.0
All Others	8.0
	100.0

Source: Portland Cement Association, "The U.S. Cement Industry: An Economic Report," 1978.

Table 13 presents the various end uses of cement. Residential construction comprises the largest share of the end-use market.

TABLE 13. CEMENT USE BY FUNCTIONAL AREA

Functional Area	Percent of Total
Residential Construction	29%
Industrial-Commercial Markets	19%
Public Building	10%
Public Works	20%
Transportation	17%
Miscellaneous	5%
	100%

Source: Standard & Poor's Industry Surveys: Building-Basic Analysis, September 15, 1977.

Purchase Methods

Prices in the cement industry are likely to be based on a "cost-plus" mechanism. For a level of output above the break-even point, the average cost per ton is estimated and a given percentage of this cost is added to cover fixed costs and desired profits per ton. The price based on this formula is called the normal price. The actual price per ton charged by a given firm is the normal price, plus the published freight charge per ton from the mill to the customer location, minus any discounts and allowances. Therefore, cement prices traditionally vary between market areas. Since it is a basic commodity product with little product differentiation from one producer to another, the lowest price in the market prevails. Competitors tend to meet price competition to preserve market share and customer relationships.

Cement appears to be a relatively price inelastic commodity. The lack of competitive substitutes, its small portion of total construction cost (generally 5% or less) and its availability from a number of different producers in any market area cause total demand to be relatively insensitive to price changes.

Imports and Exports

Because of the weight versus transportation cost relationship, portland cement is not an important factor in international trade. Typically, imports account for less than 3 percent of total U.S. consumption. (See Table 14). Cement shortages caused by construction booms have occasionally caused this figure to rise much higher (7.7 percent in 1973). It is projected that imports of cement will show a steady increase through the year 2000, although they will still account for only approximately 4.6 percent of consumption. Canada is the leading exporter to the U.S., supplying 49% of the imported cement and clinker*, followed by Norway with 10 percent; Bahamas 9%; and France and Spain with 8 percent each.

U.S. cement exports are a small fraction of imports, primarily because the U.S. cement industry historically could not compete in price with most overseas countries. Table 14 also shows exports contrasted with total U.S. shipments.

* On September 29, 1978, the U.S. International Trade Commission published a notice in the Federal Register stating that the U.S. portland cement industry was not being injured as the result of importation of portland cement from Canada that is being, or likely to be, sold at less than fair value. The Commission conducted this investigation based on advice received from the U.S. Department of the Treasury on June 23, 1978.

TABLE 14. U. S. CEMENT CONSUMPTION, IMPORTS, EXPORTS, AND TOTAL CEMENT SHIPMENTS

Year	U.S. Cement Consumption (Thousand Tons)	Imports (Thousand Tons)	Imports as Percent of Total	U.S. Cement Shipments (Thousand Tons)	Exports (Thousand Tons)	Exports as Percent of Total
1960	58,515	770	1.3%	61,500	35	0.06%
1961	59,938	681	1.1	63,400	54	0.09
1962	62,186	1,038	1.7	65,200	71	0.11
1963	65,135	758	1.2	68,600	86	0.13
1964	67,967	683	1.0	72,000	134	0.19
1965	69,382	1,035	1.5	73,500	141	0.19
1966	70,555	1,328	1.9	74,500	201	0.27
1967	69,005	1,112	1.6	73,600	184	0.25
1968	73,540	1,386	1.9	77,800	177	0.23
1969	75,750	1,821	2.4	78,637	67	0.09
1970	72,625	2,597	3.6	74,607	123	0.16
1971	78,089	3,088	4.0	80,396	84	0.10
1972	80,840	4,911	6.1	83,336	83	0.10
1973	86,253	6,683	7.7	88,467	268	0.30
1974	79,113	5,702	7.2	80,500	N/A*	N/A*
1975	67,243	3,637	5.4	67,000	N/A*	N/A*
1976	70,696	3,074	4.3	N/A*	N/A*	N/A*
1977	77,081	3,981	5.2	N/A*	N/A*	N/A*

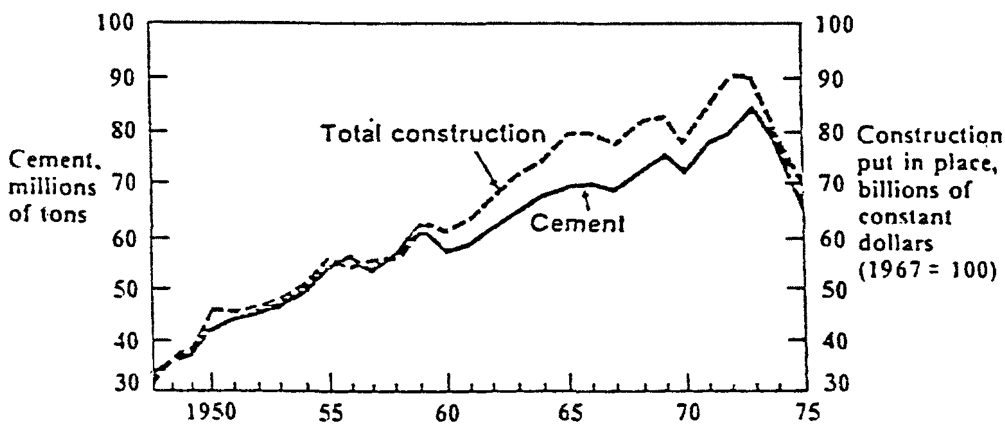
* N/A = Not Available

Sources: Portland Cement Association, "The U.S. Cement Industry: An Economic Report," 1978.

U.S. Department of Commerce, "The Hydraulic Cement Industry in the United States: A State-of-the-Art Review," 1976.

Growth Trends

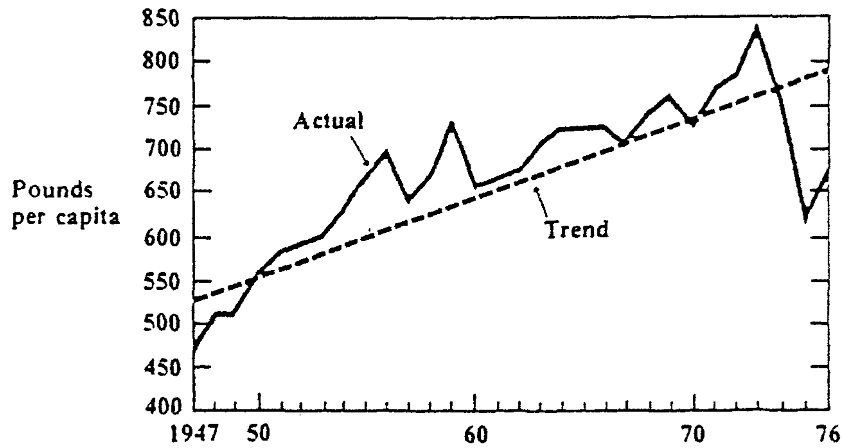
Cement consumption historically has closely followed total construction volume. This is clearly indicated in Figure 2 below. Total volumes consumed therefore depend on trends in construction activity. For example, with the current boom in construction, it is estimated that the demand for cement in 1978 will reach 81 million tons. However, the Portland Cement Association forecasts a slowdown in homebuilding in 1979, which may reduce 1978 consumption levels by as much as 2-3 percent. Demand is expected to rebound in 1980, and may possibly reach 82 million tons.



Source: Portland Cement Association, "The U.S. Cement Industry: An Economic Report," 1978.

Figure 2. Comparison of total construction put in place with cement consumption.

To get a picture of long range historical growth in the industry, analysts commonly look at per capita consumption. Recent national per-capita cement consumption data is presented in Figure 3. The actual data in the figure clearly illustrate the variations caused by changes in construction volume. However, the long term trend line indicates that per-capita use nationally has grown approximately 4% in the period 1947-1977. Some analysts believe that these historical gains in per-capita use of construction materials will level off as the U.S. economy matures. Others feel that per-capita use of cement will continue to grow -- and perhaps accelerate -- as environmental needs and energy costs create a higher demand for concrete, which takes less energy to produce and install than most other materials serving similar functions.



Source: Portland Cement Association, "The U.S. Cement Industry: An Economic Report," 1978.

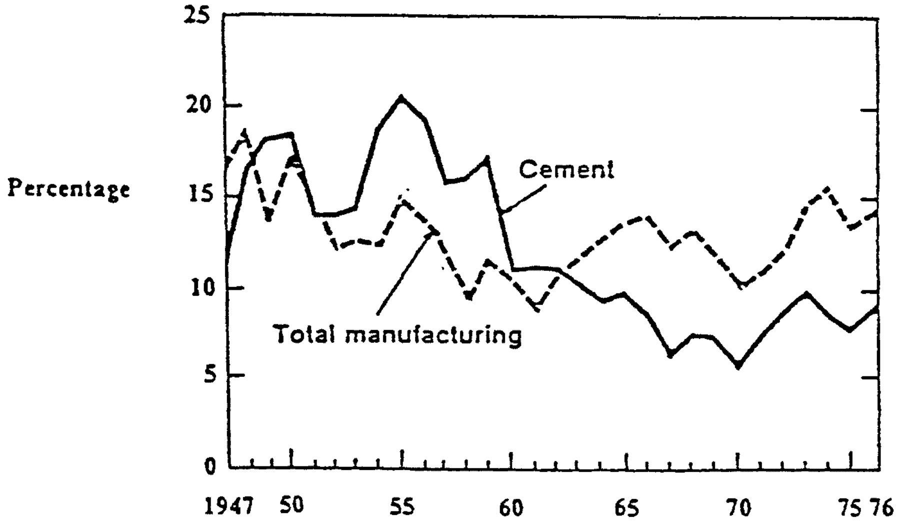
Figure 3. U.S. cement consumption per capita (1947-1976).

INDUSTRY FINANCE AND CAPITAL INVESTMENT

Cement Industry Profit Record

Since the late 1950's, when the cement industry achieved above-average profitability relative to manufacturing industries, overall industry profitability has been declining. Over the past ten years, profit performance has been significantly below that of U.S. industry in total, although there have been significant variations in profitability by individual cement companies. This trend is shown in Figure 4. Since 1967, profit margins have been at or below 5 percent and cash flow as a percent of investment has been in the 6-7 percent range.

Declines in profitability have taken place despite the fact that capacity utilization has been increasing. Industry expansion in the middle 1970's came at a time when construction was in one of its worst depressions. The cement industry found itself with excess capacity and low returns. Return on investment dropped to 8.5 percent in 1974, and to 6.5 percent in 1975, far below the 15 percent return necessary to attract the capital needed for capacity modernization, energy conversion and environmental modifications.



Source: Portland Cement Association, "The U.S. Cement Industry: An Economic Report," 1978.

Figure 4. Average annual rate of return for cement industry and total manufacturing. (Net income after taxes as percentage of net worth.)

Since the 1975 low, the industry picture has improved somewhat, as seen in Table 15 below.

TABLE 15. PERCENT RETURN ON NET WORTH

1972	7.4
1973	9.9
1974	8.8
1975	7.1
1976	9.8
1977	13.0

Source: Portland Cement Association, "The U.S. Cement Industry: An Economic Report," 1978.

Industry Research and Development

Poor profitability and low rates of return in the cement industry have restricted corporate investments in research and development. The Portland Cement Association estimates that less than $15 million is spent by cement firms annually on direct research activities. A few of the larger producers employ people to do process-oriented research on a part-time basis. However, the majority of the firms in the industry contribute to the Portland Cement Association to support its research efforts in the areas of product development, environmental and energy conservation. Beyond research undertaken by the industry's trade association, industry participants have relied upon research performed by equipment manufacturers and foreign industries as major sources of technological innovation. The U.S. cement industry has typically lagged behind its foreign counterparts in implementing new production technologies. For example, conversion from wet to dry processing has been slow, due to high construction costs which result in a low return-on-investment.

New Capital Investment

The following table outlines the capital needs of the cement industry projected by the Portland Cement Association for the period 1976 to 1985.

TABLE 16. CAPITAL REQUIREMENTS OF U.S. CEMENT INDUSTRY, 1976-1985

	$ Billion
New Capacity Additions	1.00
Replacement and Modernization of Plants Built Before 1946	0.74
Process Conversion and Modernization from Wet Process to Dry Process	2.15
Modernization of Existing Dry Process Capacity	0.75
Total for 10-year period	4.64
Work in Process 1976-1980	0.29
Remaining Needs 1981-1985 (stated as 1976 dollars)	4.35

(continued)

TABLE 16. (continued)

	$ Billion
Remaining Needs 1981-1985 - restated to reflect 5% annual inflation over 10-year period (assuming 1981-1985 needs are spread equally over 5 years)	6.15
Work in Process 1976-1980	0.29
Total Capital Needs 10-year period	6.44

Source: Portland Cement Association, "The U.S. Cement Industry: An Economic Report," 1978.

Sources of Capital

According to the Economic Research Department of the Portland Cement Association, financing for past capital projects in the cement industry has depended heavily on internally generated funds (retained earnings and depreciation) as well as on debt issues. Since equity prices in the industry remain below or near book value, equity funding will probably not be a viable source for generating new capital. Therefore the industry will probably continue to rely on its internal cash flow and the debt market as the primary souces of new capital.

Pollution Control Investments

Pollution control facilities have been financed in many cases by municipal guarantee of tax-exempt bonds. Loan repayment is typically accomplished through leasing arrangements. The tax-exempt status of municipal bonds provide a low-cost source of capital for pollution control investments.

After the passage of the Clean Air Act Amendments of 1970, and subsequent development by EPA of new source performance standards, the cement industry was required to restrict the amount of particulate matter emitted in kiln exhaust gas as well as any other area of the cement plant. Prior to 1970, the cement industry invested almost $216 million in air pollution control equipment. In 1974, an estimated 8-14 percent of the capital cost of new construction was attributable to pollution control requirements. Based on plant interviews, it is estimated that 1978 costs for pollution control equipment are 10-15 percent of new plant capital costs. Industry representatives have also indicated that pollution control activities account for roughly 6-10 percent of total operating costs.

Plant closings in recent years may be seen as a response partially to the increasing demand for capital dollars in non-producing pollution control facilities. The Federal Energy Administration Energy Conservation Potential in the Cement Industry, pg.21, indicates that the cement industry has more readily invested in energy conservation technology. Fuel conversion expenditures are ultimately recovered in production cost savings due to reduced fuel requirements.

SECTION 5

PROCESS ANALYSIS

OVERVIEW

There are basically two commercial cement manufacturing processes: the wet process and the dry process. The wet process involves the grinding of raw materials with water to form a slurry containing 30 to 40% moisture. The slurry is blended, as required, and subsequently fed to the kiln. The dry process, on the other hand, does not introduce water during grinding and the raw materials are fed to the kiln in the form of a dry powder.

The wet process was the original cement manufacturing process, and until recently, had advantages over the dry process due to ease of handling and blending of raw materials as well as yielding higher quality clinker. However, improvements in dry blending and material handling techniques, in combination with lower energy consumption used in the dry process, has served to minimize the advantages of the wet process over the dry process. Most new plants or production lines have turned to dry processes in light of increasing energy pressures and the favorable shifts in dry process technology. In fact, eight of the last ten new kilns built have utilized the dry process.

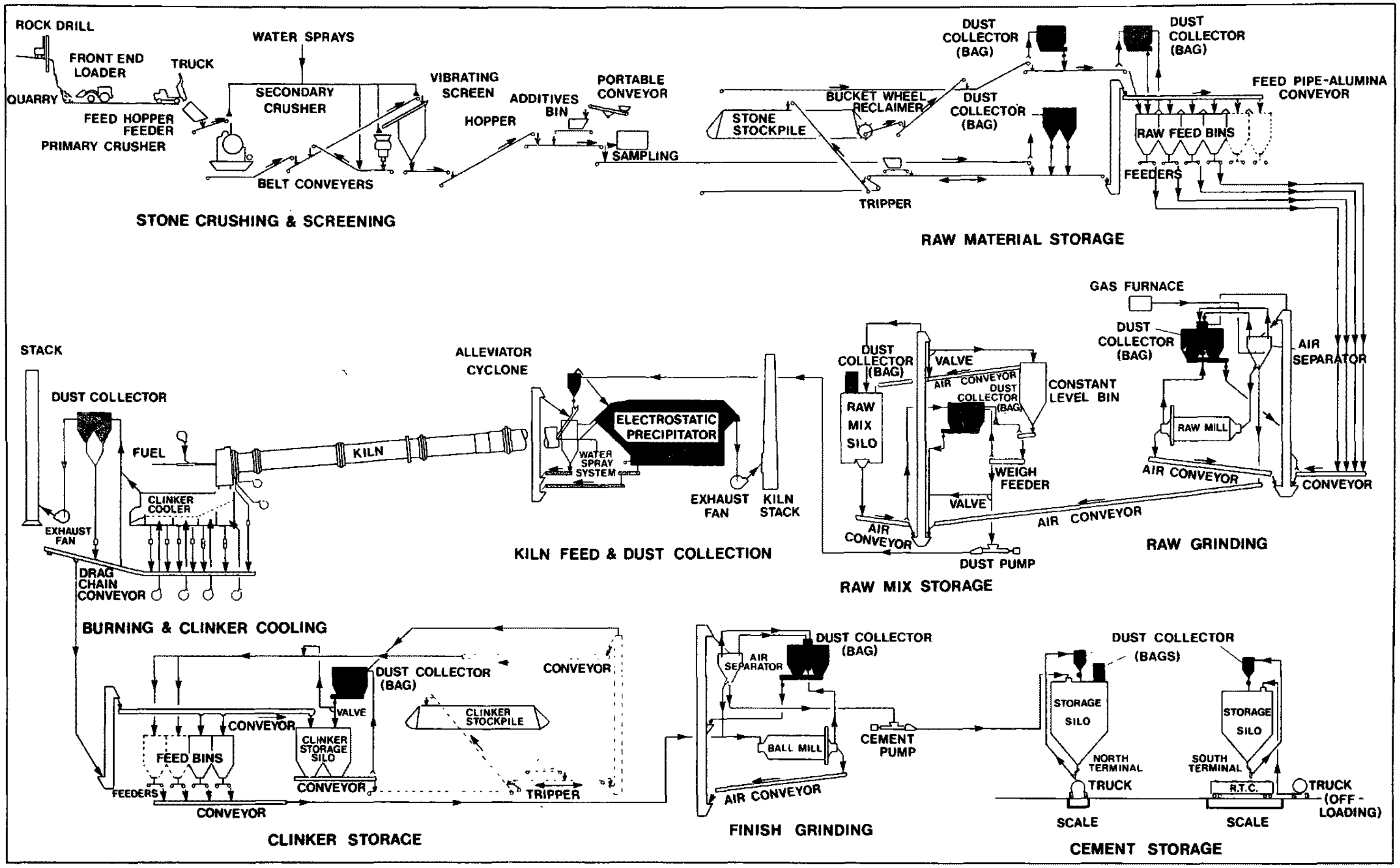
According to the Minerals Yearbook, the concept of larger single-kiln plants will have to be adopted for new plants. This will reduce manpower requirements and yield significant improvements in energy efficiency.[4]

MANUFACTURING PROCESS

Cement manufacturing involves four basic processing stages:

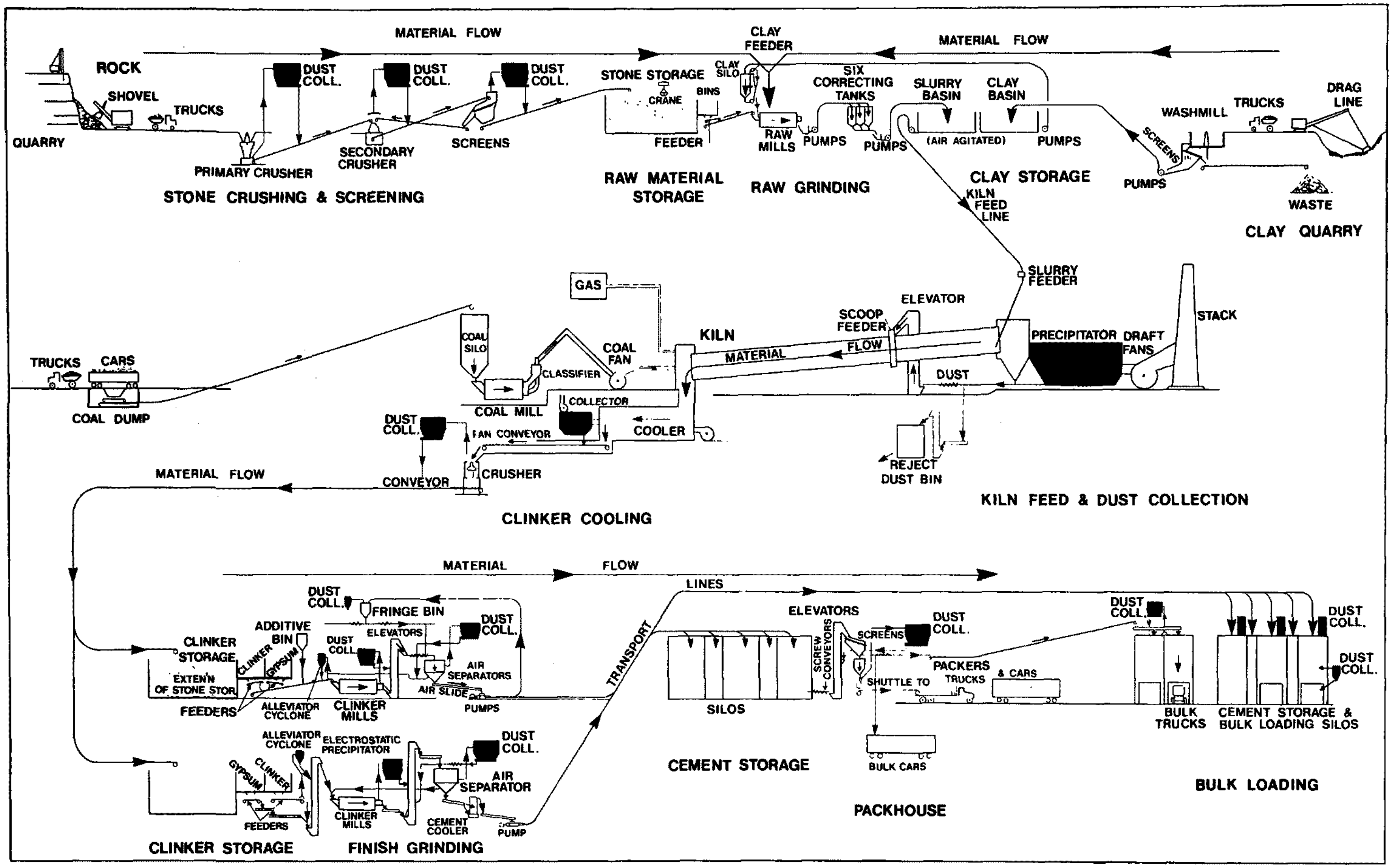
1. Quarrying and Crushing
2. Mixing and Grinding
3. Burning
4. Finish Grinding, Packaging, and Shipping

Typical cement plants using the dry process and wet process are shown in Figures 5 and 6, respectively. Each processing stage is briefly described in the following paragraphs.



Source: Environmental Protection Service, Canada, "Air Pollution Emissions and Control Technology. Cement Industry," Air Pollution Control Directorate, April 1974.

Figure 5. Typical cement plant - dry process.



Source: Environmental Protection Service, Canada, "Air Pollution Emissions and Control Technology. Cement Industry," Air Pollution Control Directorate, April 1974.

Figure 6. Typical cement plant - wet process.

Quarrying and Crushing[1]

Cement production begins with raw materials extraction, generally from a quarry at or near the cement plant. The raw material is comprised of some combination of limestone, cement rock, marl, shale, clay, and iron ore.

Rock is transported to a crushing plant either at the quarry or the cement plant. The primary crusher reduces rock from roughly five feet in diameter to about five inches in diameter. A further reduction in size to about one-half-inch diameter is effected using the second crusher. This material is then stored in silos prior to mixing with other stored raw materials such as clay, silica, alumina, or iron ore.

Other than fugitive dust generation and exhaust gas produced by vehicles in the quarrying and transporting operations, there is little pollution emanating from these operations. Overburden is the material above, and possibly between, seams of limestone. It usually consists of soft clay or soil that would clog the crushers if too much were removed from the quarry with the limestone. Overburden is either hauled away and dumped in some type of land disposal site or piled in an abandoned section of the quarry.

Dust, which can be generated in material transfering operations, is commonly collected by baghouse dust collectors.

Mixing and Grinding

The preparation of raw materials for the kiln involves drying, proportioning, grinding and blending of the various raw materials. Due to the variations in the chemical compositions of these raw materials, no single formula for cement manufacture can be appplied.

This stage of the cement manufacturing process differs depending on whether the dry process or the wet process is implemented. In the dry process, the free moisture content of the crushed raw materials is generally reduced to less than one percent before or during grinding. Direct-contact rotary dryers (6-8 feet in diameter and 60-150 feet long) are widely used in the industry, although the trend in newer plants is for simultaneous drying and grinding. Heat for either process may be derived from kiln gases, clinker cooler exhaust, or directly fired fuels. Figure 5 shows a gas furnace providing hot process air in a system with a rotating raw mill which mixes and grinds the various raw materials. After grinding, the raw material particle size is equivalent to about 200 mesh.

In the wet process, the raw materials are usually proportioned, ground with water in a raw mill, and slurried with approximately 30-40 percent water in large basins. The mixture is fed to agitated storage basins.

With either the wet or the dry process, no significant pollution problems are encountered in the mixing and grinding operation. However, Figure 5 shows baghouse dust collectors in use for material transfer operations.

Burning

Blended and ground raw materials are fed to a kiln. Rotary kilns are most commonly used in both the wet and dry manufacturing processes. Kiln length can be 60-760 feet with diameters of 6-25 feet.

Raw materials are fed into the raised end of the kiln and travel down the incline to the other end where coal, oil, or gas is burned as a fuel. The retention time in the kiln is roughly 1-4 hours, and the temperature range at the lower end of the kiln is 2500°- 3000°F.

Product from the kiln consists of dark, hard nodules called clinker. These nodules are 3/4-inches or less in size and are cooled with air in a clinker cooler prior to storage and further processing. The recovered heated air from the cooler serves as secondary air in firing the kilns.

Air from the clinker cooler, along with combustion gases and water vapor introduced in wet process sytems, passes from the higher end of the kiln through some form of dust collection system, and finally out the stack. These gases carry entrained dust and volatilized matter from the kiln into the dust collection system. The gases also contain varying concentrations of nitrogen oxides (NO_x) and sulfur oxides (SO_x), making this gas stream the most significant source of pollutants in the cement plant. The characteristics of these pollutants and the controls being used are described in Section 6 of this report.

Dust is generated in the clinker cooler where collection devices must be used. Dust collectors are also used on the conveying systems from the clinker cooler to the clinker storage area.

Finish Grinding, Packaging, and Shipping

Clinker is ground into cement with about 3-6 percent gypsum (calcium sulfate) which retards the cement's setting time. Other additives such as air-entraining, dispersing, and waterproofing agents can be added.

Two basic types of grinding circuits can be used. Clinker can be grouped in an open circuit mill or a closed circuit (with recycle of large particles) mill. The final product is about 10 microns in size, similar to the consistency of facial powder. Cement is stored for eventual shipment via rail, truck, or barge.

As shown in Figure 5 and 6, dust collectors are used to control particulate emissions during transfer operations.

TECHNOLOGICAL DEVELOPMENTS

New technology being implemented by the cement industry in the United States deals mainly with the burning stage, but new developments are also taking place regarding raw materials processing and manufacturing process automation. These major developments are briefly reviewed here. A detailed documentation of ongoing world-wide process technology innovations is presented in "Energy Conservation Potential in the Cement Industry."[10]

Preheaters

One of the most significant technological developments in recent years concerns the suspension preheater. This unit can only be used in dry processes, where it is installed just upstream of the kiln. The preheater consists of a series of cyclones connected by pipes through which gases from the kiln pass upward and counter-current to the dry raw material flowing down and around the cyclones.

Suspension preheaters* offer a number of advantages. First, they provide conservation of energy through the transfer of heat from the gas into the raw material feed dust. This, in turn, leads to roughly 40 percent calcination of the feed before it enters the kiln. In designing new plants, the use of preheaters means that the rotary kiln only needs to be about half the length as would be required without a preheater. Detailed descriptions of various types of preheaters used in cement plants are presented in another recent EPA report.[19]

The 1975 Minerals Yearbook reports that an improved preheater system, termed the reinforced suspension preheater (RSP), has been developed by Kawasaki Heavy Industries, Ltd. and Onoda Cement Co. It was claimed that the RSP sytem makes possible the production of cement at rates three times those of conventional supension preheaters. The RSP process is also claimed to be able to reduce atmosphere emission during cement production.[4]

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* Sometimes referred to as air suspension preheaters.

This process is essentially a small direct-fired furnace located between the air suspension preheater and the kiln. Roughly 90 percent calination of the raw materials is achieved in the RSP process which effects an increase in production capacity or a reduced load on the kiln. In the case of a new cement plant, an RSP system allows the use of much shorter kilns. Similar preheating systems have been developed by other Japanese firms.

Fluid Bed (Flash) Calciner

The fluid bed calciner was developed in Japan by Mitsubishi Mining and Cement Company. A fluid bed reactor is fed from the air suspension preheater system to precalcine raw material before feeding them to the kiln. Gagan notes that "the degree of precalination and the specific production is not improved to the same degree with this system as with other precalcining processes although the system is claimed to give improved continuity of operation and better brick life with comparable economy."[9]

Similar systems have been commercially implemented in Japan and Europe. A flash calciner installation is now in the start-up phase at a cement plant in Alabama, the first such unit in the United States.

Roller Mills

A new type of roller mill for the mixing and grinding stage has been implemented in recent years, primarily to improve productivity and improve energy efficiency. The crushing, grinding, drying, mixing, and classifying of raw materials is combined in a single unit which is located between the storage of separate dry raw materials and blended raw materials. Roller mills are used only in dry processes.[2]

Automation

New and modernized cement plants are incorporating relatively sophisticated instrumentation to monitor and, in some cases, control certain aspects of the manufacturing process. Centralized air-conditioned control rooms are being installed where plant personnel can monitor and control ongoing production operations.

FINDINGS

Some of the key points of this section are as follows:

1. Although both wet-process and dry-process plants are presently in operation, practically all new plants will use the dry process with an air suspension preheater.

2. Changes in manufacturing technology are primarly caused by the need to improve energy efficiency.

3. The major source of pollutant emissions is kiln off-gas which contains dust, nitrogen oxides, and sulfur oxides to varying degrees.

4. There is a large number of places in the manufacturing process from which fugitive dust can escape.

5. Much of the new technology has been developed in Japan and in Europe.

SECTION 6

WASTE STREAM CHARACTERISTICS AND CONTROLS

INTRODUCTION

Cement plants generate air pollutants, solid wastes, and water pollutants during the course of their operation. Some of these waste streams offer significant control problems while others are controlled by conventional means. The purposes of this section are to describe each of the waste streams generated by cement plants and to discuss the types of pollution abatement technology applied to the waste streams.

Air emissions are discussed first. These include particulate matter (dust), nitrogen oxides, and sulfur dioxide. Next, solid waste (i.e., waste kiln dust) is covered. The final major area is water pollutants, comprising both point-source and non-point source waste water generation.

AIR EMISSIONS

There are a large number of potential sources of air emissions from cement plants as shown in Table 17. The two most significant sources of emissions are the kiln and clinker cooler where particulate matter is discharged to the atmosphere.

EPA has promulgated new source performance standards (NSPS) limiting the quantities of particulate allowed to be discharged from new or expanded cement plants built or expanded after August 17, 1971. Allowable particulate matter from cement kilns is 0.15 kg/metric ton of feed on a dry basis (0.30 lbs./tons).

Clinker cooler emissions must not contain particulate matter in excess of 0.050 kg/metric ton of feed on a dry basis (0.100 lbs./ton). In addition, for all other operations within the cement plant, no emission source should have an opacity of 10 percent or greater.

Although EPA has not issued NSPS for cement plants covering any other air pollutants, such as nitrogen oxides or sulfur dioxide, the states have developed regulations covering plants built prior to August 17, 1971. All states regulate particulate emissions, and a growing number are regulating nitrogen oxides and sulfur dioxide as well.

TABLE 17. SOURCES OF AIR EMISSIONS

1. Quarry Operations	(a) Drilling
	(b) Blasting
	(c) Loading broken rock
	(d) Transporting or conveying to cement plants
2. Crushing Operations	(a) Unloading rock from quarry
	(b) Crushing rock
	(c) Screening rock
	(d) Conveying to and from storage
	(e) Storage
3. Preparation of Raw Materials	(a) Drying operations
	(b) Conveying and feeding to grinding circuit
	(c) Grinding of raw materials and conveying of ground material (dry process)

(continued)

TABLE 17. (continued)

4. Kiln Operation	(a) Feeding raw material to kiln(s) - dry process
	(b) Gases exhausted from kiln(s)
5. Clinker Cooling	(a) Excess air exhausted from clinker cooler(s)
	(b) Conveying clinker from cooler(s) to finish-grinding mill(s)
6. Finish Grinding	(a) Conveying clinker from storage to finish-grinding mill(s)
	(b) Finish grinding of clinker, gypsum, and additives
	(c) Air classification of finished product and conveying to storage
	(d) Storage
	(e) Bulk loading operations
7. Waste Dust Handling and Disposal	
8. Fugitive Dust	

Source: Gagan, E. W. Air Pollution Emissions and Central Technology. Cement Industry Report EPS 3-AP-74-3, Environmental Protection Service, Department of the Environment, Ontario, Canada 1974.

KILN DUST

Cement kiln exhaust gas contains substantial quantities of particulate matter and is the largest source of air pollution in the plant. In fact, approximately 12 percent of the kiln feed exits from the kiln with the gas (upstream of any air pollution control equipment). As of 1975, about 16.4 million tons of dust are collected annually from cement kiln exhaust gas. Throughout the industry, roughly 73 percent is returned to the cement-making process, while the remaining 27 percent is discarded in some manner.[11]

Thus, for the average portland cement plant in the United States, having an average production rate of 1,670 tons/day, about 325 tons/day of kiln dust are generated. To comply with EPA new source performance standards of 0.3 lbs/ton of feed, about 324.6 tons/day of dust must be collected. This assumes an air pollution control device collection efficiency of 99.88 percent.

Collected kiln dust has a wide particle size range as shown in Table 18. Over 90 percent of the dust particles in this sample were less than 12 microns in diameter. The dust, from which this sample was taken, was collected by an electrostatic precipitator.

Table 18 also shows the concentration distribution of alkalies (sodium and potassium compounds) in the dust sample. The alkali content of collected kiln dust is the most important factor in determining whether the dust can be recycled to the cement manufacturing process. High alkali concentrations in kiln feed can upset kiln operation and may result in off-specification product when low-alkali cement is being produced.

Little analytical information is available on the chemical characteristics of kiln dust. The composition will depend on the particular raw materials used in the kiln feed and the conditions that the dust particles encounter in the kiln. Thus, there is no typical dust composition.

TABLE 18. PARTICLE SIZE ANALYSIS (A) AND DISTRIBUTION ALKALIES IN A SPECIMEN KILN DUST (B)

Particle Size Range (Microns)	Weight Percent	Total Alkalies Percent		Water Soluble Alkalies Percent		Water Insoluble Percent
		Na_2O	K_2O	Na_2O	K_2O	K_2O
+68	0	-	-	-	-	-
-68+48	0.3	0.30	3.62	(C)	(C)	-
-48+34	0.4	0.31	3.46	(C)	(C)	-
-34+24	0.7	0.35	4.51	0.094	1.927	2.58
-24+17	1.8	0.38	5.08	0.117	2.560	2.52
-17+12	5.1	0.40	5.15	0.134	3.072	2.08
-12+6	27.3	0.33	5.35	0.134	3.252	2.10
-6	64.4	0.42	10.72	0.242	8.191	2.53

Notes: (A) Particle size analysis was carried out by the Allis-Chalmers Corporation using an "infrasizer" particle size analyzer.

(B) Low chloride precipitator kiln dust cf. Table 18 No. 2.

(C) Insufficient sample for analysis.

Source: Greening, N. R., F. M. Miller, C. H. Weise, and H. Nagao Elimination of Water Pollution by Recycling Cement Plant Kiln Dust, EPA-600/2-76-194, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 69 pp.

Analyses of two dust samples, one from Germany and the other from Polk County, Georgia, are shown in Table 19. Heavy metals concentrations for these two samples are shown in Table 20. These tables demonstrate that the concentrations of specific cations and anions can vary widely and that some heavy metals, such as lead and zinc, can be present in relatively high concentrations.

TABLE 19. DRY KILN DUST ANALYSES#

		Concentration, Weight Percent A*	B+
Cations			
Lithium	(Li)	0.0064	0.0064
Sodium	(Na)	12.25	0.23
Potassium	(K)	24.50	0.40
Rubidium	(Ru)	0.475	
Magnesium	(Mg)	Trace	0.52
Calcium	(Ca)	9.26	27.31
Aluminum	(Al)		4.16
Anions			
Fluoride	(F)	0.46	
Chloride	(Cl)	1.43	
Bromide	(Br)	0.040	
Iodide	(I)	0.0552	
Carbonate	(CO_3)	29.59	
Sulfate	(SO_4)	9.06	
Borate	(BO_3)	0.152	
Phosphate	(PO_4)	Not detected	
Sulfide	(S)	Trace	

Sample A - Dust collected in Blaubeuren, Germany.

Sample B - Cement dust from Polk County, Georgia used in animal feeding study. Complete elemental analysis not published.

Note: (#) The total number of constituents present in the samples was not reported. Thus, the values shown above do not add up to 100 percent.

Sources: (*) Davis, T. A., and D. B. Hooks. Disposal and Utilization of Waste Kiln Dust from Cement Industry. EPA-670/2-75-043, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975.

(+) Wheeler, W. E., and R. R. Oltjen - Cement Kiln Dust in Diets for Finishing Steers Agricultural Research Service, U.S. Department of Agriculture. ARS-NE-88. Beltsville, Maryland, 1977.

TABLE 20. HEAVY METALS CONTAINED IN KILN DUST SAMPLES, PARTS PER MILLION

	A*	B+
Copper		42
Cobalt		3
Zinc	16,200	145
Chromium	110	110
Lead	5,620	124
Cadmium		4
Manganese	130	152
Selenium		17
Molybdenum		5
Iron	8,400	11,100
Strontium	150	15
Mercury		0.5
Arsenic		7
Cesium	74	
Rubidium	4,750	

Sample A - Cement dust collected in Blaubeuren, Germany.

Sample B - Cement dust collected in Polk County, Georgia.

Sources: (*) Davis, T. A., and D. B. Hooks. Disposal and Utilization of Waste Kiln Dust from Cement Industry. EPA-670/2-75-043, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975.

(+) Wheeler, W. E., and R. R. Oltjen. Cement Kiln Dust in Diets for Finishing Steers. Agricultural Research Service, U.S. Department of Agriculture. ARS-NE-88. Beltsville, Maryland, 1977.

Kiln dust is separated from exhaust gases using one or a combination of the following types of equipment:

1. Cyclone separators
2. Electrostatic precipitators
3. Baghouse collectors
4. Wet scrubber (one known location)
5. Settling chambers

The distribution of dust collection equipment in 101 cement plants surveyed by Southern Research Institute in 1975 is shown in Table 21.

TABLE 21. DISTRIBUTION OF KILN DUST COLLECTION SYSTEMS IN WET AND DRY PROCESS CEMENT PLANTS[1]

Kiln-Dust Collection System	Type of Process and Number of Plants	
	Wet	Dry
Single dust collector		
Cyclones	2	2
Precipitators	31	3
Baghouses	3	3
Wet scrubbers	1	0
Settling chamber	1	0
Combinations of Dust Collectors		
Precipitators and wet scrubbers	1	0
Cyclones and wet scrubbers	1	0
Cyclones and precipitators	14	12
Cyclones and baghouses	4	16
Cyclones, baghouses, and precipitators	2	2
Baghouses and precipitators	1	1
Baghouses and wet scrubbers	0	1

Source: Davis, T. A., and D. B. Hooks. Disposal and Utilization of Waste Kiln Dust from Cement Industry. EPA-670/2-75-043, U. S. Environmental Protection Agency, Cincinnati, Ohio, 1975.

Industry personnel interviewed during the course of this study generally speculated that electrostatic precipitators probably would be used in the design of most future cement plants. They advised that precipitators, along with certain other systems, generally allow them to meet existing federal and state air pollution control standards for kiln dust.

CLINKER COOLER DUST

The clinker cooler is the second largest air pollution source in cement plants. Dust collected from this source is returned to the process (usually clinker storage) rather than wasted. The types of air pollution control equipment used to handle clinker off-gas include the following:

1. Granular bed filters
2. Baghouse collectors
3. Electrostatic precipitators

Interviews with industry personnel indicated that granular bed filters were popular because of cost, dust collection efficiency (air pollution control standards are being met using this equipment), and ease of operation. Granular bed filters are relatively maintenance-free and are able to withstand higher temperatures than baghouse collectors and electrostatic precipitators.[13]

OTHER SOURCES

There are numerous other sources of air pollution generating dust within the cement plant, although they are less significant than kiln exhaust gas and clinker cooler off-gas. These sources were previously listed in Table 17.

Baghouse collectors appear to be most frequently used to control dust emissions from these various sources. According to industry personnel contacted during the course of the study, baghouse collectors allow compliance with applicable federal and state dust emission standards. One of the plants visited had 25 baghouse collectors in use at various locations in the plant. An addition 15 baghouse collectors were being installed at other locations. Another plant had approximately 20 baghouse collectors in use.

Fugitive dust emanates from a variety of sources including raw material storage, clinker storage, coal files, and material transfer operations. Fugitive dust settles on plant property and outside the plant boundaries resulting in varying degrees of damage. For example, alkaline dust can damage automobile finishes. Dust is also a nuisance on roads within cement plants. Either water or oil are used for dust control although neither have proven very effective.

NITROGEN OXIDES

Nitrogen oxides (NO_x) are comprised of nitric oxide (NO) and nitrogen dioxide (NO_2). These gaseous pollutants are formed in combustion processes in quantities that are affected by the following factors:

- Flame temperature
- Kiln temperature profile
- Length of time combustion gases are maintained at high temperatures
- Rate of gas cooling
- Percentage of excess air (particularly in the flame zone
- Nitrogen content in the fuel

McCutchen estimated that the cement industry overall generates 120,500 tons/yr. of NO_x. This compares with a total estimated NO_x generation rate in the United States in 1975 of just over 11.15 million tons/yr., the majority of which comes from steam boilers.

NO_x emissions from three different cement kilns using a dry process were in the range of 43-1,050 ppm, based on tests reported by Daugherty and Wist.[8]

No "end-of-pipe" treatment is presently used by the cement industry to reduce NO_x levels. In fact, little is presently known about how to better operate cement kilns or modify the process to minimize NO_x generation without sacrificing cement product quality.

The Portland Cement Association is currently planning a study to gather additional data on NO_x generation in cement kilns and to determine how various operating conditions affect the formation of NO_x.

Under the Clean Air Act, EPA has the authority to issue NO_x regulations for cement plants as well as other industries. While EPA has not yet specified NO_x standards for the cement industry, such standards have been promulgated for nitric acid plants and certain types of steam boilers. Additional industries will probably be regulated in the future. Also, a growing number of states (e.g., Alabama, Connecticut, Illinois) are regulating NO_x emissions.

As noted previously, little "end-of-pipe" technology has been applied to nitrogen oxides removal. However, automobile manufacturers have reduced NO_x emissions from cars through a combination of engine modifications, exhaust gas recirculation, plus the use of special catalysts to reduce NO_x back to elemental nitrogen and oxygen.

SULFUR OXIDES

Sulfur oxides may be generated in cement kilns from sulfur introduced from the fuel or raw materials. However, these oxides react with oxides of sodium, potassium, or calcium to form sulfate salts inside the kiln. Thus, the emission of sulfur oxides from the stacks are generally minor.

With the trend toward increased use of coal as the primary fuel in cement plants continues, it is expected that larger quantities of high-sulfur coal will be used. The effects of high sulfur coal on cement kiln stack emissions are unknown.

No federal regulations for SO_x removal apply specifically to cement plants. Only one state, Arizona, presently regulates sulfur oxides emissions (6 pounds per ton of cement kiln feed).

DETACHED PLUMES

Stacks from some cement plants periodically exhibit detached plumes which form 20-30 feet above the top of the stack. On-line opacity meters monitoring inside the stack indicate that the plume is not particulate matter as does the fact that there is no visible plume up to 20 feet above the stack. The plume, when it develops, remains visible for unusually long distances down-wind of the stack, suggesting that the plume is probably not simply water vapor. Industry personnel have advised that detached plumes have been observed at cement plants in Alabama, California, Colorado, and Texas.

The exact nature of detached plumes is unknown although it is speculated that they are the result of "smog" formation (i.e., complex reactions among hydrocarbons, ozone, nitric oxide, and nitrogen dioxide). There is little, if any, work presently underway to formally characterize detached plumes.

SOLID WASTE

Dust collected from cement kiln exhaust gas is the principal solid waste generated in cement plants. The physical/chemical characteristics of cement dust were described earlier in this section under "Kiln Dust".

Davis and Hooks have estimated that roughly 73 percent of cement kiln dust that is collected is recycled back to the cement manufacturing process. The dust that is not recycled generally has excessive concentrations of alkali (sodium and potassium oxides) and sulfates that could prevent the final cement product from meeting specifications.

Some plants have installed leaching systems to reprocess collected kiln dust for alkali removal, so that the dust can be recycled to the cement manufacturing process. Leaching involves mixing kiln dust with water, than clarifying the mixture. Clarifier underflow is recycled to the cement kiln while the overflow (which contains most of the sodium and potassium salts) goes to some form of waste water treatment process (to be discussed later in this section).

The use of leaching processes has declined over the past five years due to the need for treating process waste water. Less than a dozen plants in the industry presently have leaching operations.* Other leaching methods have been researched, but none have been commercialized.

The most prevalent method for discarding waste kiln dust is dumping it on or near the plant site. This may be done in piles on unused areas or may be in abandoned sections of near-by quarries from which raw materials have been extracted. Davis and Hooks report that leachate and run-off from kiln dust piles have been found to have pH values in the range of 12-13.[11] This is highly alkaline. No information was found on the extent to which any heavy metals leach from the dust into the run-off or leachate streams, but low metals leaching rates are expected, based on the high pH levels.

Fugitive dust problems from the kiln dust piles do not appear to be severe. At some plants, the dust is wetted down, thus forming cement-like nodules on the surface of the piles which prevents significant amounts of dust from blowing away. One plant reported that morning dew provides sufficient moisture at the surface of their dust pile to generate nodules and minimize fugitive dust problems.

* Personal communication J. Levin, A. T. Kearney, Inc., and J. Riley, EPA Effluent Guidelines Division. July 19, 1978.

Kiln dust has been or can be used in a number of different ways, including those listed below. The Portland Cement Association is conducting experimental work in the use of waste kiln dust for a number of these applications.

- Landfill and soil stabilizer
- Sub-base for roads
- Dump in strip mines to neutralize acid mine drainage
- Fillers for bituminous paving materials and asphaltic roofing materials
- Neutralize acidic waters of bogs, lakes, and streams (as appropriate)
- Neutralize certain industrial wastes such as spent pickle liquor, leather tanning waste and cotton seed delinting waste
- Waste sludge stabilization
- Substitute for lime in waste water treatment systems
- Absorption of SO_2 from stack gas in wet scrubber slurries
- Replacement of soda in green glass[11]

Agricultural uses of cement kiln dust are being researched world-wide, and a number of research studies have been conducted by the U.S. Department of Agriculture. For example, researchers have found that some types of dust have 80 percent of soil neutralizing capacity of lime and about the same liming qualities as pulverized limestone.[15, 16] Dust also provides an inexpensive source of certain fertilizer nutrients, particularly potassium.[17]

Cement dust has also been used in cattle feeding experiments by the Department of Agriculture. The experiments have shown that steers fed cement dust as part of a complete mixed diet had a higher average daily weight gain and an improved feed/gain ratio compared to steers fed a normal control diet.[12] These experiments are continuing. Dust used in these experiments has been taken from a single source.

It is not now known whether any heavy metals present in the dust used for agricultural purposes will have adverse environmental health effects.

WATER POLLUTION

Water pollution is not generally considered a serious problem by the cement industry either for wet-process or dry-process plants. One of the most significant sources of waste water is from leaching operations. However, as noted earlier in this section, less than a dozen of the 172 plants in the United States have leaching operations.

EPA has issued effluent guidelines for cement plant leaching operations. For leaching streams, the limitations to be achieved by 1977 are a pH of 6.0 to 9.0 and total suspended solids of not more than 0.4 kg/kkg (0.8 lbs/ton) of dust leached. These limitations were estimated to be achievable by neutralization and sedimentation. By 1983, no discharge of pollutants will be permitted. The technology recommended to attain zero-discharge is based on electrodialysis.

Non-leaching cement plants were to attain essentially no discharge of pollutants by 1977.[18]

Run-off from coal piles, raw materials piles, and kiln dust is the other main type of waste water generated by cement plants. Effluent guidelines call for containment or treatment of run-off from material storage piles by 1977 to neutralize and reduce suspended solids prior to discharge.

Analysis of waste water from both leaching and non-leaching plants are shown in Tables 22 and 23, respectively. Most cement plants presently do not discharge process waste water into navigable waterways.

LAND USE

Eventually, quarries and mines, from which cement plant raw materials are extracted, are abandoned. Presently, there is little or no attempt to reclaim or backfill these areas. Since quarries are worked for fifty years or more, back-filling would be a long and expensive task.

Land use is also concerned with the location of new cement plants, mines, quarries, and other raw material extraction operations. Bills are presently pending before Congress which would establish a national policy and perhaps call for the promulgation of regulations regarding land use.

TABLE 22. LOADINGS OF POLLUTANT PARAMETERS FOR LEACHING PLANTS

			Leaching Plants			
Parameter	Units Loading/Products	Number of Plants Reporting	Mean Value	Standard Deviation	Minimum	Maximum
pH		11	9.9	2.125	6.0	12.0
Total Dissolved Solids	kg/kkg (lb/ton)		6.621 (13.24)	3.260 (6.52)	0.056 (0.11)	13.056 (26.11)
Total Suspended Solids	kg/kkg (lb/ton)	10	0.906 (1.81)	1.552 (3.10)	0 0	4.497 (8.99)
Alkalinity	kg/kkg (lb/ton)	10	1.381 (2.76)	1.307 (2.61)	0 0	4.013 (8.02)
Potassium	kg/kkg (lb/ton)	4	3.298 (6.59)	4.624 (9.25)	0.178 (0.36)	11.291 (22.58)
Sulfate	kg/kkg (lb/ton)	6	6.667 (13.33)	5.413 (10.83)	0.614 (1.23)	15.677 (31.35)
Temperature Rise	°C (°F)	9	4.45 (8.0)	3.525 (6.3)	0 0	11.0 (19.8)

Source: Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Cement Manufacturing Industry. EPA-440/1-74-005-a, U.S. Environmental Protection Agency, Washington, D.C., 1974, 123 pp.

TABLE 23. LOADINGS OF POLLUTANT PARAMETERS FOR NONLEACHING PLANTS

			Nonleaching Plants			
Parameter	Units Loading/Products	Number of Plants Reporting	Mean Value	Standard Deviation	Minimum	Maximum
pH		77	8.2	1.011	6.0	12.3
Total Dissolved Solids	kg/kkg (lb/ton)	60	0.272 (0.54)	1.374 (2.75)	0 (0)	7.870 (15.74)
Total Suspended Solids	kg/kkg (lb/ton)	58	0 0	4.114 (8.23)	0 (0)	7.337 (14.67)
Alkalinity	kg/kkg (lb/ton)	61	0.087 (0.17)	0.628 (1.26)	0 (0)	3.866 (7.73)
Potassium	kg/kkg (lb/ton)	11	0.078 (0.16)	0.389 (0.78)	0 (0)	1.212 (2.42)
Sulfate	kg/kkg (lb/ton)	56	0 0	0.448 (0.90)	0 (0)	1.619 (3.24)
Temperature Rise	^{o}C (^{o}F)	58	4.53 (8.2)	3.51 (6.3)	0 (0)	17.0 (30.6)

Source: Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Cement Manufacturing Industry. EPA-440/1-74-005-a, U.S. Environmental Protection Agency, Washington, D.C., 1974, 123 pp.

SECTION 7

ENVIRONMENTAL RESEARCH

CURRENT STATUS

Most of the environmental research applicable to the cement industry in the United States is carried out by the Portland Cement Association, pollution control equipment manufacturers, and foreign cement manufacturers and engineering firms. As discussed previously in Section 4, few cement manufacturers in this country devote significant in-house resources to research in the areas of product, process, energy, or environment. This seems to be due to low industry profitability and rate of return on investment. Another factor contributing to relatively low expenditures in R&D is that larger, diversified firms engaged in cement manufacture preferentially devote their research efforts to what are considered higher technology areas with a better promise for profitability such as aerospace, chemicals, and transportation.

Of course, research for the cement industry is ongoing, including environmental R&D. The Minerals Yearbook, 1975, notes that a Japanese firm has developed a highly efficient electrostatic precipitator termed the EP-ES type. This precipitator has been demonstrated to reduce kiln dust concentration in exhaust gas to less than 0.03 grams per normal cubic meter under full operating conditions. Precipitator performance was extremely stable during fluctuations in cement plant operating conditions.

The Portland Cement Association is engaged in a number of environmental research programs including the following:

1. PCA has recently started a small program to measure NO_x emissions at cement plants and determine methods for control, particularly in terms of kiln operating parameter adjustments.

2. A program is being developed with a solid waste management firm to test the feasibility of burning municipal refuse mixed with other fuels in cement kilns.

3. A potential contract with Babcock & Wilcox and the EPA to study the use of FGD scrubber sludge in cement plants.

4. A research program to develop and improve methods of high-alkali kiln dust disposal, treatment, and reuse, including zero-discharge leaching is underway.

Certain environmental research currently being conducted by the U. S. Environmental Protection Agency's Office of Research and Development is expected to be beneficial to the cement industry. For example, a pulverized coal burner is being developed in El Toro, California under an ORD contract which apparently has the potential to reduce nitrogen oxide emissions 80-85 percent over uncontrolled levels.* ORD is also investigating catalytic reduction systems and wet scrubbing devices to effect NO_x removal from industrial and utility combustion systems.

Coal cleaning systems to remove sulfur, both chemical and physical in nature, are being tested in the lab and at power plants. Flue gas desulfurization (FGD), or scrubbing technology, is still under development.

The U. S. Department of Agriculture is continuing its testing program on the use of kiln dust in cattle feeding programs at the Meat Research Center in Nebraska. Tests conducted to date in Beltsville, MD, on steers and lambs have shown that cement dust as a diet supplement enhances growth. Chemical analyses of the animals' vital organs (e.g., heart, brain, liver, kidneys) indicate no apparent uptake of heavy metals from the dust.**

PROCEDURE

Determining current environmental research activities relevant to the cement industry was useful in providing a base-line for estimating the need for future work in this area. Recommendations for future environmental research projects for the cement industry were requested from the following sources:

1. Industry personnel during site visits.

2. The Portland Cement Association.

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* EPA Press Release. September 22, 1978.

** Telephone conversation between Dr. W. E. Wheeler, USDA, and J. E. Levin, A. T. Kearney, Inc., September 21, 1978.

3. EPA personnel familiar with the industry.

4. Other U. S. government personnel working in areas related to cement industry environmental research.

5. Environmental Protection Service, Department of the Environment, Canada.

6. Equipment manufacturers.

7. Kearney personnel familiar with the industry.

A complete listing of the ideas received for environmental research needs of the cement industry from the above sources are listed in Appendix B. In evaluating these ideas in terms of their significance, the following subjective criteria were applied.

1. Research that could have a short-term impact on cement plant pollution control requirements.

2. Research that could have general use by a significant number of cement plants.

3. Research that could help improve national environmental quality.

SPECIFIC ENVIRONMENTAL RESEARCH PROJECTS

This sub-section describes specific environmental research projects which appear to be of most pressing concern. The projects are listed in order of priority as measured against the selection criteria.

Waste Kiln Dust Management

Waste kiln dust is probably the most serious pollution control problem facing the cement industry at this time. Relatively little is known about the dust, so environmentally adequate management techniques are difficult to specify. Therefore, the principal objectives of the proposed project are to (1) characterize waste kiln dust, and (2) determine environmentally adequate waste dust management techniques. Work elements for this project are shown in Table 24.

The project basically consists of data and information compilation, plant visits, sample collection, chemical analytical work, data assessment, and report preparation. About 12-18 months would be required to conduct this work at a level of effort approaching six person-years. Reductions in time and resource requirements could be obtained by minimizing or eliminating some sub-elements.

TABLE 24. WORK ELEMENTS FOR THE PROPOSED WASTE KILN DUST MANAGEMENT STUDY

I. Waste Dust Characterization

A. Quantities Generated

1. Estimate national, regional, and state waste generation rates.

2. Identify factors affecting generation rates (e.g., raw materials, product specifications).

3. Differences in dust generation between plants using wet process, dry process, dry process with preheaters.

4. Project generation rates over the next ten years.

B. Physical Chemical Properties (includes heavy metal concentrations, particle size analysis, alkalies, etc.)

1. Variation in properties between plants.

2. Variation in properties at a single plant over time.

3. Variation in properties between manufacturing processes.

4. Ascertain if any sources of dust are hazardous pursuant to draft Section 3001 regulations being developed by EPA under RCRA.

C. Current Disposal Methods and Costs

1. Onsite vs. offsite disposal.

2. Most common disposal method.

3. Other methods used.

4. Estimated trends.

(continued)

TABLE 24. (continued)

II. Adequate Storage, Handling, Disposal/Reuse Practices (dependent on results of the waste characterization).

1. Description of adequate options and practices.

2. Costs (capital; O&M).

3. Onsite vs. offsite considerations.

4. Availability of sites (where appropriate).

5. Environmental impacts.

6. Economic impacts.

7. Specifically address the adequacy of using waste dust in agricultural/food chain applications (i.e., use on farmland as a lime and nutrient supplement or use as a diet supplement for cattle, sheep, etc.).

Nitrogen Oxides Control

The generation of nitric oxide and nitrogen dioxide appears to be a significant nation-wide air pollution problem, most particularly in urban areas. Since EPA data currently show that cement plants are one of the major stationary sources of NO_x generation, it is appropriate to analyze cement plant NO_x generation.

Like the waste kiln dust project described previously, the NO_x control project would begin with a detailed characterization of NO_x emissions by cement plants. The work elements suggested for this project are listed in Table 25. The emphasis in this project is placed on stack gas testing to determine nitric oxide and nitrogen dioxide concentrations and emission rates under a wide variety of processing conditions. After the plant testing program, options to minimize NO_x generation would be identified and a plant-scale demonstration program undertaken.

TABLE 25. WORK ELEMENTS FOR THE PROPOSED NITROGEN OXIDES CONTROL STUDY

I NO_x Characterization (both NO and NO_2)

- A. Current Emissions Rates
- B. Variations Among Processes and Fuels in Use
- C. Relationships Between Operating Conditions (i.e., flame temperature, excess air, etc.) and NO_x Generation

II Review of Control Options and Their Costs

- A. Process Modifications
- B. Special Burners
- C. External Physical/Chemical Systems

III Plant-Scale Demonstration of Most Attractive Option(s)

The entire project would require roughly two years to complete, assuming one year for the first two phases and another year for the third (demonstration) phase. A level of effort of 5-6 person-years is estimated, excluding demonstration equipment and installation costs.

Use of Cement Kilns as Waste Incinerators

The U.S. Environmental Protection Agency has conducted studies to demonstrate the capability of cement kilns to burn hazardous organic wastes such as waste oils, PCB's and pesticide wastes. This project would determine the overall feasibility of burning such hazardous wastes from other industries in cement kilns.

While this project does not directly address pollution control problems of the cement industry itself, it deals with certain serious nation-wide pollution problems which the cement industry seems to be technologically suited to solve.

The first element to this project is to determine what types of wastes have been successfully disposed of in cement kilns and under what conditions. Further technical demonstrations are not an objective of this project. The key objective is to determine the feasibility of burning hazardous wastes in cement kilns on a long-term commercial scale. What issues must be identified and resolved before commercial operation can take place? How can they be resolved?

The issues that could arise are classified in four basic areas: regulatory, economic, institutional, and social. A few issues are presented as examples.

1. Who would be responsible for conducting burning operations: cement company employees, contractors, government employees, or others? Would labor unions allow non-company employees to conduct burning operations?

2. What would be the price/cost structure for carrying out these operations?

3. What added monitoring, reporting, and control activities would be required? What new regulations would be imposed?

4. What additional liabilities must be assumed by cement manufacturers to carry out these operations?

An illustration of problems that could be encountered is presented in Figure 7.

The project would be conducted by meeting with industry executives, the trade association, government agency personnel and other relevant parties to identify issues and determine how to resolve them. About one year is required to complete the project and prepare a final report. Approximately three person-years of effort would be required.

Sulfur Oxides Control

This project, considered as having the lowest priority of the four presented in this section, is similar in nature and structure to the nitrogen oxides control study. A key reason for conducting this project, however, is that cement plants could prove to be a way to use high-sulfur coal without causing air pollution control problems or adversely affecting product quality. Lime in the raw materials tends to react with sulfur compounds, removing them from the combustion gas. The practical limit to which this phenomenon takes place should be ascertained.

Physical Flow	Physical Functions	Potential Problem Areas	Cost Areas	Regulatory/ Personnel Interface
Hazardous Waste Generator	Containerize Store Ship	Accidents, spills		DOT, EPA
Cement Plant	Unload ---------------- Store ---------------- Move from Storage Feed Kiln	Personnel exposure, spills Corrosion, seepage Personnel exposure, Accidents, spills	Handling, Facilities, Insurance Personnel training	Union, EPA, OSHA
Cement Kiln	Burn	Product quality Equipment damage Operational upsets	Labor, Controls, Fuel savings	Union, EPA, OSHA
Container Disposition	Store ----------------- Transport, Recondition	Corrosion, Personnel exposure, Lack of local options	Transportation, Disposal	EPA, DOT
Air Emissions	Exhaust --------------	Air Pollution	Monitoring, Reporting	EPA

Figure 7. Framework for analysis of issues concerning hazardous waste combustion.

The work elements for the project are listed in Table 26. Sulfur oxides emissions from cement plant stacks would be measured under varying conditions. Control options applicable to sulfur oxides removal would then be determined and analyzed and their interaction with other effluents elucidated.

TABLE 26. WORK ELEMENTS FOR THE PROPOSED SULFUR OXIDES CONTROL STUDY

I SO_x Characterization (particularly SO_2)

- A. Current Emissions Rates
- B. Variations Among Processes and Raw Material Consumption
- C. Variation with Percent Sulfur in Coal
- D. Relationships Between Operating Conditions and SO_x Generation
- E. Effect of SO_x Changes on Particulate and NO_x Concentrations

II Review of Control Options and Their Costs

- A. Process Modifications
- B. Special External Physical/Chemical Systems

III Plant-Scale Demonstration of Attractive Options (as appropriate)

Based on the results of the field monitoring and the review of control options, a decision would be made on the need to demonstrate the most attractive control technology at a cement plant using high sulfur coal.

The first two phases of this program could be completed and a report prepared within one year. About 3-4 person-years would be needed. The time and effort required for a demonstration program would depend on the nature of the system to be demonstrated.

SECTION 8

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APPENDIX A

CEMENT MANUFACTURERS AND PLANT LOCATIONS

State	Company/ Total Capacity (thousand ton)	Plant Location	Cement Capacity (thousand ton)
Alabama	Alpha Portland/2,050	Birmingham	345
	Citadel/1,050	Birmingham	300
		Demopolis	750
	Ideal/6,310	Mobile	470
	Martin Marietta/4,940	Roberta	820
	National Cement/800	Ragland	800
	Universal Atlas/3,614	Leeds	634
		Total Alabama	4,119
Arizona	Amcord/3,952	Clarkstate	620
	California Portland/3,030	Rillito	1,100
		Total Arizona	1,720
Arkansas	Arkansas Cement/850	Foreman	850
	Ideal/6,310	Okay	395
		Total Arkansas	1,245

APPENDIX A

CEMENT MANUFACTURERS AND PLANT LOCATIONS
(Continued)

State	Company/ Total Capacity (thousand ton)	Plant Location	Cement Capacity (thousand ton)
California	Amcord/3,952	Riverside	733
		Oro Grande	1,147
	California Portland/3,030	Cotton	780
		Mojave	1,150
	Flintkote/2,440	San Andreas	630
		Redding	290
	General Portland/4,892	Lebec	610
	Haiser/3,743	Permanente	1,598
		Lucerne Valley	1,015
	Lone Star/6,023	Davenport	395
	Monolith/700	Monolith	500
	South Western/2,660	Victorville	1,128
		Total California	9,976
Colorado	Ideal/6,310	Portland	885
		Boettcher	325
	Martin Marietta/4,940	Lyons	436
		Total Colorado	1,646
Florida	Florida Mining/Minerals/560	Brooksville	560
	General Portland/4,892	Tampa	1,110
		Miami	528
	Maule/1,200	Hialeah	1,200
	Rinker Portland Cement/520	Miami	520
		Total Florida	3,918

APPENDIX A

CEMENT MANUFACTURERS AND PLANT LOCATIONS
(Continued)

State	Company/ Total Capacity (thousand ton)	Plant Location	Cement Capacity (thousand ton)
Georgia	Marquette/4,268	Rockmart	255
	Martin Marietta/4,940	Atlanta	662
	Medusa/3,656	Clinchfield	800
		Total Georgia	1,717
Hawaii	Cyprus Hawaiian Cement/450	Ewa Beach	450
	Kaiser/3,743	Waianae	320
		Total Hawaii	770
Idaho	Oregon Portland/775	Inkom	210
		Total Idaho	210
Illinois	Centex/1,071	La Salle	376
	Marquette/4,268	Oglesby	509
	Medusa/3,656	Dixon	611
	Missouri Portland/2,630	Joppa	1,314
		Total Illinois	2,810
Indiana	Lehigh/2,955	Mitchell	750
	Lone Star/6,023	Green Castle	752
	Louisville/2,360	Logansport	520
		Speed	1,250
	Universal Atlas/3,614	Buffington	594
		Total Indiana	3,866

APPENDIX A

CEMENT MANUFACTURERS AND PLANT LOCATIONS
(Continued)

State	Company/ Total Capacity (thousand ton)	Plant Location	Cement Capacity (thousand ton)
Iowa	Lehigh/2,955	Mason City	605
	Marquette/4,268	Des Moines	467
	Martin Marietta/4,940	Davenport	512
	Northwestern States/1,050	Mason City	1,050
	Penn-Dixie/2,281	West Des Moines	440
		Total Iowa	3,074
Kansas	Ash Grove/1,306	Chanute	516
	General Portland/4,892	Fredonia	407
	Lone Star/6,023	Bonner Springs	451
	Monarch/600	Humbolt	600
	Universal Atlas/3,614	Independence	412
		Total Kansas	2,386
Kentucky	Flinkote/2,440	Kosmosdale	660
		Total Kentucky	660
Louisiana	Lone Star/6,023	New Orleans	414
	OKC/1,105	New Orleans	675
		Total Louisiana	1,089
Maine	Martin Marietta/9,940	Thomston	495
		Total Maine	495

APPENDIX A

CEMENT MANUFACTURERS AND PLANT LOCATIONS
(Continued)

State	Company/ Total Capacity (thousand ton)	Plant Location	Cement Capacity (thousand ton)
Maryland	Alpha Portland/2,050	Lime Kiln	420
	Lehigh/2,995	Union Bridge	900
	Marquetta/4,268	Hagerstown	541
		Total Maryland	1,861
Michigan	Aetna/600	Essexville	600
	Amcord/3,952	Detroit	752
	Dundee/2,260	Dundee	1,000
	Jefferson Maine/270	Detroit	270
	Medusa/3,656	Charlevoix	769
	National Gypsum/3,468	Alpena	2,382
	Penn-Dixie/2,281	Petoskey	612
	Wyandotte/400	Wyandotte	400
		Total Michigan	6,785
Mississippi	Marquette/4,268	Brandon	288
	Texas Industries/1,543	Artesia	415
		Total Mississippi	703
Missouri	Alpha Portland/2,050	St. Louis (Lemay)	280
	Dundee/2,260	Clarksville	1,260
	Marquette/4,268	Cape Girardeau	335
	Missouri Portland/2,630	St Louis	752
		Kansas City	564
	River	Selma	1,200
	Universal Atlas/3,614	Hannibal	625
		Total Missouri	5,016

APPENDIX A

CEMENT MANUFACTURERS AND PLANT LOCATIONS
(Continued)

State	Company/ Total Capacity (thousand ton)	Plant Location	Cement Capacity (thousand ton)
Montana	Ideal/6,310	Trident	330
	Kaiser/3,743	Montana City	320
		Total Montana	650
Nebraska	Ash Grove/1,306	Louisville	790
	Ideal/6,310	Superior	235
		Total Nebraska	1,025
Nevada	Centex/1,041	Fernley	400
		Total Nevada	400
New Mexico	Ideal/6,310	Tijeras	500
		Total New Mexico	500
New York	Alpha Portland/2,050	Cementon	510
		Jamesville	170
	Atlantic/1,550	Ravena	1,550
	Flintkote/2,440	Glens Falls	560
		Howes Cave	300
	Hudson/750	Kingston	750
	Independent Cement/670	Hudson	670
	Lehigh/2,955	Cementon	495
	Marquette/4,268	Catskill	649
		Total New York	5,654

APPENDIX A

CEMENT MANUFACTURERS AND PLANT LOCATIONS
(Continued)

State	Company/ Total Capacity (thousand ton)	Plant Location	Cement Capacity (thousand ton)
N. Carolina	Ideal/6,310	Castle Hayne	610
		Total N. Carolina	610
Ohio	Columbia/950	Zanesville	600
	General Portland/4,892	Paulding	554
	Marquette/4,268	Superior	285
	Medusa/3,656	Sylvania	282
	Southwestern/2,660	Fairborn	730
		Total Ohio	2,451
Oklahoma	Ideal/6,310	Ada	620
	Martin Marietta/4,940	Tulsa	617
	OKC/1,105	Pryer	430
		Total Oklahoma	1,667
Oregon	Oregon Portland/775	Huntington	205
		Lake Oswego	360
		Total Oregon	565

APPENDIX A

CEMENT MANUFACTURERS AND PLANT LOCATIONS
(Continued)

State	Company/ Total Capacity (thousand ton)	Plant Location	Cement Capacity (thousand ton)
Pennsylvania	Amcord/3,952	Stockertown	700
	Copley/1,250	Nazareth	1,250
	Keystone/660	Bath	660
	Lone Star/6,023	Nazareth	658
	Louisville/2,360	Bessemer	590
	Marquette/4,268	Neville Island	471
	Martin Marietta/4,940	Northampton	426
	Medusa/3,656	Wampum	723
		York	471
	National Gypsum/3,468	Evansville	870
	Penn-Dixie/2,281	Nazareth	305
		West Winfield	330
	Universal Atlas/3,614	Northampton	427
		Universal	475
	Whitehall/790	Cementon	790
		Total Pennsylvania	9,146
S. Carolina	Giant/855	Harleyville	855
	Gifford-Hill/1,410	Harleyville	564
	Santee/1,270	Holly Hill	1,220
		Total South Carolina	2,639
S. Dakota	South Dakota Cement/1,140	Rapid City	1,140
		Total South Dakota	1,140

APPENDIX A

CEMENT MANUFACTURERS AND PLANT LOCATIONS
(Continued)

State	Company/ Total Capacity (thousand ton)	Plant Location	Cement Capacity (thousand ton)
Tennessee	General Portland/4,892	Chattanooga	477
	Ideal/6,310	Knoxville	470
	Marquette/4,268	Nashville	235
		Cowan	233
	Penn-Dixie/2,281	Kingsport	330
		Richard City	264
		Total Tennessee	2,009
Texas	Alpha Portland/2,050	Orange	325
	Capitol Aggregates/355	San Antonio	355
	Centex/1,071	Corpus Christi	265
	General Portland/4,892	Fort Worth	731
		Dallas	475
	Gifford-Hill/1,410	Midlothian	846
	Gulf Coast/600	Houston	600
	Ideal/6,310	Houston	620
	Kaiser/3,743	San Antonio	490
	Lone Star/6,023	Houston	526
		Maryneal	545
	San Antonio Portland/390	Cementville	390
	Southwestern/2,660	El Paso	327
		Odessa	275
		Amarillo	200
	Texas Industries/1,543	Midlothian	1,128
	Universal Atlas/3,614	Waco	352
		Total Texas	8,450

APPENDIX A

CEMENT MANUFACTURERS AND PLANT LOCATIONS (Continued)

State	Company/ Total Capacity (thousand ton)	Plant Location	Cement Capacity (thousand ton)
Utah	Ideal/6,310	Devil's Slide	360
	Utah Portland/350	Salt Lake City	350
		Total Utah	710
Virginia	Lone Star/6,023	Roanoke	1,200
		Norfolk	330
		Total Virginia	1,530
Washington	Columbia/950	Bellingham	350
	Ideal/6,310	Seattle	490
	Lehigh/2,955	Metaline Falls	205
	Lone Star/6,023	Seattle	752
		Total Washington	1,797
W. Virginia	Martin Marietta/4,940	Martinsburg	972
		Total West Virginia	972
Wisconsin	Natural Gypsum/3,468	Superior	216
	Universal Atlas/3,614	Milwaukee	95
		Total Wisconsin	311
Wyoming	Monolith/700	Laramie	200
		Total Wyoming	200
		Total U.S.A.	96,492

Source: Economic Research Department, Portland Cement Association, December 31, 1977.

APPENDIX B

SUGGESTIONS RECEIVED FOR CEMENT INDUSTRY ENVIRONMENTAL RESEARCH

Air Pollution Control

1. Investigate the nature of detached plumes which occasionally emanate from some cement plant stacks. How can these plumes be controlled if they are potentially harmful to air quality?

2. Characterize plume composition especially with respect to nitrogen oxides (NO_x) emissions from cement plants. How can kiln operating variables be modified, without sacrifice to product quality, to minimize NO_x generation?

3. Assess the effects of high-sulfur coal on emissions from cement plants as well as on the properties of the final product. Should larger amounts of high-sulfur coal be used in cement plants?

4. Conduct overall material balances for sulfur compounds in the kiln system.

5. Analyze the physical and chemical characteristics of stack emissions in plants where efficient dust collectors are in use.

6. What are the effects of non-homogeneity of fuels and other raw materials on kiln system dust collector performance?

7. Determine the disposition of trace elements (e.g., heavy metals) in kiln systems where non-premium or refuse-derived fuels are used.

8. Characterize the emissions from a kiln system equipped with an air suspension preheater and a flash calciner. Are these emissions different from those of wet-process systems or dry-process systems without preheaters?

9. Evaluate the phenomenon of alkali flaking at the kiln electrostatic precipitator. What are the effects on precipitator performance?

Solid Waste Management

1. Find better ways to achieve fugitive dust control, particularly from raw material storage piles, coal piles, and clinker storage areas.

2. What is the benefit of controlling cement dust emissions? Are they really harmful?

3. Develop environmentally acceptable dust control agents for roads in cement plants.

4. Determine economically-feasible and environmentally acceptable ways to dispose, reuse, or recycle waste cement kiln dust.

5. Demonstrate the feasibility of burning municipal refuse mixed with other fuels in cement kilns.

6. The chemical characteristics of waste kiln dust should be assessed.

7. Determine the variation in heavy metal content in waste kiln dust from various plants. What are the primary sources of the heavy metals?

8. Where waste kiln dust is used on farmland, what is the extent of metals uptake by various types of crops?

9. Assess the ecological and medical impacts of the trace elements in waste kiln dust.

Hazardous Wastes Disposal

1. The technical feasibility of incineration of PCB and other hazardous substances in cement kilns should be further demonstrated.

2. Demonstrations for burning refuse-derived fuels and waste fuels in cement kilns should be conducted.

3. Assess the regulatory, economic, social, and other institutional factors associated with burning PCB's, waste fuels, or other types of hazardous wastes in cement kilns.

Water Pollution Control

1. Study non-point source water pollution generation at cement plants and evaluate the costs and benefits of controls implementation.

Process/Product Issues

1. Determine the feasibility of relaxing cement standards for alkali content to some extent, thereby reducing the amounts of waste kiln dust generated.

2. Demonstrate use of cement plant waste dust as a substitute for limestone in scrubbers, especially for power plants.

3. Demonstrate the use of FGD sludge as a substitute for gypsum in cement.

4. Define the institutional issues involved in changing product specifications so that smaller amounts of low-alkali cement would be required.

5. Demonstrate innovative kiln and furnace designs, and determine the nature and quantities of their emissions.

6. Assess the feasibility of an increased use of non-thermal cement.

7. To what extent and at what costs can kiln raw materials be changed to reduce alkali problems?

8. Develop improved particulate collects which could stand high temperature excursions and higher air-to-surface ratios, possibly incorporating electrostatic precipitation.

Regulatory Issues

1. What are the overall effects of all government regulations on the cement industry?

2. Establish a procedure to assure that regulations issued by various Federal, state, and local agencies do not conflict with each other.

3. The standard-setting process for separate environmental pollutants should be coordinated in a way that is likely to achieve minimum adverse environmental impacts while recognizing that tightening the standard for one pollutant may limit the capability to reduce another pollutant below some regulated level.

4. The feasibility of changing the units for gaseous emissions regulations to mass per unit of production should be investigated.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

This project was initiated to obtain a comprehensive assessment of the cement industry and its environmental research needs. This report contains a profile of the U.S. cement industry; an analysis of the cement manufacturing processes; a discussion of waste stream characteristics and controls; and an assessment of research needs for the cement industry. Recommendations for further investigation were proposed in several areas: waste kiln dust management, nitrogen oxides control, use of kilns as waste incinerators, and sulfur oxides control.

17. KEY WORDS AND DOCUMENT ANALYSIS

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