CHOICE OF TECHNOLOGY IN THE CEMENT INDUSTRY – A COMPARISON OF THE UNITED STATES AND SWEDEN*

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1. INTRODUCTION

In recent years, a number of studies have shown that there are large international differences in energy consumption per unit of output in many industries. There are several reasons why such differences arise: the output mix varies, even within industries; the choice of technology varies; and input combinations differ even if the same technology is used.

It is natural for an economist to suppose that a large share of these differences can be explained by long-run international differences in relative factor prices. This was shown to be true, for example, in a recent study which compared the composition of industrial output and the use of energy in industry in the United States, Sweden and West Germany.[1] But it is obvious that there are many factors besides relative prices which also play an important role.

It is the purpose of the present paper to provide a more complete framework and, within this framework, to explain why the choice of technology varies internationally. Obviously, this kind of study requires rather detailed analysis and it is necessary,

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[1] B. Carlsson, "Relativprisutvecklingen på energi och dess betydelse för energiåtgång, branschstruktur och teknologival i en internationell jämförelse" (The Development of Relative Energy Prices and Its Impact on Energy Use, Industrial Structure and Choice of Technology; An International Comparison). Appendix 12 to the report to the Energy Commission by the Expert Group on Policy Instruments. DS I 1977:17, Stockholm 1977. Also published by IUI as Booklet no. 83.

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therefore, to focus on a particular sector and even on a single process.

For several reasons the cement manufacturing process has been chosen for this study: The output is homogeneous; the production process is relatively uncomplicated and separable from other processes; and it is known from the start that the choice of production techniques has been very different in various countries, at least up until recently. In addition, cement manufacturing is one of the most energy consuming processes in the whole of manufacturing industry.

As indicated in table 1, there are at least five types of processes used in cement production. The differences among them will be explained below. The purpose of the table is merely to show that even in an extremely homogeneous and capital intensive industry, the choice of technology may vary substantially among countries. The question with which we are concerned is why different choices are made. For reasons having to do with data availability, the analysis will be limited to a comparison of the United States and Sweden.

Table 1. International Differences in the Distribution of Cement Manufacturing Capacity by Process

Country		Wet process %	Semi-dry process %	Dry process, %			Shaft %
				Total	Long dry	Suspension preheater	
United States	(1976)	55	-	45	29	16	0
Sweden	(1975)	56	8	36	-	36	0
West Germany	(1974)	5	26	66	..	..	3
United Kingdom	(1974)	69	16	15	..	..	0
Italy	(1974)	13	46	40	..	..	1

Sources: Portland Cement Association, U.S. Portland Cement Industry: Plant Information Summary, December 31, 1976;
Cementa AB;
Gordian Associates, Industrial International Data Base, The Cement Industry, NATO/CCMS-46. New York.
Energy Research and Development Administration, 1976, p. 37.

Section 2 describes the cement manufacturing process and provides a brief history of the technological development of the industry. Section 3 brings out some salient features of the industry and how they differ between Sweden and the United States. This analysis is based largely on interviews conducted by the author during the Spring of 1977 in both the Unites States and Sweden. In Section 4, some investment cost calculations for both wet and dry kilns using price data for 1970 and 1975 will be presented. Section 5 discusses the differences between actual and theoretical costs of wet and dry process plants and section 6 analyzes the reasons for the delayed introduction of the suspension preheater process. Section 7 concludes the study.

2. THE CEMENT MANUFACTURING PROCESS - DESCRIPTION AND BRIEF HISTORY

The raw material for cement production consists mainly of limestone which is crushed and then ground into a fine powder. In the dry cement manufacturing process, the powder is fed directly into a kiln where it is calcined (burned) to form clinker. In the wet process, water is added to form a slurry which is then fed into the kiln. The kiln is essentially a huge cylindrical steel rotary tube lined with firebrick. Some kilns have a diameter up to 8 meters and are up to 230 meters long -- longer than the height of a 70-story building. The kiln axis is slightly inclined, and the raw material (either slurry or dry) is fed into the upper end. At the lower end is an intensely hot flame which provides a temperature zone of about 1500^{o} C by the precisely controlled burning of coal, oil or natural gas under forced draft conditions.[1]

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[1] Energy Conservation Potential in the Cement Industry, Conservation Paper number 26, prepared by the Portland Cement Association for the Federal Energy Administration. June 1975 (Springfield,Va.: U.S. Department of Commerce, National Technical Information Service, PB-245 159), p.1.

After the clinker is cooled, it is ground with 4-6 % gypsum into cement.

The earliest cement kilns were dry process but of a different type (vertical shaft kilns) than the modern ones. In the early 1900's, long rotary horizontal kilns began to be introduced. Because of the relative ease of grinding and homogenizing the raw materials under wet conditions, the wet process came to dominate. The drawback of the method, however, is that it is much more fuel consuming than the dry process, since the water added in the raw mill must be dried away before calcination can take place.

In 1927, a semi-dry process was patented in Germany. It was named the Lepol process (acronym for the inventor, Lellep and the equipment manufacturer, Polysius).[1] The basic principle of the process is to use the exhaust gases from the kiln for drying and preheating the raw materials before inserting them into the kiln. Thus, the main advantage is energy saving. The process became popular in Europe but was hardly used at all in the United States.

In 1933, yet a new type of dry process cement kiln was patented in Czechoslovakia. Then World War II intervened, but after the war the patent was acquired by a German equipment manufacturer, and the first installation was made in 1950 in Germany.[2] In a conventional dry kiln, three sub-processes take place simultaneously. At the upper end, where the materials are fed into the kiln, preheating takes place. In the middle, calcining occurs, and at the lower end the final burning. Since only a fraction of the raw materials on the rotating kiln wall is exposed to the hot air,

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[1] S. Mängel, Technischer Fortschritt, Wachstum und Konzentration in der Deutschen Zementindustrie. Doctoral dissertation. 1972, p. 24.

[2] Hoke,M. Garrett, "The Potential Promise - Prospects and Pitfalls in Energy Conservation by the U.S. Cement Industry", in Proceedings of the FEA-PCA Seminar on Energy Management in the Cement Industry. Federal Energy Administration Conservation Paper Number 47, FEA/D-76/091, p. 268.

the heat exchange is very inefficient and the fuel consumption therefore high. Also, since the sub-processes require different temperatures, it is difficult to optimize the temperature throughout the kiln, and different scale factors seem to apply. A number of interviews conducted by the author have indicated that difficult operational problems arise in long conventional kilns as the scale is expanded.

The essence of the new kiln is that it separates the preheating from the other sub-processes which take place in a conventional kiln. Preheating of the materials takes place in cyclones where hot air from the kiln is blown in the opposite direction to that of the powder, with the result that the powder is temporarily suspended in the air. This provides a much more efficient heat exchange between the air and the materials than can be achieved in a kiln and the amount of energy required is therefore reduced very significantly.

In recent years, Japanese firms with license rights on West German suspension preheaters have developed an auxiliary burner system in the preheater, so that not only preheating but also up to 95% of the calcination takes place before the feed enters the kiln. In such a precalcining system both the length and the diameter of the kiln can be further reduced, and energy consumption may also be slightly reduced. But the main advantage of the precalcing system may lie in its ability to deal with some operational problems encountered in suspension preheater systems.[1] The first precalcining system was developed in Japan in 1966.[2] The process has already been introduced in the United States (1976) and is currently being introduced in Sweden.

The development of cement production technology over the past 30 years is illustrated in figure 1. Until 1950, conventional long

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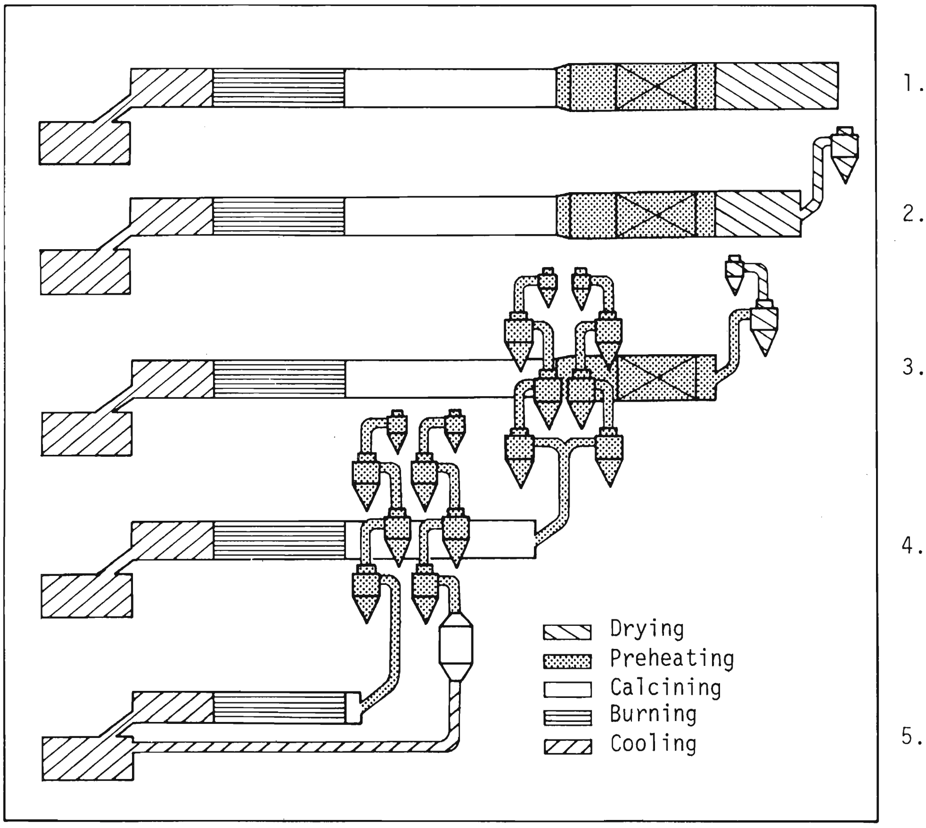
[1] Gordian Associates, Industrial International Data Base, The Cement Industry. NATO/CCMS-46. New York: Energy Research and Development Administration. 1976, p.14.

[2] FEA-PCA Proceedings, p.267.

Figure 1. Technical Change in Cement Kilns



1. Conventional long (dry) kiln
2. Dry kiln with 1-stage preheater
3. Dry kiln with 2-stage preheater
4. Dry kiln with 4-stage preheater
5. Dry kiln with 4-stage preheater and precalciner

Source: FLS-newsfront. F.L. Smidth. Copenhagen 12.1974.

kilns were used. With the arrival of cyclone preheaters, the length and diameter of the kiln could be substantially reduced. In order to produce 1 225 tons in 1950, a kiln of 143 meters and 4.8 meters' diameter was required. In the 1970's, a kiln of 63 meters and a diameter of 4.2 meters could produce the same output.[1]

With the preheating of the materials taking place outside the kiln, the length and the diameter of the kiln can be substantially reduced for the same capacity. This, in turn, means a (theoretical) saving in capital cost, since preheater cyclones are cheaper to build and install than the additional kiln section which would otherwise be required. Alternatively, for the same capital cost, much larger capacity can be obtained. Since the number of people required to operate the kiln is about the same, no matter what size and type of the kiln, the suspension preheater process also offers substantial labor saving.

3. INDUSTRY CHARACTERISTICS

3.1 Post-War Development in the U.S. and Swedish Cement Industries

Output and Capacity

Cement production grew in the United States at a rate of 2.9% per year 1950-73 and at 2.3% per year in Sweden 1950-75. In both countries cement production grew less rapidly than total manufacturing output. However, as can be seen in figure 2, the growth rate has been fairly constant over the whole period in the United States while it was high in Sweden up to 1965 and has since stagnated. It is shown also in figure 2 that from the mid-1950's U.S. production capacity increased much faster than output. This re-

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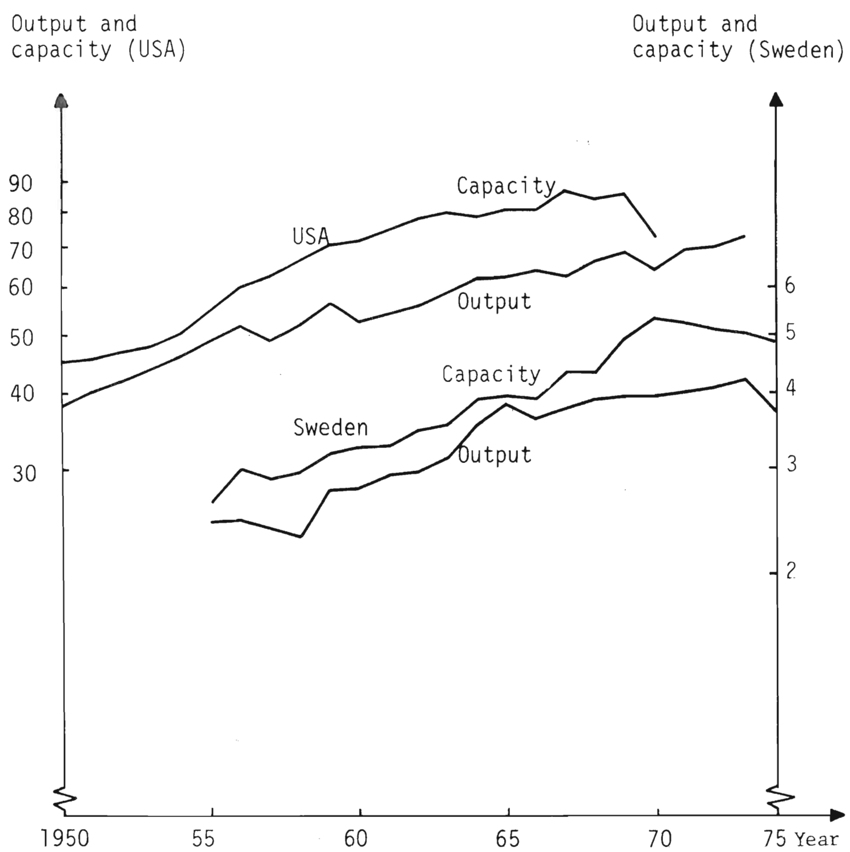
[1] H.R. Norbom, "Wet or Dry Process Kiln for your New Installation?" Rock Products, Vol.77, No.5 (May 1974), pp.92-93.

Figure 2. Actual Output and Production Capacity in the Cement Industry in the United States and Sweden 1950-1975

Million metric tons



Sources: Energy Conservation Potential ..., op.cit., p. 6 (Production obtained as U.S. consumption minus imports); FEA-PCA Proceedings ..., op.cit., p. 43; Cementa AB sulted in considerable overcapacity which persisted until the end of the 1960's. In Sweden the capacity utilization has been higher on the average than in the United States (85% vs. 81%), but it has fallen drastically after 1968 when the increases in the demand for cement fell far short of the capacity increases.

Kiln and Plant Size

In spite of the fact that Swedish cement capacity in 1975 was only about 6% of U.S. capacity, table 2 shows that Swedish cement kilns are larger, on the average, than American ones. This is true not only at the present time; they have also been larger in each time period (with two exceptions: 1936-40 and 1961-65).

In table 3 the size and age structure of cement kilns and their distribution by process in the United States and Sweden are shown. The majority of cement kilns and more than half of cement capacity in both countries are still wet process. However, in Sweden no wet kilns have been installed since 1967, while in the United States the last wet kilns were put in in 1975.

Other major differences between Sweden and the United States arise through the differences in the size and distribution by process of dry kilns. Swedish dry kilns are 50% larger than U.S. dry kilns. This has to do with the fact that over 80% of the Swedish dry kiln capacity is in suspension preheaters, whereas in the United States the corresponding figure is only 35%. No long dry kilns at all exist in Sweden, but there are two semi-dry kilns which are scheduled to be scrapped in 1978. It is also noteworthy that the two Swedish SP kilns built in 1969-70 are larger than the five American SP kilns built in 1976.

It is also true that Swedish cement plants are larger than U.S. plants: the average Swedish plant had a capacity in 1975 of 725 000 tons of cement, while the average American plant had a capacity in 1976 of 545 000 tons.[1]

[1] "Tons" refers to metric tons throughout unless otherwise stated; 1 metric ton = 1.1023 short tons.

Table 2. Size and Age Structure of Kilns in the Cement Industry in the United States (1976) and Sweden (1975)

	United States			Sweden		
Kiln age	No. kilns	Clinker capacity 1 000 metric tons	Average capacity per kiln 1 000 metric tons	No. kilns	Clinker capacity 1 000 metric tons	Average capacity per kiln 1 000 metric tons
1976	6	2 800	467	0	-	-
1971-1975	34	13 766	405	0	-	-
1966-1970	34	11 606	341	3	1 732	577
1961-1965	47	14 272	304	4	858	215
1956-1960	82	16 336	199	1	214	214
1951-1955	59	8 930	151	4	584	195
1946-1950	36	4 757	132	3	584	195
1941-1945	9	1 316	146	1	190	190
1936-1940	7	1 366	195	4	620	155
1931-1935	6	615	103	0	-	-
Before 1931	65	5 687	87	0	-	-
	385	81 451	212	20	4 993	250
Year of construction of average kilns						
based on number of kilns			1952		1953	
based on clinker capacity			1959		1953	
Share of clinker capacity in dry process, %			45		44	

Sources: PCA, U.S. Portland Cement Industry: Plant Information Summary. December 31, 1976; Cementa AB.

Table 3. Size and Age Structure of Cement Kilns and Distribution by Process in the United States (1976) and Sweden (1975)

	United States				Sweden			
	No. kilns	Clinker capacity 1 000 metric tons	Average kiln capacity 1 000 metric tons	Share of total capacity %	No. kilns	Clinker capacity 1 000 metric tons	Average kiln capacity 1 000 metric tons	Share of total capacity %
Wet process								
Total	214	44 750	209	55	13	2 796	215	56
1976	0	-	-		0	-	-	
1971-75	14	5 236	374		0	-	-	
1966-70	24	8 129	339		1	445	445	
Dry process	171	36 700	215	45	7	2 197	314	44
Long dry[a]								
Total	119	23 300	196	29	2	412	206	8
1976	1	240	240		0	-	-	
1971-75	2	917	459		0	-	-	
1966-70	9	3 098	344		0	-	-	
Suspension preheater								
Total	52	13 400	258	16	5	1 785	357	36
1976	5	2 560	512		0	-	-	
1971-75	18	7 612	423		0	-	-	
1966-70	1	379	379		2	1 287	644	
Total all processes	385	81 450	212	100	20	4 993	250	100

[a] Refers to semi-dry kilns in Sweden.

Sources: See table 2.

Labor Productivity

Even though both kilns and plants tend to be larger in Sweden than in the United States, labor productivity in the United States has remained higher than in Sweden throughout the period. Se figure 3. However, the labor productivity gap has narrowed from 49% difference in 1950 to 25% in 1974. On the other hand, it is also shown in figure 3 that the total wage cost per hour has increased far more rapidly in Sweden than in the U.S., so that in 1975 the Swedish wage rate exceeded the American one. Thus considering the labor productivity difference, the Swedish wage cost per ton of cement surpassed the U.S. wage cost in 1971 and was as 51% higher than the American wage cost in 1974. (See also figures 6 and 7 below.)

Energy Consumption

At the same time as labor productivity has increased in both countries, fuel consumption has also been reduced, as illustrated in figure 4. The reduction has been about 25% in the United States and 20% in Sweden, but the remaining difference is still very large. For comparison, the fuel consumption in West Germany during the same period is also shown in figure 4 and is found to be still lower than that in Sweden.

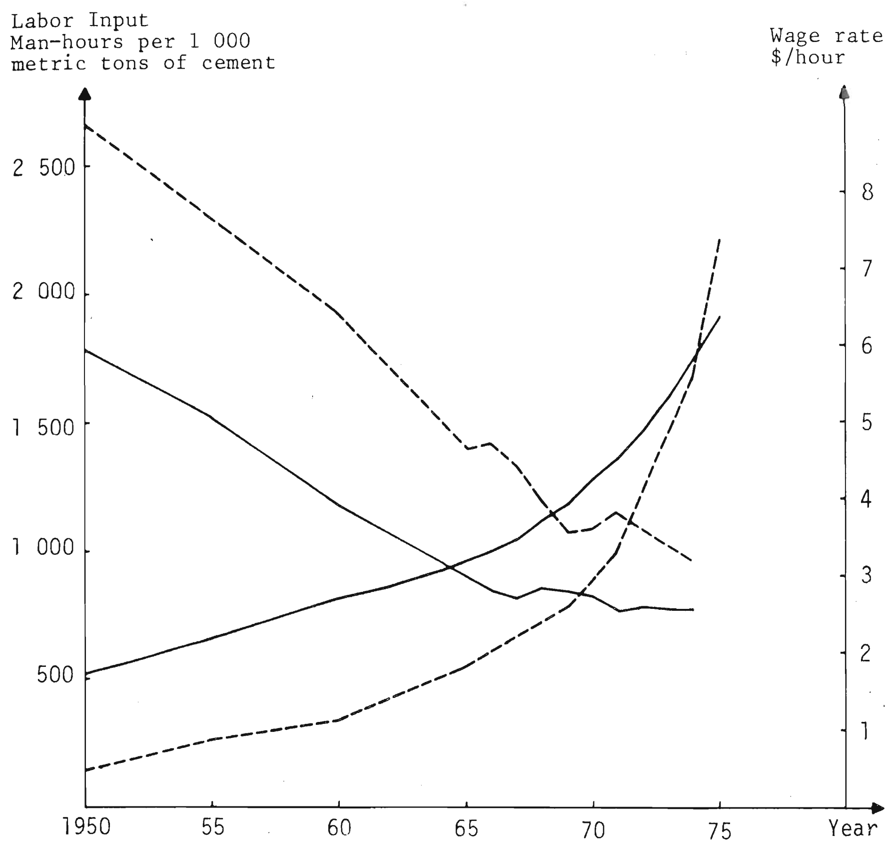
3.2 Overall Industry Characteristics

There are four characteristics of the cement industry which go a long way towards explaining the differences between the Swedish and the American cement industries observed above. These are economies of scale, high energy intensity, high transport costs, and homogeneous output.

a) Economies of Scale

The presence of economies of scale in the cement industry is illustrated in figure 5. There are substantial economies of scale in both wet and dry plants. The investment cost per ton of annual capacity is lower (at least theoretically) for dry than for wet

Figure 3. Development of wage rates and labor productivity in the cement industry 1950-75 in the United States and Sweden

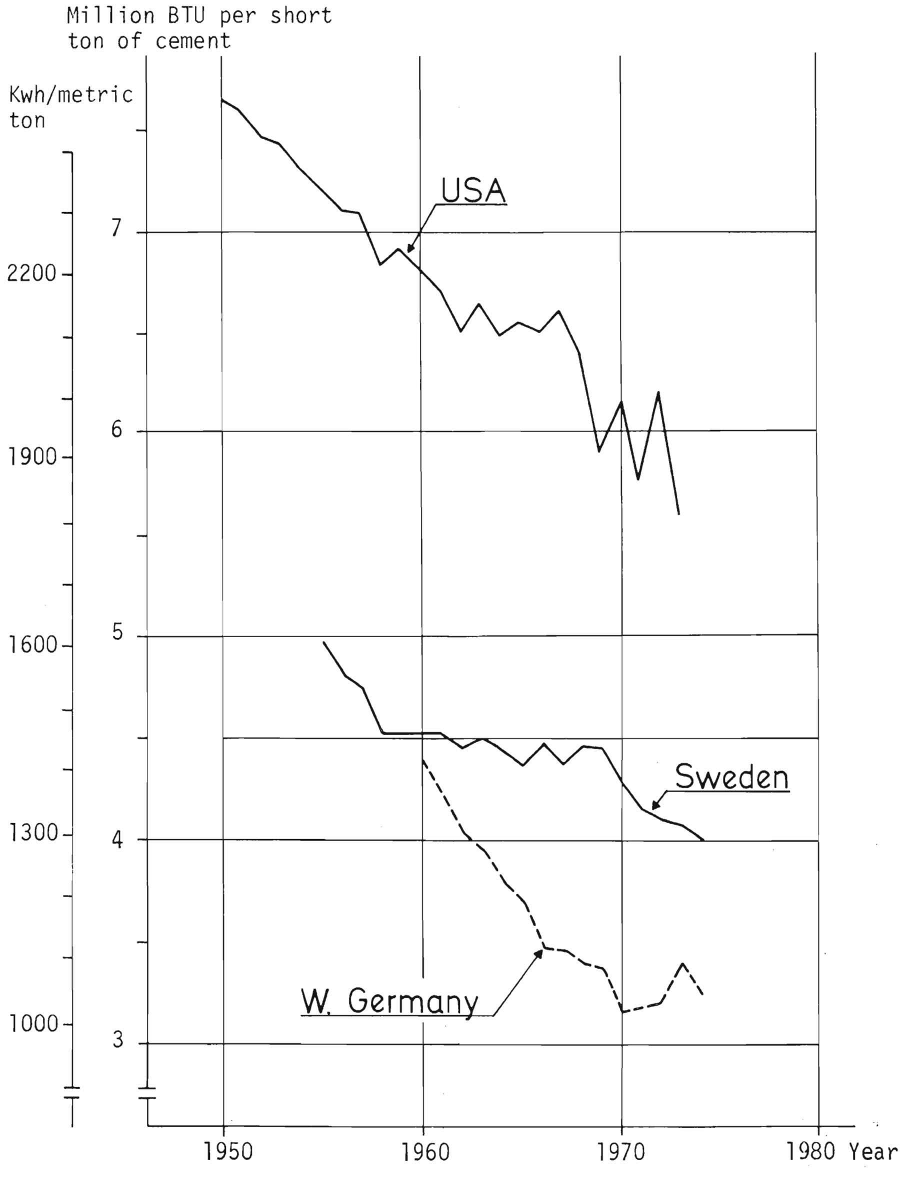


Note: U.S. figures include both direct and overhead labor. The Swedish figures have been made comparable in the following way: Administrative personnel are assumed to work the same number of hours as production workers, and the number of hours in these two categories have been added for the cement industry. The same assumption is made for employees in limestone quarries. Employment in limestone quarries has been obtained by assuming that the proportion of limestone quarry employees out of total quarry employment has remained at the 1973 level throughout. This was the only year for which separate data for limestone quarries were available.

Sources: Labor productivity:SOS, Industri for each year; FEA-PCA proceedings, op.cit, pp.25-27. Wage rate in manufacturing:Swedish Employers' Confederation, Direct and Total Wage Costs for Workers, Various issues. U.S. figures for 1950 and 1955 have been obtained by chaining together with data from Council of Economic Advisers, Economic Report of the President, January 1966 (Washington: USGPQ, 1966), p.243. Swedish hourly salaries 1950-73 have been obtained from SOS, Löner 1973, Part 2, and for 1974-75 from Allmän Månadsstatistik. Total wage costs have been obtained by adding fees and charges for social benefits according to information from the Swedish Employers' Confederation. The Wage rate is expressed in current prices. The Swedish figures have been converted into dollars using the average official exchange rate for each year.

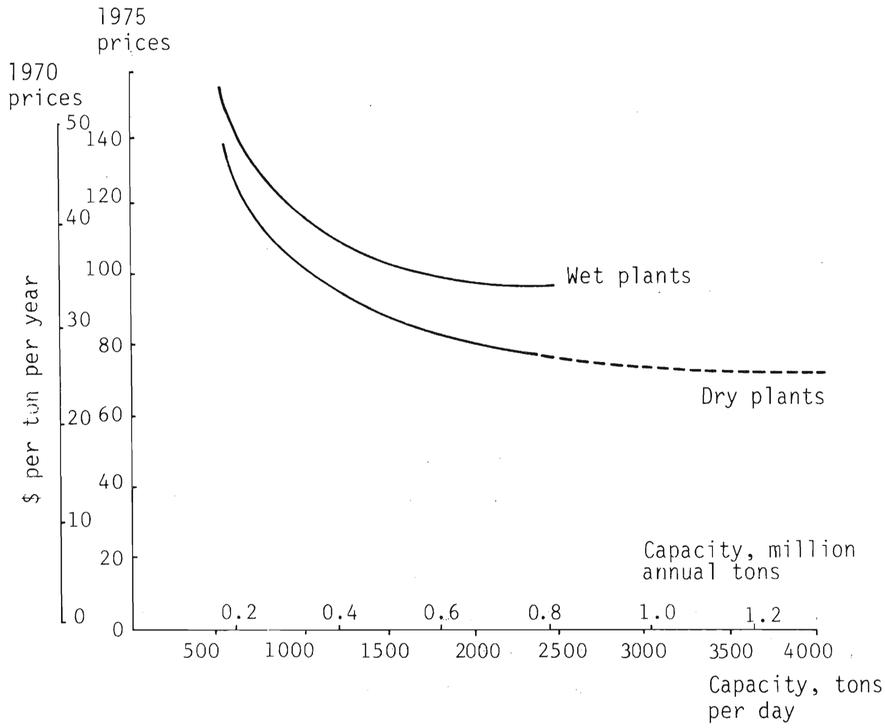
Figure 4. Fuel consumption in cement production in the United States, Sweden and West Germany 1950-74

Million BTU per short ton of cement



Sources: G.A. Schroth, "Grade Preheater Kiln Systems" in FEA-PCA Proceedings, op.cit., p. 253. Cementa AB.

Figure 5. Investment Costs in Wet and Dry Cement Plants, 1970 and 1975



Sources: K.T. Andersen, "Kiln Selection", in Proceedings of the FEA-PCA Seminar on Energy Management in the Cement Industry, Conservation Paper No. 47, 1975, p. 207.

S. Mängel, Technischer Fortschritt Wachstum und Konzentration in der Deutschen Zementindustrie, doctoral dissertation, pp. 47-48.

plants and continues to decrease beyond where the investment cost per ton in wet plants levels off.

b) High Energy Intensity

The cement industry is extremely energy intensive. In Sweden, the fuel and electricity cost has ranged between 29 and 41% of the value of sales during the period 1950-75. In the United States, the corresponding range was 19 to 28%. The energy cost has been higher than the labor cost throughout the period studied in both countries.[1] We will return later to the energy considerations in detail when discussing the choice of technology.

c) High Transport Costs

Because of the relatively low price per ton, the relative transport costs of cement are extremely high. This means that the cement industry is highly local in character, especially in regions without water transport facilities. It costs as much to transport a ton of cement 100 km by truck in Sweden as 600 km by small coastal shipping vessels or 2 000 km by large bulk carries.[2] Therefore, in order to utilize scale economies fully, cement plants must be located either in large metropolitan areas or on waterways.

Because of the high transport costs not only for the finished product but also, and even more so, for raw materials, the cement industry is forced to rely on local raw materials which may vary greatly in quality among locations. Thus, the moisture content and purity of the raw materials as well as their hardness and accessibility vary substantially among plants.

d) Homogeneous Output

Although the quality of cement can theoretically vary among plants and locations, most countries impose fairly stringent requirements

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[1] See figures 6 and 7 below.

[2] B. Carlsson, "Industrins energiförbrukning 1974-80" (Industrial Energy Consumption 1974-80), Appendix 7 to <u>IUI:s långtidsbedömning 1976</u> (IUI's Medium Term Survey 1976), IUI. Stockholm, 1977, p.277.

which must be met by cement sold domestically. These requirements pertain to compressive strength, fineness, chemical composition, etc. They vary somewhat among countries, although the differences are not great among Western countries. It does seem, however, as though the U.S. specifications are more stringent in terms of both fineness and purity (esp. concerning the presence of alkalis) than those of West European countries.[1] The fact that U.S. cement is more finely ground essentially leads to slightly higher energy consumption than would otherwise be the case. The stricter alkali requirements may have more far-reaching consequences for the choice of technology, however, as will be shown below.

The presence of substantial economies of scale in combination with high transport costs has important implications for market structure. In Sweden, six out of a total of seven cement plants are located near water. This has made it possible to take advantage of scale economies in production. In addition, because of an extremely high degree of concentration (there is now only one domestic cement firm in Sweden after a merger in 1974), it has been possible to plan the production expansion in such a way that there is very little overlap geographically between plants. The primary reason why the Swedish government allowed the merger to go through was precisely the argument that this would facilitate achieving a more optimal industry plant structure, provided at the same time that there would be no tariff or other protection, and that the company would be subjected to price control. The product on capacity of the Swedish cement company is large enough to place it among the four largest U.S. firms.

By contrast, there were 52 cement companies in the United States in 1976, the largets of which had 6.7% of industry capacity. The four and eight largest firms accounted for 22.3 and 39.2% respectively.[2]

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[1] Gordian Associates, op.cit., p.39.

[2] Portland Cement Association, op.cit., p.3.

The plants within the largest firms are also widely scattered geographically, making it difficult to concentrate production to one location without involving major changes in regional market shares. There were 162 plants in the U.S. in 1976. This large number can be explained by both geographical factors (population density, transport costs, large inland areas without access to water transport facilities, etc.) and historical factors (most plants were built when scale advantages were less pronounced in areas where cement was needed and local raw materials were available).

While the above factors explain the plant structure of the U.S. industry, the size structure of kilns may be regarded as the consequence of another but related set of factors. During the last fifteen years, kilns built in the United States have tended to be relatively small. Immediately after the Second World War there was a shortage of cement capacity in the United States which led to overinvestment in the 1950's and early 1960's. The resulting overcapacity seems to have lasted into the early 1970's, making it unattractive to invest in anything but replacements of old, inefficient facilities. Since replacing an old wet kiln by a suspension preheater system would involve replacing much of the raw material handling equipment as well, there is a certain minimum scale below which the capital cost would be prohibitive.

How can one explain the observed labor productivity differences, when there are no differences in the average age of kilns and the size factor should imply an advantage for Swedish producers? While it has not been possible within the framework of this investigation to penetrate this question, since it would require a very large set of data for each plant, at least <u>one</u> plant comparison has been made. See table 4, where an old wet process American plant is compared to a relatively new Swedish plant with one wet and one large dry kiln.

Table 4. Comparison of structure of employment in an American and a Swedish cement plant 1976

	American plant	Swedish plant
Production capacity, 1000 metric tons/year	270	820
Average age of kilns, years	51	10
Number and type of kilns	3 wet	1 wet, 1 dry
Total number of employees	109	330
Hourly	73	254
Salaried	36	76
Potential labor productivity 1000 tons/employee/year[a]	2.5	2.5
Distribution of labor force, %		
Quarry	4	9
Raw grinding	6	4
Burning and cooling	7	5
Finished grinding	6	9
Laboratory	11	3
Packing and shipping	13	16
Mechanical maintenance	23	22
Electric maintenance	7	7
Yard + other	23	25

[a] At full capacity utilization.

Note: Administration and other overhead employment has been distributed on the various departments according to the number of production workers.

Sources: Firm interviews.

The Swedish plant is about three times as large as the American plant in terms of both capacity and employment, i.e. labor productivity is about the same (namely 2,500 tons/employee/year which works out to about 720 man-hours per 1 000 metric tons under the assumption of 1 800 working hours per year -- or 6 % higher than the U.S. national average in 1974 and 25 % higher than the Swedish average). The proportion of salaried employees is slightly higher in the American than in the Swedish plant. As far as the employment in various departments is concerned, the differences do not seem to be overwhelming. The fact that the Swedish plant has more than twice the employment of the American plant in the quarry has to do with the fact that the raw material is a soft marl which can simply be bulldozed in the American case and hard limestone which requires the use of explosives in the Swedish case. The lower Swedish shares in the raw grinding and burning and cooling departments as well as the laboratory may be due to the newer, larger and more fully automated equipment. This is true especially in the laboratory. Both plants have relatively high employment in the finished grinding and packing and shipping departments, since they are both versatile plants which produce a variety of types of cement in both bulk and bagged form. (Most plants in both Sweden and the U.S. produce only one type of cement which is sold only in bulk.) Differences in product mix may explain the differences which do exist in these departments. The remaining service departments have virtually the same shares of employment in both plants.

The conclusion which emerges from this comparison is that there seems to be no major difference in the structure of employment in these two plants other than in the quarry and in the laboratory. But perhaps no such difference should be expected, since labor productivity is the same in both plants. It is remarkable, however, that labor productivity is as high in an old American plant as in a relatively new, clearly above average, Swedish plant. It would be interesting to compare the American plant to a Swedish plant of the same size and age, but unfortunately that has not yet been possible. Visits by the author to a number of both Swedish and U.S. plants indicate that Swedish plants tend to have considerably larger employment in the quarry (due to raw material differences) and yard departments (due to differences in preferences regarding working conditions and the amount of services in terms of cafeterias, health care, etc., offered by the company). In the operative departments, there seem to be no major differences. But this can only be conjecture until a more thorough investigation is made.

3.3 Production Costs and Cement Prices

In view of the fact that there have been 50-60 cement companies in the United States throughout the period and only one or two in Sweden, one might expect the pressure of competition to have kept the price lower in the United States than in Sweden. A look at figures 6 and 7, however, will show that just the opposite has been true. The price of cement has been 13 to 63 % higher in the U.S. than in Sweden, the price difference being especially great around 1960.

Cost differences seem to explain only part of this difference. As shown in figures 6 and 7, the total variable cost (labor plus fuel and electricity) was higher in the U.S. until 1965 but has since been lower. The U.S. labor cost per ton of cement was substantially higher than the corresponding Swedish figures during the 1950's, approximately the same during the 1960's and early 1970's and then 20 % lower in the last few years due to extremely rapid Swedish wage increases, coupled with devaluation of the dollar. Swedish fuel costs per ton of cement were considerably higher than those in the United States in the 1950's, only slightly higher in the 1960's, rising again in the 1970's in relation to the U.S. fuel costs. Thus, even though the U.S. fuel consumption was about 40 % higher than the Swedish one throughout the period, the fuel costs were lower than in Sweden, primarily due to the availability of cheap domestic natural gas and coal. Sweden

Figure 6. Production Costs and Cement Prices in the United States 1950-74

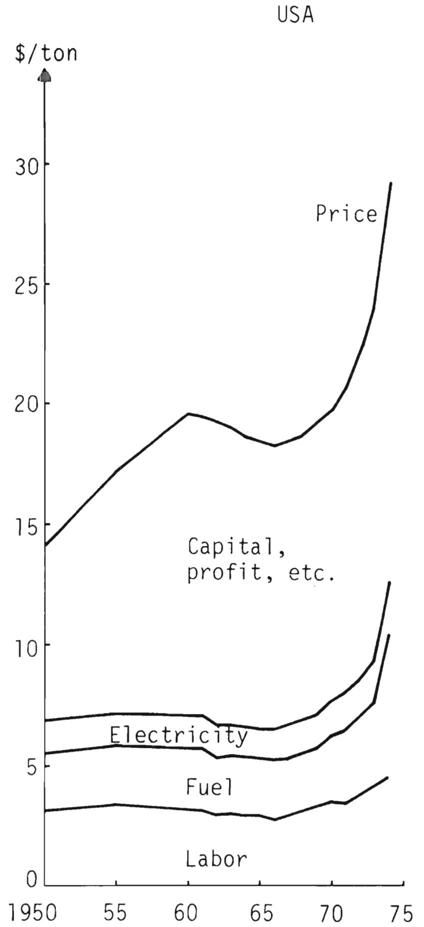
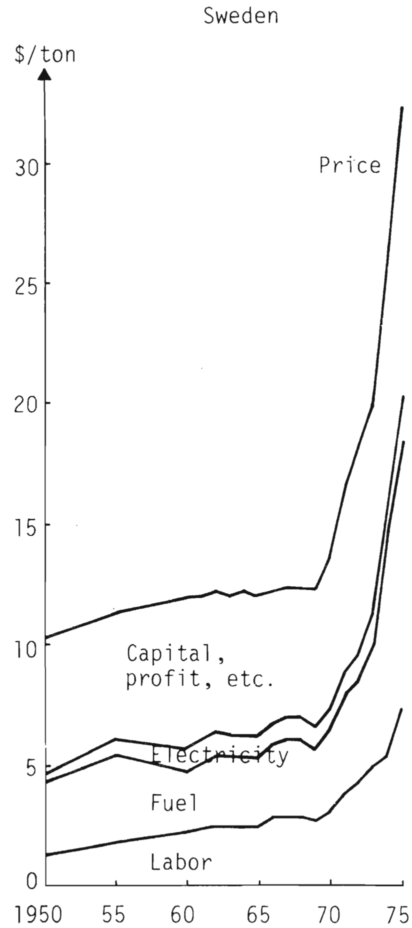


Figure 7. Production Costs and Cement Prices in Sweden 1950-74



Sources: See next page.

Figure 6 (Sources)

Cement price:	1950-70: FEA-PCA Proceedings ..., op.cit., p.43. 1971-74: U.S. Bureau of Mines, Minerals Yearbook 1974, Vol.1, p.283.
Electricity cost:	Electricity consumption: G.A. Schroth, op.cit., p. 236. Electricity price: Edison Electric Institute, Historical Statistics of the Electric Utility Industry, EEI Publication 62-69, New York, 1962, table 45. EEI, Statistical Yearbook of the Electric Utility Industry for 1975, EEI Publication No.76-51, New New York, 1976, table 60 S.
Fuel cost:	Total energy use: PCA, Conservation Potential .. op.cit., p.15. Distribution of energy consumption on fuel type: FEA-PCA Proceedings ..., op.cit., p.35. Price of coal: Minerals Yearbook, various issues. Price of gas: American Gas Association, Gas Facts, 1950, 1951, 1975, 1976, Arlington, Va. Price of oil: Platt's Oil Price Handbook and Oil Manac 1976, New York, McGraw-Hill Inc, 1976
Labor cost:	FEA-PCA Proceedings ..., op.cit., pp. 25-27.

Figure 7 (Sources)

Cement price:	SOS Industri, National Central Bureau of Statistics Stockholm, various issues.
Electricity cost:	Electricity consumption: Ibid. Electricity price: State Power Board.
Fuel cost:	Fuel consumption: SOS Industri Fuel prices: Svenska Petroleum Institutet, En bok om olja, Stockholm, SPI, 1971; Svenska Esso AB, Oljeåret 1975; SOS Utrikeshandel, various issues.
Labor cost:	Figure 3 in the present paper.

lacking both of these resources, had to import fuel and came to rely primarily on oil.

However, the availability in Sweden of cheap hydro power led to low electricity prices which show up in our calculation. Thus, the cost of electricity per ton of cement was only 1/3 of the U.S. electricity cost in 1950. In absolute terms, the cost difference was about the same throughout the period. Taken together, fuel and electricity costs have been roughly the same in both countries until 1971 when fuel costs began to rise in Sweden.

The overall conclusion one can draw from this price and cost comparison is that gross profit per ton of cement has been very substantially higher in the United States than in Sweden during the entire period. It has grown from $ 7.18 per ton in 1950 to $ 16.52 in 1974, while the corresponding Swedish figures are $ 5.50 and $ 9.77. Even if capital costs in the U.S. had been higher than in Sweden, which may have been the case but is relatively unlikely, it seems fair to conclude that net profits must have been considerable higher per ton in the U.S. than in Sweden over the whole 24-year period. It is apparent, however, that the overcapacity which existed in the U.S. cement market in the 1960's put a substantial downward pressure on prices and thereby profits. Given the general rate of inflation in the economy, the profits squeeze may have been serious in many companies by the early 1970's -- but worst in Sweden where the general rate of inflation has been higher than in the United States.

In order to put these results in some perspective, it can be mentioned that the Portland Cement Association has estimated that the investment cost of a new cement plant in the U.S. was $ 88 per metric ton in 1974.[1] Assuming 20 years' depreciation and 15 % discount rate, the capital cost amounts to $ 14 per ton in 1974 prices. This is only slightly less than the average 1974 gross profit per ton calculated above for the U.S. and over 40 %

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[1] Energy Conservation Potential ....., op.cit., p. 19.

higher than the calculated Swedish gross profit. Although the development of investment costs per ton of cement over the last 25 years is not known, it is not likely that investment in the cement industry has been very profitable since 1960.[1]

4. WET vs. DRY PLANTS -- A THEORETICAL COST COMPARISON

It was argued earlier that all the major cost components are theoretically lower for preheater dry than for wet process kilns: the investment cost per ton of capacity is lower, and the labor and fuel costs per ton of output are also lower. But if this is true, also in practice, how is it possible that U.S. firms kept investing in wet kilns until 1975 and that the wet process share of total U.S. cement production increased until at least 1970? [2] How big are the cost differences between preheater dry and wet process kilns?

In order to gain some idea of the answer to this question, let us make a standardized cost calculation for a typical wet process and dry process installation in 1970 and then a similar comparison for 1975 (after the energy price changes), using aggregate national price data for both years. We will then report on the range of variation in actual costs and input requirements among individual plants obtained from interviews with cement firms in both Sweden and the United States.

In table 5 a comparison is made of the total cost of production in a new wet plant in the U.S. and Sweden to that of a new preheater dry plant, using average prices for both countries in 1970 and representative input requirements. The price assumptions are based on available national price averages for energy

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1 It is an interesting question for further research what the reasons are for the low profitability in Sweden and whether this is a general phenomenon.

2 Energy Conservation Potential ..., op.cit., p. 12.

Table 5. Hypothetical Cost Comparison between Dry and Wet Process Cement Plants in the U.S. and Sweden, 1970

Cost item	Price per unit, $		Wet method, 600 000 tons/year				Dry method, 600 000 tons/year			
			Requirement per ton of cement		Cost, $/ton of cement		Requirement per ton of cement		Cost, $/ton of cement	
	U.S.	Sweden	U.S.	Sweden	U.S.	Sweden	U.S.	Sweden	U.S.	Sweden
Coal	0.40	0.68	2.1 MBTU	0.0	0.84	0.0	1.40 MBTU	-	0.56	-
Natural gas	0.38	-	2.6 MBTU	0.0	0.99	0.0	1.75 MBTU	-	0.67	-
Fuel oil	0.49	0.60	0.5 MBTU	4.8	0.25	2.88	0.35 MBTU	3.1	0.17	1.86
Total fuel	0.40	0.60	5.2 MBTU	4.8	2.08	2.88	3.50 MBTU	3.1	1.40	1.86
Electric power	9.50	7.30	0.13 MWh	0.10	1.24	0.73	0.14 MWh	0.10	1.33	0.73
Total energy					3.32	3.61			2.73	2.59
Other variable costs	1.00	1.00	1.50 $	1.50	1.50	1.50	1.00 $	1.00	1.50	1.50
Total variable costs					4.82	5.11			4.23	4.09
Labor	4.25	3.00	0.45 hours	0.54	1.91	1.62	0.45 hours	0.54	1.91	1.62
Capital	1.00	1.00	5.51 $	5.51	5.51	5.51	4.71 $	4.71	4.71	4.71
Total production cost					12.24	12.24			10.85	10.42
Cement price					19.43	13.68			19.46	13.68

Note: MBTU = Million British Thermal Units. 1 MBTU = 293 kWh.
Sources: See text.

and labor in the stone, clay and glass products industry. The investment cost per annual ton of plant capacity has been obtained from a German study. See figure 5.

The investment cost assumptions made for 1970 in table 5 are \$ 34.50 per ton of annual capacity for the wet plant and \$ 29.50 for the dry plant. With a 15 % discount rate and 20 years' depreciation this amounts to a capital cost per ton produced of \$ 5.51 and \$ 4.71, respectively.

As far as labor requirements are concerned, it is assumed that both plants would require 150 employees in the U.S. and 180 in Sweden, with an average of 1 800 hours worked per year.

The energy consumption (both fuel and electricity) is assumed to be that of best practice plants of the respective kind in both countries. As indicated in the table, the American energy consumption figures are somewhat higher than the Swedish ones in view of the existing differences in operating practices and product specifications. The distribution on types of fuel corresponds to the averages for the cement industry in each country in 1970.

In spite of the large differences in both prices and input requirements, the overall cost picture turns out to be remarkably similar in the two countries both for the total costs and for the major cost components. The wet method turns out to be about 15 % (or about \$ 1.50) more expensive per ton produced than the dry process in both countries. But in Sweden the existing price of cement permitted a profit of only \$ 1.50 per ton with the wet method, while the profit margin was \$ 3 per ton with the dry method. Due to the considerably higher prices in the U.S., <u>both</u> methods were highly profitable, although the profit margin was about \$ 1.50 per ton larger for the dry process.

In table 6, the same comparison is made using 1975 prices and input requirements. Relative prices have changed considerably, and the distribution on fuel types has changed in line with present trends. Thus, both fuel prices and investment costs have approximately trebled, while the wage rate increased by "only" 140 % in Sweden and by 50 % in the U.S. In this manner the costs of cement production more than doubled in both countries. The dry method is still considerably cheaper than the wet process, but the absolute cost difference has trebled. At the same time the cement price development has been such that it is no longer possible to cover the costs of production in newly built wet plants even in the United States. On the other hand, the dry method does not seem very profitable either. But this is probably due largely to the excess supply of cement in the world market during the last several years.

5. ACTUAL vs THEORETICAL COST DIFFERENCES BETWEEN WET AND DRY PLANTS

Thus, if we look at national averages, it is easy to see why no wet kilns have been built in Sweden since 1967 nor in the United States since 1975. But if our cost calculations are at least roughly representative of the industry, there still remains a good bit to be explained. If firms are rational, and if a higher profit is regarded as more desirable than a lower profit, then how can we explain why wet plants continued to be built for so long in both countries? Perhaps the national averages gloss over differences among plants which would explain this seemingly erratic or irrational behavior? Perhaps the cost differences between wet and dry plants are not as great in practice as in theory?

In May-June, 1977, the author of this study carried out a number of interviews with representatives of cement firms in both Sweden

Table 6. Hypothetical Cost Comparison between Dry and Wet Process Cement Plants in the U.S. and Sweden, 1975

Cost item	Price per unit, $		Wet method, 600 000 tons/year: Requirement per ton of cement		Wet method, 600 000 tons/year: Cost, $/ton of cement		Dry method, 600 000 tons/year: Requirement per ton of cement		Dry method, 600 000 tons/year: Cost, $/ton of cement	
	U.S.	Sweden	U.S.	Sweden	U.S.	Sweden	U.S.	Sweden	U.S.	Sweden
Coal	1.12	1.71	4.05 MBTU	2.40	4.54	4.10	2.73 MBTU	1.55	3.06	2.65
Natural gas	0.99	-	0.73 MBTU	-	0.72	-	0.49 MBTU	-	0.49	-
Fuel oil	1.93	2.09	0.42 MBTU	2.40	0.81	5.02	0.28 MBTU	1.55	0.54	3.24
Total fuel	1.17	-	5.20 MBTU	4.80	6.07	9.12	3.50 MBTU	3.10	4.09	5.89
Electric power	19.20	11.80	0.13 MBTU	0.10	2.50	1.18	0.14 MBTU	0.10	2.69	1.18
Total energy					8.57	10.30			6.78	7.07
Other variable costs	1.00	1.00	1.50 $	1.50	1.50	1.50	1.50 $	1.50	1.50	1.50
Total variable costs					10.07	11.80			8.28	8.57
Labor	6.50	7.20	0.45 hours	0.54	2.93	3.89	0.45 hours	0.54	2.93	3.89
Capital	1.00	1.00	15.60 $	15.60	15.60	15.60	14.11 $	14.11	14.11	14.11
Total production cost					28.60	31.29			23.32	26.57
Cement price					26.52	25.40			26.52	25.40

Note: MBTU = Million British Thermal Units. 1 MBTU = 293 kWh.

Sources: See text.

and the United States, major equipment manufacturers, a consultant firm, and the industry's branch organization in the United States, the Portland Cement Association. Data were gathered for a large number of plants in both countries. Emphasis was put on plants built in the late 1960's and mid-1970's -- investment costs, operating and price data, and especially the judgements made in connection with major investments and the reasons for building the particular type and size of plant.

Looking first at the empirical evidence concerning energy, a glance at table 7 will show quite clearly that suspension preheater and precalciner systems do offer considerable energy savings in comparison with both wet and conventional (long) dry systems. Converted into cost terms by using 1976 U.S. energy prices, the difference in energy consumption between preheater dry and wet process plants amounts to $ 2.00-2.50 per ton of cement. The savings are greatest in fuels, whereas at least in U.S. operations the electricity consumption is higher in preheater dry than in wet systems. In both dry and wet systems, the Swedish plants seem to be more energy efficient.

The prices quoted for coal in 1977 ranged from $ 0.84/MBTU ($ 22 per metric ton) to $ 1.75/MBTU ($ 46 per ton) in the United States. For national gas the price range was $ 0.78/MBTU to $ 2.15/MBTU, and for fuel oil from $ 1.95/MBTU ($ 12.10/barrel) to $ 2.03/MBTU ($ 12.60/barrel).

Combined with the differences in fuel requirements observed above, this implies that the fuel cost difference between a wet and a dry plant could range from $ 2.50 to $ 16.50 per metric ton.

As far as electric power is concerned, the prices quoted ranged from 1.5 ¢/kWh to about 5 ¢/kWh in the United States and from 2.5 to 3.5 ¢/kWh in Sweden.

Table 7. Energy Consumption in Wet and Dry Process Plants

Plant nationality	Year of instal-lation	Fuel con-sumption kWh/ton	Electricity consumption kWh/ton	Total energy consumption kWh/ton
Wet				
United States	1972[a]	1 775	145	1 920
United States	1960[a]	2 230-2 260	143	2 373-2 403
Sweden	1967	1 770[b]	129[a]	1 889
		1 689[a]		1 809[a]
Long dry				
United States	1970[a]	1 650	130-155	1 780-1 805
United States	1976[a]	1 520		1 650-1 675
United States	1965[a]	1 455	..	..
Suspension preheater				
United States	1976	1 160	185-210	1 345-1 370
United States	1976	1 100	175	1 275
United States	1973	970	..	..
United States	1974	970	..	..
Sweden	1969	940[b]	101[a]	1 041
Sweden (projected)	1979	930[b]	109[a]	1 039
Precalciner (projected)				
United States	1978	935	106	1 041

[a] Includes older part of plant.

[b] Latest kiln only.

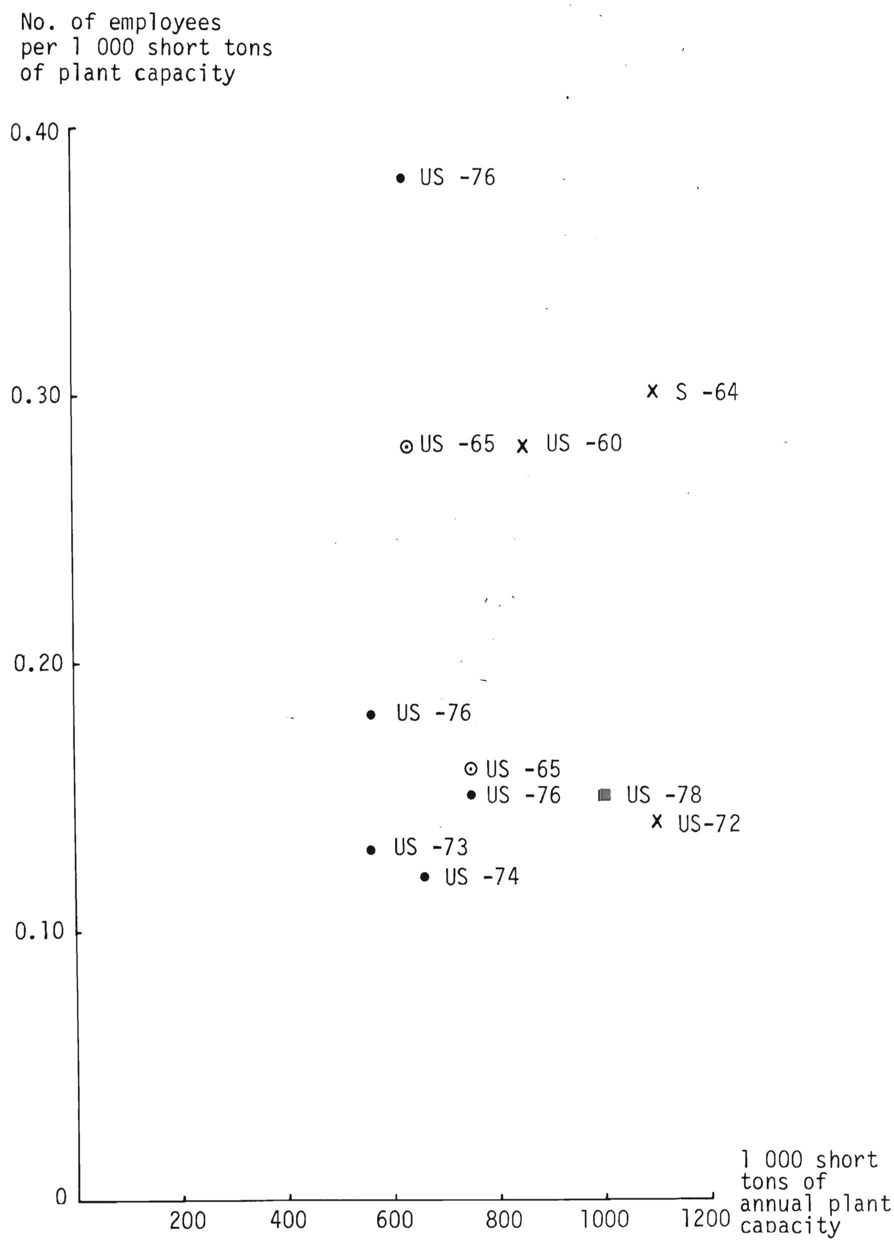
As far as the empirical evidence on the relative labor saving is concerned, the picture is less clear. If figure 8 were taken at face value, it would indicate that labor costs are substantially lower in suspension preheater systems than in wet ones. However, there are simply too few observations to permit any conclusions. But in this case the interview results are unambiguous: there are no differences to speak of, given the scale of the installation. At most, there is a difference of one man per shift more in preheater systems (preheater attendant) than in wet systems. The cost difference would amount to only $ 10-0.20 per ton of cement.[1]

Turning to capital costs per ton of capacity, the evidence is much less clear. See figure 9. The figure has been constructed in the following way. The amount of the investment as reported by each company, has been divided by the (gross) additional capacity, yielding a raw figure on the capital cost per ton of annual capacity. Using information as to what items were included in the investment, it was estimated how much of the total investment for the standard plant given in table 8 was included, and the raw capital cost was adjusted accordingly. Then the adjusted figure was deflated or inflated by a price index to obtain 1974 prices. Unfortunately, no index of investment costs in the cement industry is available, so the United States Wholesale Price Index for industrial commodities was used. The fact that the estimated capital costs for late-year investments are found to be on the high side is probably an indication that some better price index must be found.

But even apart from the price index problem, it is difficult to make much sense of the data. It does not seem possible to say that one type of kiln has consistently higher or lower capital costs than another, nor is it clear even that capital costs decrease with scale. If anything, wet process kilns seem to have lower investment costs per ton than preheater systems. Invest-

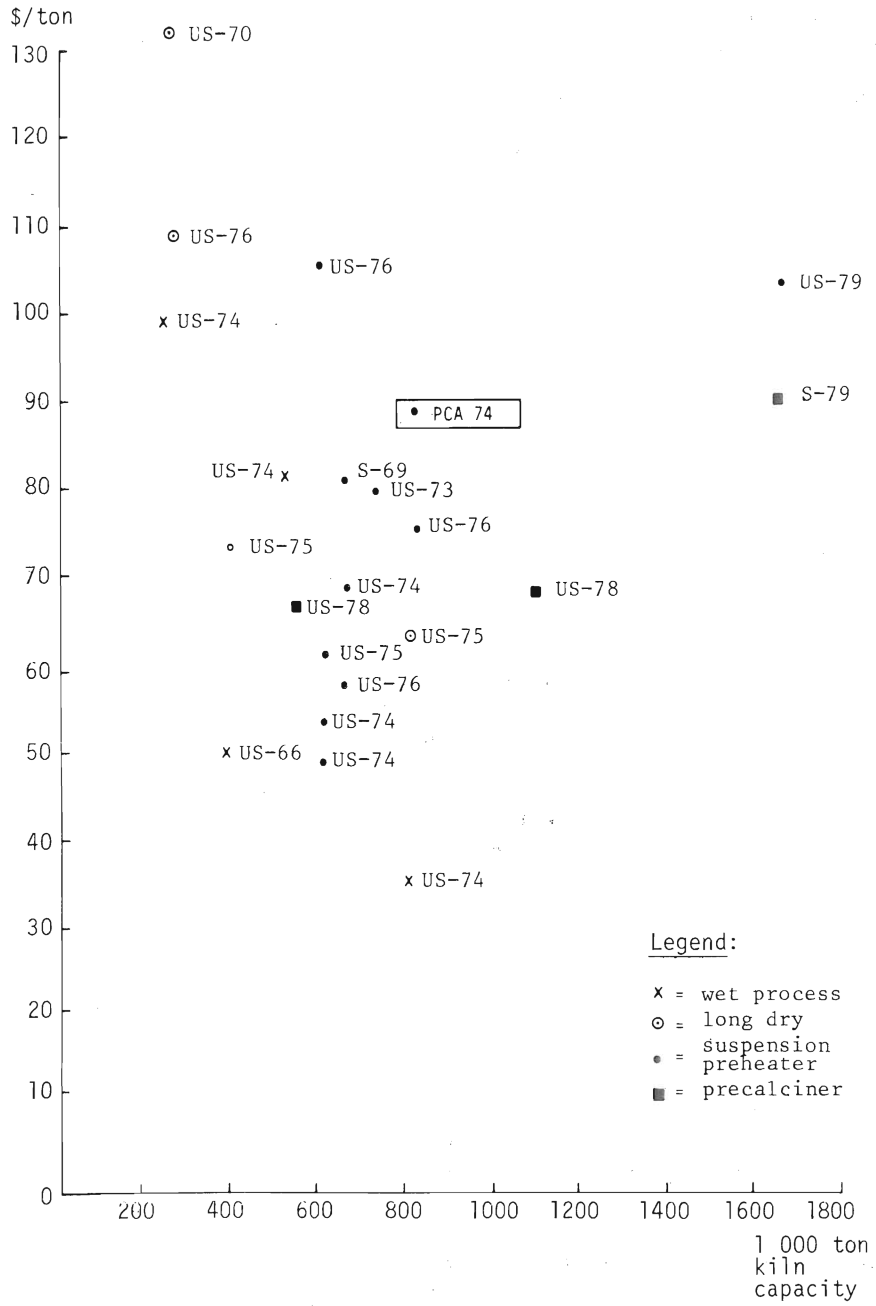
[1] Assuming three 8-hour shifts 330 days a year with a wage of $ 7.00/hour and an annual production capacity of .5 to 1 million tons.

Figure 8. Plant employment per ton of capacity



Note: Since it has not been possible to distribute employment on individual kilns, total plant employment is given, and the year given for each plant represents the average kiln age in the plant.

Figure 9. Investment cost per metric ton of capacity in cement plants
1974 prices



ment costs for precalciner systems seem to increase rather than decrease with scale, and the spread in investment costs for SP systems completed in 1976 is between $ 52 and $ 95 per short ton.

What conclusion can be drawn from these rather discouraging results concerning investment costs? Admittedly, the data are very crude, but it appears likely that no adjustment to standardize the data would be sufficient to obtain any observable pattern. There are apparently such large differences among plants that it is difficult to speak of a "standardized plant".

There are several reasons why investment costs vary widely among plants. Even though the standardized investment cost data in table 8 must be interpreted with great care, they at least indicate that the cost of installation is higher than the cost of the equipment. The installation involves various types of construction jobs -- supports for the kiln, buildings and roads, etc. -- the cost of which depends on local conditions (skill and efficiency of local contractors, ground conditions, etc.). In addition, the cost of the equipment varies substantially from one case to another. There are only a handful of cement equipment manufacturers in the world (one Danish, a few West German and Japanese; and two American companies which operate mainly on licenses from the other manufacturers) who compete in designing and selling whole systems. In order to obtain reference plants they are sometimes willing to offer extremely low prices coupled with substantial guarantees. And of course, prices are always set in negotiations between the cement firm and the equipment manufacturers.

The interview results indicate that opinions in the industry vary widely on whether wet or dry systems have lower investment costs. But it is clear that such statements usually reflect guesses rather than facts. A ong all the 14 interviews with cement firms in both the United States and Sweden concerning kilns or plants built in the last 10 years there was only one case in which a detailed comparison had been made of what a wet as opposed to a pre-

Table 8. Estimated Cost of a 2 200 Short Tons per Day Cement Plant Incorporating a Roller Mill and Suspension Preheater

Department	Equipment $ 1,000	Installation $ 1,000	Total $ 1,000	Total Percent	
Quarry equipment and amenities	4,000	300	4,000	7.4	12.6
Limestone crushing	400	900	1,300	2.3	
Limestone storage	500	1,150	1,650	2.9	
Raw grinding (roller mill)	2,250	5,200	7,450	12.9	
Additive and clay handling	600	1,400	2,000	3.5	
Blending	600	1,400	2,000	3.5	
Calcining	4,150	9,550	13,700	23.7	
Clinker grinding and gypsum handling	1,700	3,900	5,600	9.7	
Loadout and packing	600	1,400	2,000	3.5	
Electrical distribution and central process control	1,600	3,700	5,300	9.2	
Electric motors	1,200	2,750	3,950	6.8	
Land (640 acres)	1,000		1,000	1.7	
Storage facilities	1,000	3,000	4,000	6.9	
Land improvements	1,000		1,000	1.7	
Coal equipment	1,250	1,250	2,500	4.3	
Total	21,850	35,900	57,750	100.0	
Cost per ton of capacity			80		

Source: PCA Economic and Market Research Department.

heater dry installation would cost. In that particular case, the cost comparison came out 20 % lower for the suspension preheater system. But the investment covered only a capacity expansion, not an entire plant. If a whole plant had been considered, the relative cost difference probably would have been about half as large. In none of the interviews were capital cost considerations given as the main reason for choosing a particular process, and in no case was the investment cost difference between the chosen process and an alternative one deemed to be larger than 15 %.

This is not to say that investment cost differences are unimportant -- after all, even a 15 % saving on capital cost would amount to over \$ 2 per ton of cement (i.e. about as much as the energy cost differential), if the previously calculated \$ 14 per ton is a representative capital cost. But it is clear both that no careful comparison of investment costs was usually made and that fuel saving arguments were given in favor of preheater systems and raw material conditions in favor of wet systems.

To the extent that it is possible to draw any conclusion from this discussion at all, it would seem to be the following. Labor requirements play no role at all in choosing among the available technologies. Labor saving arises through increases in scale, regardless of which process is chosen. Even if it is true that capital cost considerations have not played any major role in choosing between alternative technologies in the United States, it is also true that U.S. cement installations in recent years have not been particularly large in comparison with European and Japanese plants. Instead, they have been in the size range where wet process kilns seem to have a comparative, even if not absolute, advantage. It is possible, therefore, that as plant and kiln scale continues to increase, capital cost considerations will become more important -- and labor cost differences as well. But up until now, energy savings seem to have provided the main argument for the preheater technology.

6. REASONS FOR THE DELAYED INTRODUCTION OF SUSPENSION PREHEATER KILNS

The previous discussion has indicated that the only argument for the suspension preheater technology which holds up under scrutiny is the fuel saving argument. Therefore, in order to justify continued investments in wet process plants, one would have to argue that the fuel saving argument was not applicable to the particular installation considered. There seem to be essentially four reasons why the fuel saving argument may not have been applicable in individual cases.

First at all, one factor which naturally affects the choice between wet and dry process is the moisture content of the raw materials. In our sample of plants, the moisture content varies from 1 % to over 20 %. The water content of the feed must be reduced to close to zero in any dry operation. In conventional raw grinding mills (so-called ball mills) there is enough heat generated in the grinding process, although no heat is added, to dry materials containing up to 7 % water.[1] Therefore, there seems to have been a long-standing rule of thumb in the U.S. cement industry that any material with higher than 7 % moisture content is unsuitable for the dry process.

However, a new type of grinding mill, so-called roller mills, was developed in West Germany, apparently in the early 1960's. This type of raw mill is used widely in Europe but was introduced in the United States only in 1973.[1] Roller mills use 5 to 15 % less electricity than ball mills, but they are also more amenable to combined grinding-drying than ball mills. By utilizing low-level heat in waste gases from the kiln or preheater it is possible to dry raw materials containing up to 15 % moisture.[2]

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[1] U.S. Bureau of Mines, Minerals Yearbook, 1974, p. 298.

[2] Gordian Associates, op.cit., p. 14.

By installing additional heating equipment it is possible to dry raw materials with up to 18 % moisture content. The roller mill seems to have been developed precisely to increase the range of utilization of suspension preheater kilns.

At the present time it is not clear whether roller mills per se, require higher or lower investment costs than ball mills. But since they can grind feed of much larger size than ball mills, they may eliminate a secondary crusher which is usually required. Also, they operate at a much lower noise level than ball mills, (reducing the need for noise abatement equipment). Thus, overall it would appear that the capital cost of roller mills is probably lower than that of ball mills. The cost of equipment wear is reported to be about 60 % lower than for ball mills.[1]

The implications of this are that in cases where the moisture content exceeds 15 % there may have been reasons to choose the wet rather than the dry process. Even though it seems difficult to argue that the raw materials are wetter, on the average, in the Unites States than in, say Germany or Sweden, high overland transportation costs and absence of inland water transport facilities may have led to exploitation of wet materials which might not have been used at all in Europe. In the Swedish case, the geography has permitted all but one plant to be located near water, as was noted earlier.

Another problem which affects the choice between wet and conventional dry systems on one hand and suspension preheaters and precalciners on the other is the presence of certain substances in the raw materials which cause operational difficulties or affect the quality of the product negatively. The most important of these substances are alkalis (natrium and potassium). If cement containing alkalis is mixed with certain aggregates -- prevalent in the Southeastern United States but also in certain other areas, a chemical reaction occurs which causes the concrete to crack.

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[1] U.S. Bureau of Mines, Minerals Yearbook, 1974, p. 298.

Therefore, the alkali content is regulated by law. The limit set in the United States is 0.6 %. However, even customers in areas without reactive aggregates often specify low alkali cement. Other countries also have restrictions on alkali content, although not as stringent. Efforts are currently being made in the Unites States to enforce the restrictions only when necessary.

But the presence of alkalis also creates problems in the manufacturing process itself. Since these are highly volatile substances, they will simply be blown out with the kiln exhaust gases in open systems such as wet or conventional dry kilns. But in suspension preheater or precalciner systems which are much more enclosed, alkali content builds up in the circulating air. If the alkali content of the raw material is low, or if there is just the right amount of sulfur in the raw material or fuel to balance the alkalis, there is no operational problem in the preheater. But if there is too much or too little sulfur, the preheater gets plugged up with sticky material which causes stoppages unless removed.

In order to prevent alkali buildup in suspension preheaters, a so-called by-pass has been developed which allows hot air with high concentrations of alkalis simply to escape from the system. This involves an additional investment cost and the loss of both energy and raw materials escaping with the hot air.

It is suggested by some sources [1] that at least some precalcining systems are capable of yielding low-alkali cement with difficult raw materials even with little or no by-pass. However, this is an issue which needs further investigation.

Given that high alkali content and presence of reactive substances do present difficulties in certain parts of the Unites States and much less in Sweden, the implication is that the alkali problem

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[1] See e.g. Gordian Associates, op.cit., p.25.

explains at least some of the observed differences between the two countries in the attitude to the dry process.

The obvious question that arises is whether the alkali problems are unique to the United States or why these difficulties do not seem to have played the same role in other countries. But while it is true that the restrictions on alkali content are more stringent in the U.S. than elsewhere, it is difficult to believe that something as common in the crust of the earth as limestone could vary so much in quality or composition as to be unsuitable for a particular process on one continent but not on another. The following might be at least a partial explanation. Coal is the main fuel used in the cement industry in the United States, while in the 1950's and 1960's most European producers switched to oil. Due to the refining process, the sulfur content of fuel oil is held within very narrow margins, even for high-sulfur oils, which means that it is relatively easy to maintain a certain balance between sulfur and alkali in the cement manufacturing process. Coal, on the other hand usually contains much more sulfur, but above all, the variability of sulfur content is much greater.[1] This factor, in conjunction with the alkali restrictions in the U.S., provides a third reason for the relatively slow diffusion of suspension preheaters in the United States.

A fourth reason for the delay in introducing the suspension preheater technology, particularly in the Unites States, is the bad experiences that several companies had in their early efforts to introduce the new technology. In 1953, just three years after the first SP system was installed in Germany, the first preheater system was built in the United States. This was the fourth such system built in the world until then, which shows that U.S. producers were quick to respond to the new technology. The first SP kiln was followed in the next few years by twelve more. But the majority of these preheaters ran into several operational difficulties having to do with a lack of understanding of the sulfur-alkali

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[1] Garrett, op.cit., pp. 273-277.

balance and similar problems. Consequently, many of these preheaters often clogged up, causing considerable downtime and thereby raising both capital and labor costs. About half of the thirteen original U.S. installations have now been shut down (some having been replaced by wet kilns!), and between 1955 and 1970 there were only two suspension preheater kilns sold in the United States, one of which has since been shut down.[1]

Ironically, therefore, part of the overcapacity in the 1960's was due to the installation of suspension preheaters, many of which did not function well. Both the overcapacity and the malfunctioning held back further investment in SP systems. And because of the operational difficulties, the belief became widespread that suspension preheaters were unsuitable to U.S. raw materials and operating requirements.

7. CONCLUSIONS

This study started out with the notion that a comparison between the United States and Sweden in the choice of cement production technology would be a simple illustration of substitution between energy and other factors of production in view of the differences in relative factor prices, especially relative energy prices. It was soon discovered, however, that the suspension preheater process can be regarded as theoretically superior to the wet process in almost all respects. The problem then became that of explaining why the rate of diffusion of the new process has differed among countries, particularly between Sweden and the United States. It was shown in a cost comparison of the wet and the dry process, based on national average data, that differences in relative factor prices must have been a major influence, and that the drastic price changes which took place between 1970 and 1975 probably

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[1] Garrett, op.cit., pp. 273-277.

constitute the major reason why investments in the wet technology have dwindled to zero.

However, it has also been shown that there are many factors which in actual practice reduce the theoretical cost differences quite drastically. The range of variation among plants in prices, raw materials, the market situation etc., is very large indeed. In addition, despite efforts to standardize for differences among plants in type and size of kiln, year of installation, etc., it proved very difficult to find any sensible patterns in the data other than with respect to energy.

The insights gained through this study relate to understanding the process of change within an industry, the forces which interact to generate this process, the interrelatedness of technical and market conditions, relative prices, rules of thumb, and the attitudes of decision makers in any investment decision, etc.

A final word about the future might be in order. Given the enormous spread between best practice and average practice plants in the United States - much larger than in Sweden e.g. - it appears highly probable that rising energy prices will lead to drastic structural changes within the industry. This process has already been analyzed for Sweden.[1] Interesting questions arise as to whether the U.S. cement industry will be able to effect the necessary changes, given the long history of experience with wet plants, the existing market structure, and the low profitability in recent years. There has been a number of cases recently of European firms buying up old U.S. plants in order to acquire market shares, then replacing them with new, larger equipment. This process is likely to continue unless prevented through government policy and is likely to yield a higher degree of both efficiency and concentration of ownership.

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[1] See B. Carlsson, "Industrins energiförbrukning 1974-80" (Industrial Energy Consumption 1974-80), appendix 7 in IUI:s långtidsbedömning 1976. Bilagor (IUI's Long Term Survey 1976. Appendix Volume). IUI, Stockholm, 1976; pp. 277-287.