A WORLD BANK TECHNICAL PAPER

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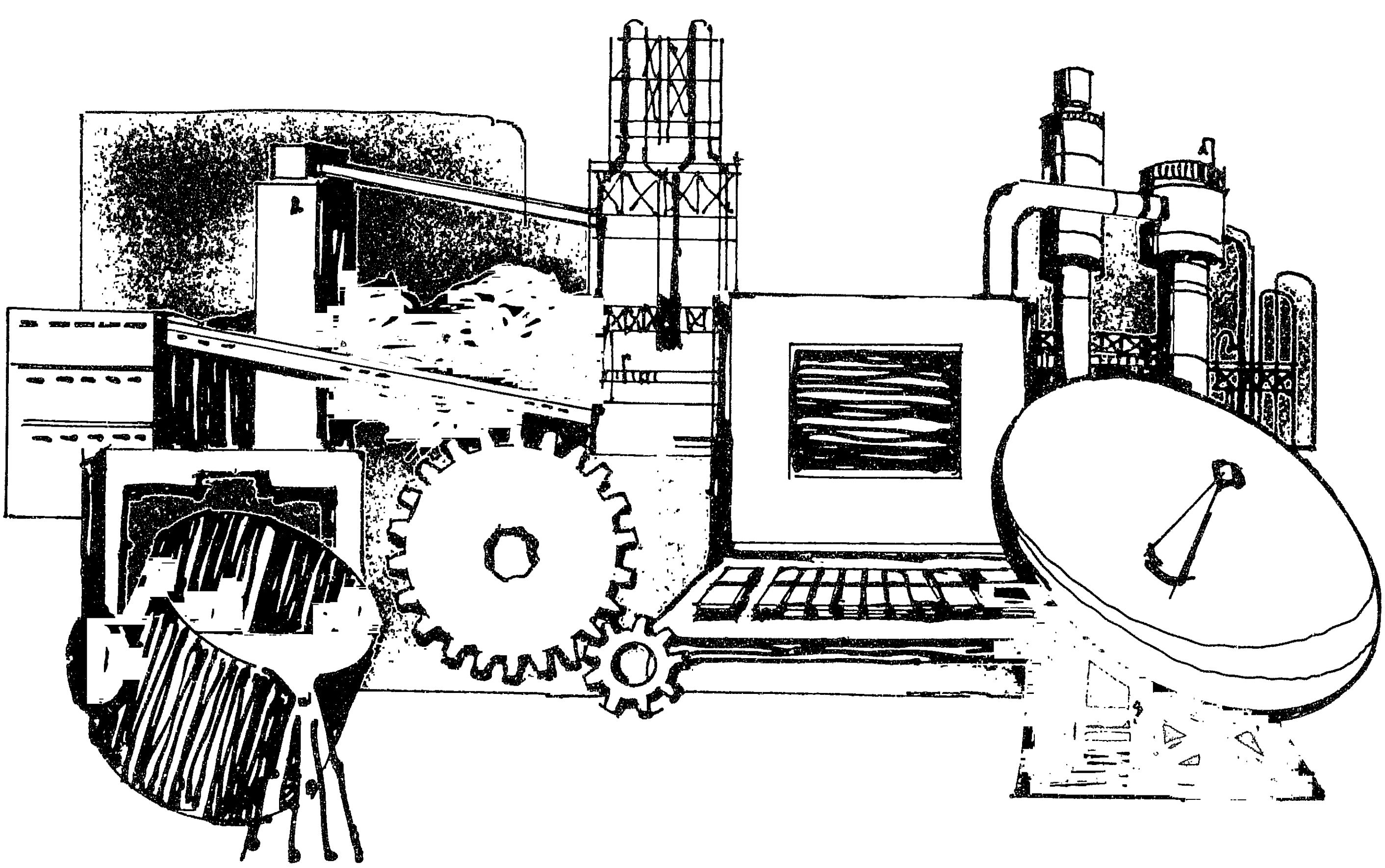
Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries

Mogens H. Fog and Kishore L. Nadkarni



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ABSTRACT

As a result of the sharp increase in the price of energy during the 1970s and the associated changes in the relative costs of alternative energy resources, all countries need to conserve energy and to replace expensive sources of energy with cheaper ones. The subjects of energy conservation and fuel substitution have therefore assumed increasing importance worldwide. The cement industry is one of the relatively energy-intensive industries with energy-related costs accounting for a major portion of the costs of manufacturing cement. The recent experience of the industrialized countries has shown that energy costs per unit of output of cement could be significantly reduced through a variety of measures ranging from better housekeeping, energy management, and improved monitoring and control systems to more capital-intensive investments in modifications to existing plant and equipment and conversion to more energy-efficient processes.

This report aims at a broad presentation of concepts, measures and issues relevant to achieving such improvements in energy efficiency in the cement industry based on experience in both industrialized and developing countries. In so doing, it identifies possible constraints to the successful execution of energy efficiency programs that can be found in many developing countries, and indicates some measures that can be taken at the government, industry and plant levels to stimulate the achievement of increased energy efficiency at the plant level.

ABSTRAIT

En raison de la forte hausse qu'a subie le prix de l'énergie au cours des années 70 et des variations correspondantes des coûts relatifs des ressources énergétiques de remplacement, tous les pays se sont trouvés astreints à des mesures de conservation de l'énergie et au remplacement de sources d'énergie coûteuses par des sources meilleur marché. Les problèmes de la conservation d'énergie et de la substitution de combustibles ont donc pris une importance croissante dans le monde entier. L'industrie du ciment est l'une des industries relativement forte consommatrice d'énergie où la hausse des coûts de production est imputable en grande partie aux coûts de l'énergie. L'expérience récente des pays industrialisés a prouvé qu'il était possible de réduire sensiblement les coûts d'énergie par unité de production de ciment par un ensemble de mesures très diverses allant d'une diminution des gaspillages, d'une meilleure gestion de l'énergie et de l'amélioration des systèmes de surveillance et de contrôle à des investissements plus capitalistiques destinés à modifier les installations et matériels existants ou à les convertir à des procédés permettant une utilisation plus efficace de l'énergie.

Le présent rapport s'efforce d'exposer d'une façon générale les principes et les mesures sur lesquels il faut se fonder pour apporter de telles améliorations à l'efficacité d'utilisation de l'énergie dans l'industrie du ciment, ainsi que les problèmes qui en découlent, sur la base de l'expérience de pays industrialisés comme de pays en développement. En même temps, il fait ressortir les contraintes qui peuvent peser dans de nombreux pays en développement sur les programmes d'amélioration de cette efficacité, et il indique certaines mesures à prendre au niveau de l'Etat, de l'industrie et des usines pour favoriser une utilisation plus efficace de l'énergie au niveau des cimenteries.

EXTRACTO

Como consecuencia del brusco aumento del precio de la energía en el decenio de 1970 y de los cambios conexos en los costos relativos de otros recursos energéticos, todos los países necesitan ahorrar la energía y reemplazar sus fuentes energéticas costosas con otras más baratas. Por consiguiente los temas de conservación de energía y sustitución de combustibles han adquirido mayor importancia en todo el mundo. La industria del cemento es una de las que registran mayor intensidad relativa de energía y en la que los costos relacionados con la energía son una proporción importante de los costos de fabricación. La reciente experiencia de los países industrializados demuest a que los costos en energía por unidad de producción de cemento podrían reducirse considerablemente mediante una variedad de medidas que van desde el mejor orden y mantenimiento de la planta, la administración de la energía y sistemas mejorados de supervisión y control, hasta inversiones con uso más intensivo de capital en modificaciones en las plantas y equipos existentes y transformación a procesos de mayor eficiencia en el uso de energía.

En este informe se pretende ofrecer una amplia presentación de conceptos, medidas y problemas pertinentes para lograr estos mejoramientos de eficiencia energética en la industria del cemento con base en la experiencia de los países tanto industrializados como en desarrollo. Al hacerlo, se identifican posibles limitaciones para el éxito en la ejecución de los programas de eficiencia energégica que pueden encontrarse en muchos países en desarrollo y se señalan algunas medidas que pueden adoptar los gobiernos, las industrias y las plantas para estimular el logro de la mayor eficiencia en el uso de la energía en las plantas.

INDUSTRY AND FINANCE SERIES

Volume 2

This series is produced by the Industry Department of the World Bank to disseminate ongoing work done by the department and to stimulate further discussion of the issues. The series will include reports on individual sectors in industry, as well as studies on global aspects of world industry, problems of industrial strategy and policy, and issues in industrial finance and financial development.

Volume 1 of the series, Structural Changes in World Industry, by Chad Leechor, Harinder S. Kohli, and Sujin Hur, was published in November 1983.

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ABBREVIATIONS AND ACRONYMS

CPE	Centrally Planned Economy
DC	Developing Country
gwh	gigawatt hours (10^6 kilowatt hours)
IC	Industrial Country
kcals	kilocalories (10^3 calories)
kg	kilogram
km	kilometers
kwh	kilowatt hours
mcals	megacalories (10^6 calories)
mt	million tons
mtoe	million tons of oil equivalent
OECD	Organization for Economic Cooperation and Development
OEDC	Oil Exporting Developing Country
OIDC	Oil Importing Developing Country
RORs	rates of return
toe	tons of oil equivalent
tpd	tons per day
tpy	tons per year

ENERGY CONVERSION FACTORS

1 kwh	=	2,500 kcals (taking into account energy conversion efficiency in modern power plants though, in specific cases, the conversion efficiency may be substantially lower, e.g., 3,500 kcals/kwh)
1 toe	=	10^7 kcals

COUNTRY CLASSIFICATION

1. Centrally Planned Economies (CPEs)

Albania, Bulgaria, Cuba, Czechoslovakia, Democratic Republic of Germany, Poland, and USSR.

2. Industrial Countries (ICs)

All countries of Western Europe (except Greece, Portugal and Turkey), USA, Canada, South Africa, Japan, Australia and New Zealand.

3. High Income Oil Exporting Countries (HIOECs)

Bahrain, Brunei, Kuwait, Libya, Oman, Qatar, Saudi Arabia, and the United Arab Emirates.

4. Developing Countries (DCs)

All countries other than CPEs, ICs and HIOECs (1, 2 and 3 above)

5. Oil Exporting Developing Countries (OEDCs)

Algeria, Angola, Bolivia, Congo, Ecuador, Egypt, Gabon, Indonesia, Iran, Iraq, Malaysia, Mexico, Nigeria, Peru, Syria, Trinidad and Tobago, Tunisia, and Venezuela.

6. Oil Importing Developing Countries (OIDCs)

All DCs other than OEDCs (4 and 5 above).

SUMMARY AND CONCLUSIONS

1. Cement is a highly energy intensive product. Concrete, the end product of cement, is however one of the least energy intensive and most widely used building materials. Cement is a typical commodity product with sales depending primarily on price. The cost of energy typically comprises 60-75% of the direct manufacturing costs of cement. Any reductions in the energy consumed during cement manufacture would improve the competitive situation of concrete and would further reduce the overall energy content in world construction. This is particularly important in developing countries (DCs), where the construction sector generally accounts for a relatively significant portion of the gross domestic product originating in industry.

2. On average the cement industry consumes between 2 to 6% of the total commercial energy production in most DCs which collectively account for about 40% of the world cement production and consumption. This share is expected to increase further as the DCs will probably expand their construction activities at a more rapid rate than the relatively more mature economies of the industrial countries (ICs).

3. The potential for reducing energy consumption and achieving energy related cost reductions in the cement industry in the DCs is significant. Ever since the oil crisis of 1973, the cement producers in the ICs have responded to the higher energy prices by undertaking major investments related to energy conservation and to conversions to use of cheaper alternate fuels, and year after year they have succeeded in reducing the specific energy consumption in cement manufacture. The technology for energy savings and fuel conversions has been available for years, and during the most recent years, energy savings programs have been developed by the cement industry in a number of countries.

4. Due to a number of factors, some of which are within, and others outside the control of individual plants, cement plants in the DCs, with some exceptions, generally tend to have higher specific energy consumption per ton of cement for the same production process and plant size compared to the cement plants in the ICs. Consequently, the potential exists for achieving substantial reductions in energy consumption in DC cement industries through a variety of short-term and longer-term measures. At the plant level, successful energy

conservation begins with comprehensive energy audits that would identify the most appropriate measures to be taken in order to improve energy efficiency, and with the setting up of an appropriate energy management and control organization to help implement the measures and to monitor the performance. A saving of 10 to 15% in energy consumption in the DC cement industries can be achieved through improvements in operating procedures attainable in the short-term without any large investments. These savings would amount to between US$1,000 to 1,500 million per year at current energy prices. In addition, further substantial annual energy savings can be obtained from more substantial capital investments involving plant modifications or replacements of specific operational units, particularly in the DCs with rapidly growing cement consumption. The striking aspect is that the successful execution of such measures not only will result in energy savings, it will also inherently increase the productive capacity of the concerned plants.

5. The successful implementation and execution of an energy savings program requires extensive planning and training and availability of some key personnel with the necessary experience. At the plant level, in general, such a program will rely on proper functioning in many individual areas, each contributing perhaps less than 1% of the total. The single most important factor, however, is to assure continuous, uninterrupted operation of the plant since interruptions reduce capacity utilization and thereby lead to higher specific energy consumption. All factors, whether inside or outside of the plant, which cause interruption of operation, must be identified and dealt with.

6. In addition to taking appropriate action at the plant level in the areas of staffing, operating procedures and equipment modifications, there are institutional constraints to overcome in many of the DCs. In many cases the government has imposed price controls, certain taxes and fees, which, however well intended, may create disincentives to an energy conservation program. Careful analysis of the various inputs to, and outputs of, the production and distribution systems of cement is required, before relevant new policies with incentives for energy conservation can be formulated. Suitable measures at the country/industry level are necessary to stimulate energy conservation at the plant level. These measures include appropriate pricing of energy inputs, and

of cement; fiscal and financial incentives for energy conservation; energy-use target-setting and monitoring schemes; promotion of energy audits; and appropriate technical assistance and training. The lack of such measures has, in the past, impeded the implementation of energy conservation programs in a number of DCs.

I. INTRODUCTION

Cement and Its Uses

1.01 Cement is a manufactured mineral product, a finely ground gray powder, obtained from processing a mix of raw materials of a closely controlled chemical composition. The main raw materials used in its manufacture are limestone, clay minerals, silica sand and energy. All of these, except energy, are abundant in most countries. Portland cement, the standard type cement, accounts for between 50% to 95% of total cement production in the ICs. Desired physical and chemical properties of cement can be obtained by changing the percentages of the basic chemical components (CaO, Al_2O_3, Fe_2O_3, MgO, SO_3, etc.), by grindir_ to different finenesses, or by intergrinding with various additives.

1.02 Cement is an intermediate building material product. When mixed with water, sand, gravel, crushed stones or other aggregates, it forms concrete, a rock-like substance that is the most widely used construction material in the world. The principal use of cement is for concrete and concrete products (about 96% in the USA); the balance is used mainly as a mortar or as an additive in soil stabilization.

Energy Intensity in Production

1.03 Cement is a highly energy intensive product, generally requiring between 1,000 to 2,000 megacalories (mcals) of energy (both fuel and electrical) per metric ton (corresponding to .10 to .20 toe/ton of cement) depending upon the specific manufacturing process. Worldwide the cement industry is estimated to consume around 2% of the total fuel and electrical power consumed; in DCs, the cement industry generally accounts for an estimated 2 to 6% of the total commercial energy consumption, though the share can be as high as 10% in some cases. While some other industrial products like steel (7,000 mcals/ton), plastics (20,000 mcals/ton) and aluminum (42,000 mcals/ton) have higher energy consumption per ton of product, the total energy consumption for cement manufacture is higher than for most other industries (with the exception of steel and chemicals) on account of the high tonnages of cement produced. This has special significance for DCs where, in most cases, the cement industry is relatively more prominent compared to other industries.

1.04 Cement has a low value to weight ratio (in the US, $0.07/kg). Transportation costs must therefore be considered carefully before determining the location and scale of production of a cement plant. In the USA, where transport infrastructure is well-developed, about 300 km is now considered to be the maximum range for truck shipments of cement.

1.05 World cement production in 1981 was about 883 million tons. The DCs accounted for about 353 million or 40%, and this percentage is expected to increase as the DCs would probably expand their construction activities at a relatively more rapid rate than the more mature economies of the ICs. Total annual energy consumption in world cement production is estimated at about 1.25×10^{12} kcals or about 125 mtoe. Since on average, DC cement plants tend to operate at higher specific energy consumption levels than comparable IC cement plants, so based on the 125 mtoe total it is estimated that the cement industry in the DCs consumes at least 50 mtoe. A saving of 10 to 15% in energy consumption in cement, which is readily feasible in most DCs through improvements in operating procedures and relatively minor investments alone, would therefore imply an estimated annual reduction in DC energy consumption of about 5 to 7.5 mtoe. At current energy prices, this means an annual saving of approximately US$1,000 to 1,500 million in the DCs alone. Further substantial annual energy savings would result from investments in plant modifications and replacements, especially in DCs where cement consumption is expected to grow rapidly.

Energy Intensity in Use

The following table shows average specific energy content for selected building materials:

Table 1.1: Average Energy Intensities of Building Materials
(kcals/kg)

Concrete aggregates	42
Concrete	192
Brick/tile	880
Cement	1,400
Refractories	1,590
Ceramic tiles	4,800
Plate glass	6,000
Steel	6,700

Source: Based on data from Lafarge Consultants

The energy consumed in the manufacturing of cement becomes more acceptable when calculated on the basis of the end product, concrete. One cubic metre (m^3) of concrete represents an energy consumption of 450 to 500 mcals. Compared to other construction end products, the energy efficiency ranks as follows:

Table 1.2: Comparison of Energy Intensities in End Products of Alternative Building Materials

	Unit Energy Consumption (mcals) Using			
	Concrete	Steel	Asphalt	Brick
Building wall (per m^2)	90-100			130-150
Bridge (per m^2)	900	1,900		
Roadway (per m^2)	200		750	

Source: Based on data from Lafarge Consultants

As seen, concrete is more energy efficient for the given uses than the other building materials.

II. THE CEMENT INDUSTRY - AN OVERVIEW

Cement Production and Consumption

2.01 World cement production in 1981 was about 883 million tons, of which the industrial countries (ICs) accounted for 347 million tons (mt) or 39%, the centrally planned economies (CPEs) for 173 mt (20%), the high income oil exporting countries (HIOECs) for 10 mt (1%), and developing countries (DCs) for the remaining 353 mt (40%). Details of cement production and consumption for major cement producers in each of the three groups are given in Annex 2-1 and briefly discussed in the following paragraphs.

2.02 The largest cement producers in the world (with 1981 cement production and percentage share in world production in parentheses) are USSR (127 mt, 14%), Japan (84mt, 10%), China (82 mt, 9%) and USA (65 mt, 7%). After China, the largest DC cement producers are Brazil (26 mt, 3%), India (20 mt, 2%), Mexico (18mt, 2%), Romania, Korea and Turkey (each approximately 15 mt, 2%), Greece (13 mt, 1.5%) and Yugoslavia (10 mt, 1%). In the following, special emphasis will be given to the specific experience and prospects in the various DCs. Generally, per capita cement consumption tends to be substantially lower in most DCs than in ICs (Annex 2-1), which indicates a potential for growth in the consumption of cement in the DCs.

2.03 World cement production and consumption increased rapidly from 130 mt in 1950 to 717 mt in 1973, an annual average rate of 7.7%. The increase in energy prices in 1973 and the accompanying adverse effects on world economic growth made world cement consumption growth slow down to an annual rate of 2.6% during 1973-81 to reach 883 mt in 1981. However, both oil importing and oil exporting DCs (OIDCs and OEDCs respectively) 1/ had a faster than average cement consumption growth in this period of 6.9% and 12.2% respectively due to the faster growth in their construction sectors as compared to the ICs. Overall, between 1950 and 1981, DCs increased their share in world cement production from 16% to 40% and in world cement consumption from 22% to 40%.

1/ Oil exporting DCs comprise Algeria, Angola, Bolivia, Congo, Ecuador, Egypt, Gabon, Indonesia, Iran, Iraq, Malaysia, Mexico, Nigeria, Peru, Syria, Trinidad and Tobago, Tunisia, and Venezuela.

Cement Technology and Energy Requirements

2.04 Process Flow: Pyroprocessing is the most important part of the cement manufacturing process and is the principal user of energy. With very few exceptions, the rotary kiln is the equipment used for this production phase. The main steps in the manufacturing process are the following: (i) quarrying and extraction of raw materials from deposits; (ii) crushing and preblending of raw materials; (iii) grinding of raw materials in the raw mills; (iv) preparation of kiln feed by homogenization of ground raw materials; (v) burning (pyroprocessing) in kilns to form clinker; (vi) cooling of clinker; (vii) grinding of clinker in finish mills with gypsum to make cement; and (viii) packing and shipping of cement.

2.05 Main Processes: The two basic manufacturing processes are the wet and the dry processes. In the wet process, water is added when the crushed and proportioned raw materials are ground in the raw mill, so that the kiln feed takes the form of a slurry. In the dry process, the raw materials are dried with hot kiln gases while they are being ground in the raw mill, and the kiln feed becomes a dry powder. In the pyroprocessing phase, the two processes are very similar; the feed moves down through the kiln countercurrent to hot gases drawn through the kiln by powerful fans. In the burning zone the materials are heated to 1500°C, and the various chemical components interact and form clinker. Downstream of the burning zone, the two processes are identical. There are less commonly used variations of these two basic processes, the semi-wet and semi-dry processes in which the raw materials are fed into the kiln in the form of cakes, nodules or pellets. The choice between the different processes is primarily dictated by the characteristics of the available raw materials. Further details of each process are given in Annex 2-2.

2.06 Historical Development: Until about 1925, clinker was produced mainly by the dry process in vertical shaft kilns (batch processing) or in rotary (continuous processing) kilns, which were relatively small and fuel inefficient, requiring an average thermal energy input of about 3,000 kcals/kg of clinker. The next technological step forward was the introduction of the wet process in the rotary kiln where the kiln feed is introduced as a slurry rather than a dry powder. This process permitted better homogenization of kiln feed, simpler and easier operation, less dust emission, more uniform cement quality, and better overall economy including a reduction in energy consumption to about 1,600 kcals/kg of clinker. The advent of better raw meal homogenization and dust collection systems led to the return of long dry rotary kilns. The major advantage was the lowering of the thermal heat requirement to about 1,000 kcals/kg. The next major technological step was the invention of the suspension preheater, which was first installed in the 1950s and has since become the standard type of cement kiln. It allowed a further reduction of the thermal energy consumption to approximately 750 to 850 kcals/kg. The preheater process was further refined in the 1960s with the precalciner process. The fuel consumption remains about the same, but the precalciner makes it possible to utilize a high percentage of low quality fuel as well as permitting a much larger clinker production for a given kiln volume. Each of these processes is further discussed below in paragraphs 2.10 to 2.12 (with details in Annex 2-2). Rotary kilns, with or without preheater/precalciner systems, account for over 90% of the world cement production. Vertical kilns are not commonly used any more. A few are working in Europe and Africa, but the greatest use is in China. Vertical kilns can be used for capacities generally up to 100,000 tpy and are viable under special circumstances, e.g., for small raw material deposits, and usually in areas where large scale plants are not economical because of small, thinly distributed markets and the resulting excessively high freight costs.

2.07 Energy Requirements: The energy sources in a cement plant are classified as primary sources, like oil, coal, gas, other fuels and electricity, and secondary sources, consisting of waste heat from one phase of the process, which can be recovered and utilized in another phase of the process. The two most energy-intensive phases in cement manufacture are pyroprocessing and grinding. Pyroprocessing consumes mainly thermal energy in the form of oil, coal or gas, while grinding consumes mainly electrical power.

2.08 Secondary heat contained in the hot kiln exhaust gases is utilized primarily in predrying and preheating materials before introduction into the kiln and raw mill. The waste heat contained in the exhaust gases from the clinker cooler serves to preheat combustion air and also to dry and preheat raw materials before entering the raw mill and kiln. A small amount of thermal energy may be needed as supplemental heat for drying purposes. Total thermal energy requirements in pyroprocessing of clinker normally range from about 750 to 2,100 kcals/kg (.075 to .210 toe/ton) of clinker depending upon the specific process used and the operating efficiencies of the concerned cement plants.

2.09 In order of importance, the major consumption areas of electrical power are: grinding mills, fans, pumps and compressors in the pyroprocessing and homogenization areas, raw material crushing plant and all material handling systems. The electrical power consumed typically ranges from about 80 to 160 kilowatt hours (kwh) (.02 to .04 toe/ton) of cement. Fuel consumption typically accounts for about 75 to 90% of the total primary energy used in a plant and electrical power for the remaining 10 to 25%. (In general, the share of electrical energy tends to be higher in dry process plants - para. 2.13). The following table summarizes the normal ranges of energy consumption in the different stages of cement manufacture:

Table 2.1: Energy Consumption by Manufacturing Stage

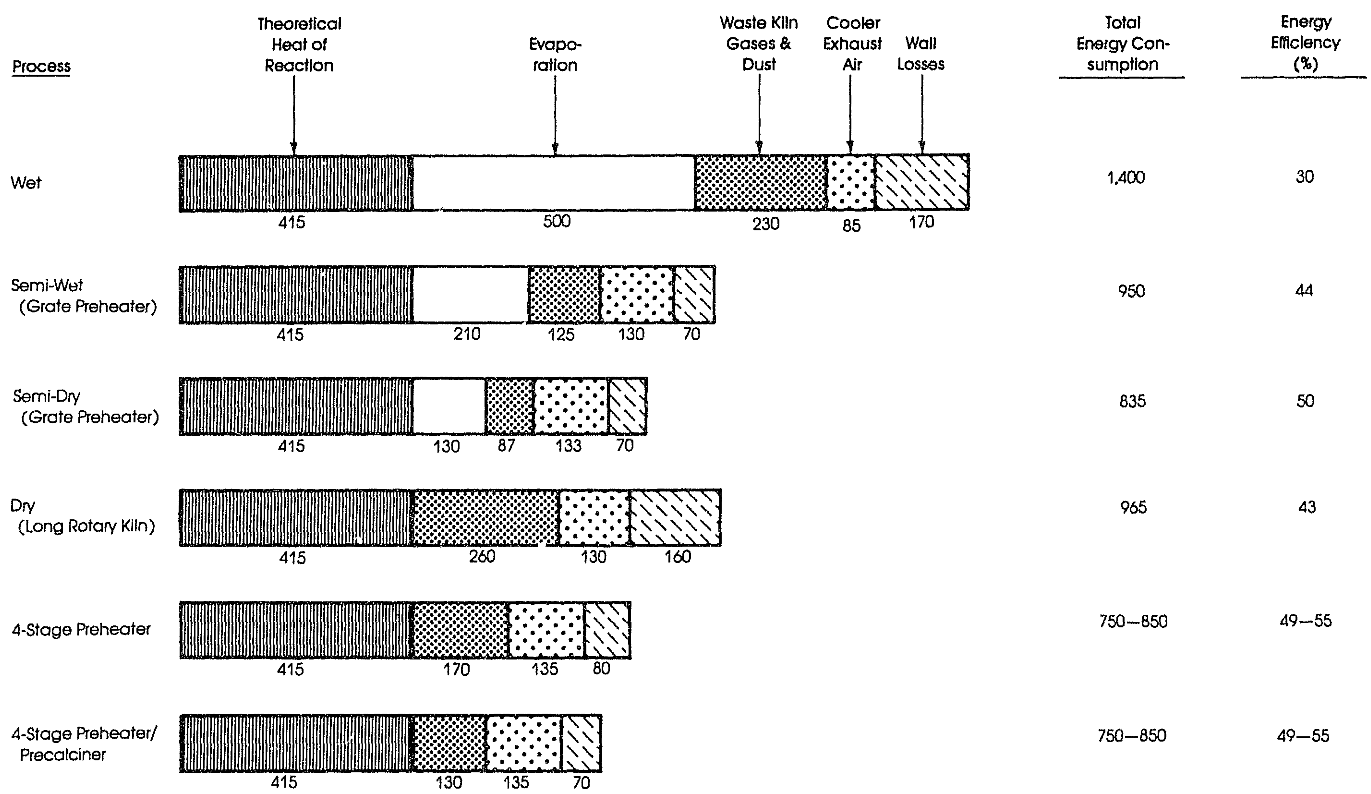
	FUEL			ELECTRICITY			TOTAL	
	Normal Range	Average		Normal Range	Average		Average	
	kcals/kg of clinker	kcals/kg of clinker	toe/ton of cement	kwh/ton of cement	kwh/ton of cement	toe/ton of cement	toe/ton of cement	% share
Quarrying	5-15	10	.0010	2-6	4	.0010	.0020	1
Raw Material Grinding & Preparation				20-40	30	.0075	.0075	6
Pyroprocessing	750-2,100	1,100	.1100	15-30	22	.0055	.1155	82
Clinker Grinding				35-64	50	.0125	.0125	9
Miscellaneous				10-16	13	.0033	.0033	2
Total	755-2,115	1,110	.1110	82-156	119	.0298	.1408	100
% Share in Total			79			21		100

Notes: Averages include weighted averages as appropriate. Average clinker to cement conversion ratio assumed, 1.00:1.04.
Energy equivalents assumed: 1 kwh = 2,500 kcals (based on energy conversion efficiency in modern power plants, though, in specific cases, the conversion efficiency may be as low as 3,500 kcals per kwh); 1 toe = 10^7 kcals.

Source: Based on data from Lafarge Consultants.

2.10 Comparative Energy Consumption in Different Processes: The principal pyroprocessing systems discussed here are the following: (i) wet; (ii) semi-wet with grate preheater; (ii) semi-dry with grate preheater; (iv) dry with long rotary kiln; (v) dry with 4-stage preheater; and (vi) dry with 4-stage preheater and precalciner. Features of each of these systems are briefly discussed below with details in Annex 2-2. The following chart illustrates average operating efficiencies for each type of process:

Chart 2.1: Comparative Thermal Energy Consumption in Various Pyroprocessing Systems (kcals/kg of clinker)



Note: Energy efficiency is the percentage ratio of the theoretical heat of reaction to the total energy consumption.

Source Based on Data from Lafarge Consultants

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The clinkerization process inherently requires 415 kcals/kg. Unfortunately none of the known processes come even close to this theoretical heat consumption. The difference between this minimum energy requirement and that encountered in actual cement operations is accounted for by the following heat losses:

(i) Radiation loss from the external walls of the pyroprocessing equipment including the kiln. This is normally not recovered.

(ii) Heat lost with the waste gases and dust exhausted from raw mill, kiln and clinker cooler. These losses are kept at a minimum by improving to the maximum internal heat exchange (lowering the exhaust gas temperature) and by keeping the amount of exhaust gases to a minimum (by eliminating infiltration air throughout the system). The collection and return to the system of all dust entrained in the gases provide another means of reducing this loss.

(iii) Heat content of clinker at discharge from clinker cooler.

(iv) Heat lost in the evaporation of water in the wet, semi-wet and semi-dry processes.

2.11 Energy consumption in each type of process is briefly discussed below:

(i) Wet Process: Wet processes (with slurry moisture content of between 24-48%) tend to have the highest specific energy consumption in pyroprocessing with a normal range of 1,200 to 2,100 kcals/kg of clinker (a weighted average of about 1,400 kcals/kg). Evaporation of water and heat loss in steam absorb a high proportion (on average, 35%) of the total energy consumption.

(ii) Semi-Wet: In the semi-wet process (slurry moisture content typically 17-22%) with grate preheater, the slurry is dewatered in mechanical filter presses and the resultant filter cake is then dried on a travelling grate preheater before entry into the kiln. Average pyroprocessing energy consumption for such processes is about 950 kcals/kg of clinker.

(iii) Semi-Dry: In the semi-dry process (moisture content typically 10-15%) with grate preheater, the dry feed is mixed with water and formed into pellets in special pelletizing equipment. In other respects, it is essentially the same as the semi-wet process.

However, since the moisture content is lower, less heat is required for evaporation and the average energy consumption is around 835 kcals/kg of clinker.

(iv) Long Dry Kiln: Without preheating/precalcining, the dry process utilizing a long rotary kiln requires, on average, about 965 kcals/kg of clinker of which about 260 kcals (or 27%) represent heat loss in kiln and clinker cooler waste gases.

(v) 4-Stage Preheater: By adding a preheater system to a kiln (Annex 2-2), the heat transfer is greatly improved because a higher percentage of the waste heat in kiln and clinker cooler exhaust gases is utilized to preheat and partly calcine (about 20-30%) the raw mix entering the kiln. As a result, less primary source heat is needed. Since less fuel is burned, less combustion gases are created and it becomes possible to obtain higher production for the same size of kiln, which further reduces specific energy consumption per kg of clinker due to the smaller radiation losses through the kiln shell. While a long dry kiln typically consumes around 965 kcals/kg, a 4-stage preheater system typically consumes about 800 kcals/kg of clinker corresponding to a savings of 18% of primary source thermal energy. Even lower specific energy consumptions (below 750 kcals/kg) have been achieved in 'best practice' situations (e.g., in the FR of Germany and Japan). However, constraints imposed by composition of the raw mix (e.g. presence of alkalies - Annex 2-2) may limit the energy efficiency of preheater systems to between 850-900 kcals/kg of clinker.

(vi) 4-Stage Preheater/Precalciner: In a precalciner system, a substantial portion (up to two-thirds) of the total fuel requirements can be burned upstream of the kiln using low grade fuels including industrial waste, shredded tires, wood chips, etc. As a result, the raw mix is already substantially calcined (up to a maximum of 85-90%) by the time it enters the kiln (as compared to 20-30% in a conventional preheater system). The addition of a precalciner therefore further increases kiln capacity for the same size kiln. Further details are given in Annex 2-2. Specific energy consumption is essentially the same as in the case of preheater systems with similar constraints regarding raw mix composition.

2.12 The comparative advantages and disadvantages of the different technologies discussed earlier are summarized in the following table:

Table 2.2: Comparative Features of Different Cement Production Technologies

		Kiln Process						
Evaluation feature		Wet	Grate (pellets)	Grate (filtercake)	Long Dry	One stage preheater	4 stage preheater	4 stage preheater w. precalciner
Thermal energy consumption	kcal/kg	1,400	800-900	940-1,060	880-1,000	860-950	750-850	750-850
Electric power consumption in kiln system	kwh/ton	18-27	18-28	18-28	20-22	22-24	27-31	30-34
Availability of secondary heat	Maximum percentage moisture in raw material which can be handled by secondary heat	N/A	4%	N/A	10%	9%	7-8%	7-8%
Sensitivity to raw materials characteristics	(desirable	-	high nodule strength	filterability	-	-	low alkalies low chloride	low alkalies low chloride
	(undesirable	high plasticity	-	-	-	-	-	-
	(critical area	chain system	preheater grate	filter	-	-	preheater	preheater

Source: Based on data from Lafarge Consultants.

2.13 Though thermal energy consumption in the dry process is substantially lower than in the wet process, particularly with the preheater/precalciner systems, the dry process does however entail a higher consumption of electrical power. A dry raw mill requires more power than a wet mill, and the homogenization and pyroprocessing areas in the dry process contain a large number of fans operating at high pressure drops with a significant power consumption. Average electrical power consumption in raw material preparation in wet process systems is usually about 22-23 kwh/ton of clinker (range 18-28 kwh/ton) and about 31-32 kwh/ton in dry process systems. However, the significant thermal energy savings in the preheater/precalciner systems offset the increased electrical power consumption several times over.

2.14 Preheater/precalciner kilns are technologically more sophisticated compared to the wet kilns and long dry kilns and therefore become relatively more difficult to maintain and operate. Special attention must be given to the physical and chemical characteristics for raw materials and fuel in the design of such kilns.

Future Outlook for the Cement Industry

2.15 Concrete, the predominant end product of cement is one of the least energy intensive building materials and is expected to remain the most widely used building material throughout the 1980s. Based on different forecasts (Annex 2-3), world cement consumption has been projected to increase from 883 mt in 1981 to between 1,100 mt to 1,200 mt by 1990, with the DCs further increasing their share from 40% in 1981 to even higher levels as their demand for cement continues to grow at a faster rate than in the more mature economies of the ICs. This increment in capacity is expected to be based mainly on the dry process, including both as new plants, and wherever economically feasible, as conversions of existing wet process plants to the semi-wet or dry process and of rotary dry kilns to preheater/precalciner systems, with simultaneous expansion of capacity (paras 4.10 to 4.16). For the new plants, the trend in the past few years towards kiln capacities of 2,000 tons per day (tpd) or higher is expected to continue through the 1980s. Also, based on availability of suitable coal and other non-petroleum based fuel resources at reasonable cost, cement manufacturers will convert plants from the more expensive oil and natural gas usage to systems based on consumption of coal or other cheaper fuels.

2.16 The use of additives like natural pozzolans and industrial byproducts (fly ash, slag) in the production of blended cements is likely to continue to grow in the future as further research promotes wider international acceptability of blended cements and the necessary additives become more widely available (e.g. increasing supply of fly ash from coal based power plants). By reducing the amount of clinker required to produce a ton of cement, the use of such additives would also reduce specific energy consumption in cement manufacture (para 4.23).

2.17 Cement prices are highly influenced by energy costs (para 3.12) and, in general, are therefore expected to follow increases in energy prices through the 1980s. However, the increase in cement prices in real terms is expected to be less than that for energy prices as cement manufacturers may be able to than that for energy prices as cement manufacturers may be able to counteract some of the increases in energy costs through improved energy efficiency and through conversion to lower cost fuels.

2.18 International trade in cement has grown from about 4% in 1970 to about 8% of world cement consumption and is expected to increase further as cement producers with a competitive edge i.e. suitable geographical locations and access to low cost fuel, take advantage of innovations in bulk cement ocean transportation to expand their markets. Therefore, prices for internationally traded cement are generally expected to continue to be influenced by international regional supply/demand considerations and by the continued willingness of exporters to price cement on the basis of marginal costs. However, while international trade may still continue to grow, its overall volume is expected to remain relatively low in relation to the expanding domestic consumption needs especially in the DCs.

III. ENERGY CONSUMPTION IN CEMENT PRODUCTION

Comparison Among Industries

3.01 Cement, along with steel, chemicals, petrochemicals and aluminum, ranks among the principal energy-consuming industries. In 1981, for the OECD countries together, total commercial energy consumption was about 2,602 mtoe of which about 34% or 890 mtoe was consumed in the industrial sector. The cement industry consumed an estimated 1.9% (49 mtoe) of the total commercial energy consumption; other large industrial users were the steel industry with about 6.7% and the chemicals and petrochemicals industries with about 4.7% each. The following table shows details of energy consumption by type of fuel expressed in mtoe:

Table 3.1: Industrial Energy Consumption in the OECD (1981)
(mtoe)

	Oil	Coal	Gas	Electricity	Total	%
Total Commercial Energy Consumption	1,435	233	537	397	2,602	100.0
of which:						
Consumption in Industry	289	191	236	174	890	34.2
of which:						
- Iron and Steel	14	108	28	24	174	6.7
- Chemicals	26	6	61	30	123	4.7
- Petrochemicals	110	-	8	4	122	4.7
- Cement	15	21	4	9	49	1.9

Source: OECD Energy Balances and Lafarge Consultants.

3.02 In DCs the importance of the cement industry in total industrial energy consumption tends to be higher than in the ICs on account of the relatively higher production of cement in the DCs as compared to that of other energy-intensive industrial products like steel and chemicals. (In 1981, the DC share in world cement production was about 40% as compared to 20% for steel and about 10% for petrochemicals). Thus, in comparison with its 1.9% share of the OECD total commercial energy consumption, the cement industry in DCs generally accounts for between 2 to 6% of total commercial energy consumption, though the share can be 10% or even higher in some cases. Details of energy consumption in the cement industry for selected DCs are given in Annex 3-1.

Energy Consumption and Type of Process

3.03 Energy consumption in cement is directly correlated with the type of process used. The following table illustrates for selected countries the effect of choice of process on total energy consumption in the cement industry. (The data shown for several ICs relate to the mid-1970s when the wet process still accounted for a major share in their cement production and are therefore relevant for illustrative purposes.)

Table 3.2: Energy Consumption in the Cement Industry in Selected Countries

	Year	Production (million tons)		% Share by Wet Process	Energy Consumed		Per ton Energy Consumption	
		Clinker	Cement		Fuel (mtoe)	Electricity (gwh)	Fuel a/ (toe)	Electricity b/ (kwh)
ICs	1976	68.6	71.2	59	10.9	11,480c/	0.158	140
- FR of Germany	1974	31.0	35.6	5	2.8	3,552	0.090	100
- UK	1974	17.7	18.4	69	2.6	1,818	0.147	99
- France	1973	27.5	31.9	30	2.9	2,935	0.105	92
DCs								
- India	1977/78	16.5	19.5	65	2.7	2,400	0.163	123
- Turkey	1978	14.8	15.4	10	1.6	n.a.	0.108	n.a.
- Portugal	1977	3.8	4.4	30	0.5	578	0.132	131
- Tunisia	1981	2.1	2.2	21	0.2	264	0.100	120
- Pakistan	1979/80	3.1	3.3	90	0.5	330	0.161	100
- Philippines	1979	3.9	4.1	27	0.5	615	0.128	150

a/ Per ton of clinker.
b/ Per ton of cement.
c/ For 1979 corresponding to cement production of 82.0 mt.

Source: Estimated based on data from U.S. Energy R&D Administration, The Cement Industry, 1975; various Bank reports; CEMBUREAU; Turkish Cement Industries Co.; Asian Productivity Organization, Energy Conservation in the Cement Industry, 1982.

The countries showing the highest per ton energy consumption are those (USA, UK, Pakistan, India) where the wet process accounted for a high share of total cement production. Correspondingly, energy consumption was the lowest in the Federal Republic (FR) of Germany where the wet process accounted for only about 5% of total cement production.2/

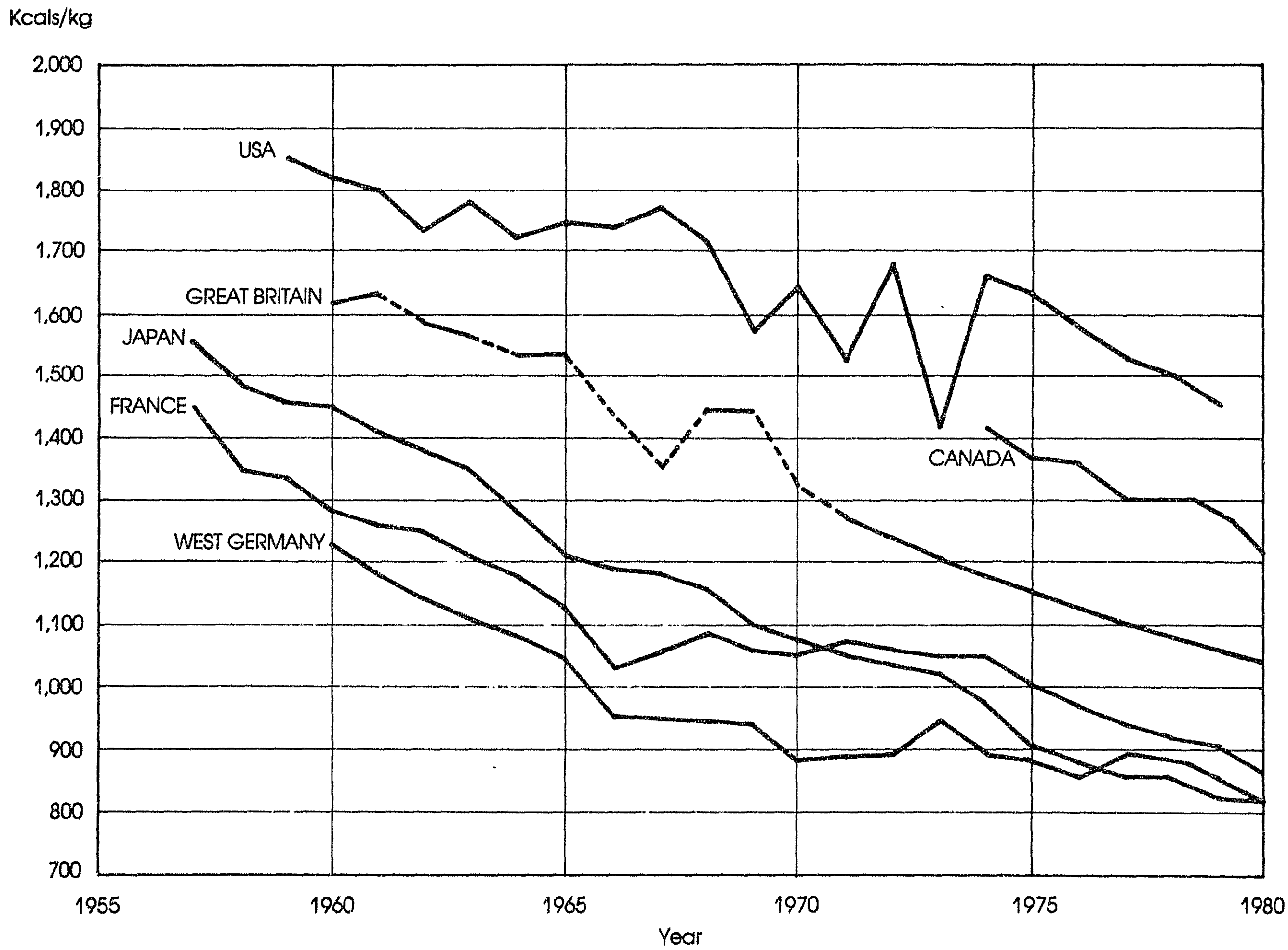
2/ The differences in the specific consumption of both fuel and electricity among the different countries are not necessarily indicative of the operating efficiencies of their cement plants since, apart from type of process, energy consumption is also affected by other factors specific to a given country, e.g., type of raw materials, prevailing cement and clinker standards, etc.

Trends in Cement Energy Consumption

3.04 Average Thermal Energy Consumption: Per kg of clinker, average thermal energy consumption has decreased substantially over the last two decades as seen from the following graph which shows trends in selected major IC cement producers:

Graph 3.1: Trends in Thermal Energy Consumption in Cement in Selected ICs, 1950 to 1980
(kcals/kg of clinker)

Chart 3.1: Trends in Thermal Energy Consumption in Cement in Selected ICs



Source: Based on Data from Lafarge Consultants

World Bank—25289

Graph 3.1 shows the gradual reduction in thermal energy consumption taking place as dry process kilns and preheaters have increasingly replaced the wet process kiln beginning from the late 1950s. The curve for the FR of Germany tends to level off from approximately 1970, which is not strange considering that the FR of Germany had already reduced its wet process capacity to 8% by 1972, and only little remained to be done with significant effect (that figure was further reduced to 3% in 1980). In contrast, the curve for USA was still steep in 1980, an illustration of the fact that in that year 52% of the US cement manufacturing capacity still utilized the wet process. (The corresponding US figure for 1972 was 72%). The lower energy efficiency of the US cement industry is due to a number of reasons which notably include (i) the availability of good quality, low-cost coal which has tended to reduce the economic incentives for improving energy efficiency; and (ii) despite some exceptions, the generally low profitability of many cement manufacturers related to the high degree of competition in the face of a relatively slow-growing domestic market which has retarded the necessary major investments in new energy efficient equipment and facilities. In addition, for any given cement industry, a number of other factors will also influence the rate at which the cement industry will accelerate its energy savings program such as: extent of competition within its own market including the threat of imports at lower price where existing infrastructure permits such invasion; government regulations; incentive programs for energy savings; projected growth of domestic cement consumption; and aggressiveness in respect of exports. For the countries shown, the most striking decreases in average thermal energy consumption occurred in Japan, UK, France and the FR of Germany which were able to reduce significantly their dependence on the wet process. Average thermal energy consumption in Japan and the FR of Germany was around 800-820 kcals/kg of clinker in 1980.

3.05 At present, around 35% of world cement production is based on the wet process. Annex 3-2 shows the distribution of cement capacity in the DCs by type of process. Even taking into account new capacity (almost wholly dry or modified dry process and its variants) currently under construction in the DCs, the overall share of the wet process in DC cement production is estimated to remain around 30%, thus providing significant scope for energy saving in the DC cement industry during the 1980s, through phasing out of wet kilns by new dry/preheater/precalciner kilns and, where economically feasible, by conversions to semi-wet or dry processes (paras 4.10 to 4.15).

3.06 Average Electrical Energy Consumption: Unlike consumption of thermal energy, specific power consumption in cement manufacture has tended to increase rather than decrease over the same period due mainly to the increasing share of the dry process (which requires higher specific power consumption in raw material preparation - para 2.13) in total production. Table 3.3 below shows trends since 1972 for selected ICs. The increased use of coal instead of oil (paras 3.08 to 3.09) in pyroprocessing also tends to increase specific power consumption since the coal has to be ground in mills driven by electric motors (para 5.03).

Table 3.3: Average Electrical Energy Consumption in Cement Manufacture in Selected ICs
(kwh/ton of cement)

	1972		1976		1980	
	Share of Dry Process (%)	Power Consumption/ton	Share of Dry Process (%)	Power Consumption/ton	Share of Dry Process (%)	Power Consumption/ton
France a/	68	92	80	95	90	102
FR of Germany	92	100	95	103	97	108
USA	28	137	41	140	48	142

a/ For France, share of dry process also includes semi-dry and semi-wet processes.

Source: Ciment et Chaux; Bundesverband der Deutschen Zementindustrie; US Portland Cement Association.

3.07 Nevertheless, there have been a number of specific improvements in the efficiency of grinding equipment towards reducing the specific power consumption. The increased use of grinding aids has tended to lower specific power consumption. In dry process plants the more energy efficient roller mill has increasingly replaced the standard ball mill for raw milling. The growing use of additives in cement manufacture has also tended to lower specific power consumption in cement manufacture by reducing the amount of clinker required to be ground per ton of cement.

3.08 Fuel Substitution: Between 1973 and 1980, international oil prices 3/ increased from about US$2.7 per barrel to US$27 per barrel while

3/ As represented by the average FOB realized price for Saudi Arabian light crude oil, 34° - 34.9° API gravity.

international coal prices 4/ increased from US$20.9 per ton to US$56.0 per ton. In a number of gas producing countries with established distribution systems and market outlets the price of natural gas increased at about the same rate as oil. The higher rate of increase in prices of oil and gas has led to a substitution of these two fuels by coal as a fuel source in a number of plants with access to low cost coal in those countries where capital and technology for conversion from oil-firing to coal-based systems were made available. The following table shows for selected ICs the significant changes in fuel sources that have occurred since 1974 and the scope for such changes in selected DCs.

Table 3.4: Shares of Different Fuels in Thermal Energy Consumption in Cement
(%)

	1974			1978			1980		
	Oil	Coal	Gas	Oil	Coal	Gas	Oil	Coal	Gas
ICs									
- USA	12	44	44				5	75	20
- FR of Germany	74	6	20				49	41	10
- France	85	4	11				67	20	13
- UK	6	80	14				2	97	1
- Canada	40	10	50				34	30	36
DCs									
- Argentina				34	3	63			
- Brazil				100	-	-			
- Egypt				100	-	-			
- Indonesia				83	17	-			
- Morocco				100	-	-			
- Nigeria				73	27	-			
- Pakistan				-	-	100			
- Portugal				100	-	-			
- Turkey				75	25	-			
- Philippines				97	3	-			

Notes: For the ICs, the shares are based on the oil-equivalents of the different energy sources. For the DCs, the figures refer to the percentage of total cement capacity produced by plants utilizing the different fuel sources.

Source: U.S. Energy R&D Administration (op.cit); Bank reports; Turkish Cement Industries Co.; Ciment et Chaux; estimates based on CEMBUREAU data.

3.09 For the DCs shown (data for others are given in Annex 3-1), oil still represents the most significant fuel source though many conversions from oil to

4/ As represented by the FOB export price of US bituminous coal.

coal and other fuels have taken place since 1978 (the year to which the data pertain). Assuming the availability of suitable coal and other appropriate non-oil fuels from local sources or the possibility of importing them at reasonable cost, significant scope should exist for such conversions in the DCs in line with the trends in the major cement-producing ICs.

Energy Costs in the Operating Cost Structure

3.10 Depending upon energy prices, process used and specific plant size, energy costs (at economic, i.e. international prices) usually range between 65 to 75% of the direct operating costs (i.e. excluding depreciation and financial charges) of producing bulk cement for oil-fired plants and around 60% for equivalent coal-fired plants. (Bagging of cement entails further costs which vary among countries). The following table summarizes direct operating costs for three different technologies for plants in the size range of 750 to 1,050 tons per day 5/ for a hypothetical IC under certain assumptions. 6/

Table 3.5: Hypothetical Bulk Cement Operating Costs

	Oil Fired				Oil Fired		Coal Fired	
	Wet Kiln (750 tpd)		Long Dry Kiln (800 tpd)		Dry Kiln with Preheater (1,050 tpd)			
	US$/t	%	US$/t	%	US$/t	%	US$/t	%
Fuel	28.6	61	20.0	50	18.0	50	8.1	30
Power	6.0	13	7.7	19	7.6	21	7.8	29
Labor	7.3	16	6.9	17	5.4	15	5.6	21
Others	4.7	10	5.2	14	5.1	14	5.3	20
Total	46.6	100	39.8	100	36.1	100	26.8	100

Source: Based on data from Lafarge Consultants.

3.11 While the costs discussed in the preceding paragraph refer to direct operating costs of producing cement, full costs of production must also include other costs like depreciation and financial charges. These vary between

5/ Corresponding to annual capacities of 225,000 to 315,000 tons based on an assumption of 300 working days per year.

6/ The relative operating costs shown here, while relevant for purposes of general comparison, should not be used to evaluate the appropriateness of estimated operating costs in specific project proposals. In order to approximate international as opposed to domestic energy prices, oil has been priced at US$200/toe; coal at US$60/ton equivalent to US$90/toe; and power at US$0.06/kwh. Average labor costs have been assumed at US$15,000/manyear for the hypothetical IC.

countries and plants depending upon the specific circumstances, e.g. plant age, depreciation practices, financial structures, and interest rates. In general, depreciation charges based on historical costs would tend to be lower in older plants than in newer plants. Also, financial charges would generally tend to be higher in newer plants on account of the probable higher level of unamortized debt in their financial structure. Thus, while newer plants would tend to have lower operating costs reflecting their more modern technology and correspondingly higher efficiency, this advantage may be offset to some extent by their higher depreciation and financial charges. Purely as an illustration, depreciation and financial charges could together amount to US$20 to 30/ton for a new plant.7/.

3.12 As seen above in Table 3.5, fuel and electric power together account for 60 to 75% of the direct operating costs of bulk cement for the plant sizes shown when priced at international economic levels. However, energy prices vary widely from country to country and substantial differences are found between the actual financial price charged to the cement plants and the corresponding economic price of the world market. Based on a sample of just 13 DCs 8/, oil prices varied between US$12 to US$390 per ton while the international economic (i.e. traded) oil price was around US$200 per ton. Similar variations can be found in the case of electric power. Such divergences between financial and economic prices cause substantial distortions in the use of particular fuels and tend to perpetuate the prevalence of energy-inefficient cement production particularly when accompanied by state-imposed controls over cement prices. Realistic pricing of both inputs (including energy) and outputs is therefore essential for motivating cement manufacturers to improve overall production efficiency, including energy-efficiency, in the DC cement industries. The experience in ICs (paras. 3.04 to 3.09) has clearly shown that cement producers can and will undertake major investments in conversion and energy saving projects in response to changing energy prices.

7/ Capital costs for new plants are assumed to range between US$140 to 200/ton depending upon plant capacity and location and have been depreciated over: 5 years for preinvestment costs; 15 years for plant and equipment; and 25 years for buildings. Financial charges have been computed assuming a debt equity ratio of 60:40 and an average interest rate of 12% per annum.

8/ Bolivia, Brazil, Ecuador, Egypt, Ethiopia, Gabon, Indonesia, Malaysia, Mali, Morocco, Niger, Panama, and Tunisia.

IV. ENERGY CONSERVATION MEASURES

4.01 Measures to improve energy efficiency consist of those that can be implemented in the short-term e.g. measures that do not require major capital outlays and where the economic return can be realized in a relatively short time, and others of a longer-term nature involving major technological changes and, consequently, higher capital costs in their application. Both these types of measures are discussed in the following paragraphs.

Readily Implementable Measures

4.02 Energy Audits: The low energy efficiency found in many plants, especially those that are quite old, often results from improper operating and maintenance procedures and, in many cases, to a lack of the appropriate control and monitoring instruments. In general, the personnel are unaware of how sensitive the energy efficiency is to operating procedures. Although operating procedures vary from plant to plant according to the characteristics of raw materials, process equipment and local conditions, there are, however, a number of procedures which should be common to all plants. By performing energy audits, usually carried out by experts in cooperation with the plant staff, very specific operating procedures can be formulated and both short and long-term energy efficiency programs can be established for the individual plant. An energy audit is a useful diagnostic tool which, through detailed investigation and measurement of existing plant operation parameters, helps to identify the areas with greatest potential for improvement and the most appropriate measures for achieving the improvement. Such audits can typically be carried out within 2 to 4 weeks, and the resulting recommendations with clearly stated goals and measures, including appropriate training of the personel involved, will enable the audited plants to reduce energy consumption and to lower operating costs. An illustrative outline of the steps involved in an energy audit for a cement plant is given in Annex 4-1.

4.03 Basic Procedures: The principles for energy conservation within the kiln system (pyroprocessing) are rather simple. Most important of all is to obtain continued, uninterrupted operation of the kiln department. All factors which cause kiln interruption, whether internal or external to the plant, should be identified and all possible measures taken to eliminate those factors. Whenever the kiln has been shut down, heat is wasted when the system is started up again because production will remain low until the temperatures throughout the system are brought up to normal. It takes a long time to balance the system out and to fine tune the individual process areas, so the operation may remain inefficient from 30 minutes to several hours, depending on how long the kiln was shut down. Once the system has been balanced out, the process of minimizing heat losses begins. As seen earlier (para. 2.10), heat losses that are common to all processes consist of:

(1) heat content of exhaust gases leaving the system;

(2) radiation losses; and

(3) heat content of the clinker when leaving the system.

Each of these is briefly discussed in the following paragraphs.

(1) Heat Content of Exhaust Gases

4.04 Included in this are: combustion gases from burning of fuel, carbon dioxide from calcination of raw materials, combustibles resulting from incomplete combustion of fuel, steam from drying of raw materials/and or kiln feed, dust entrained in exhaust gases, infiltration air from process areas with deficient seal arrangement and vent air from clinker cooler. Basically each of these contributors of heat loss will diminish as the exhaust gas temperature is lowered, but to lower the gas temperatures is usually a slow and tedious process. In the following paragraphs, brief comments are made regarding some of these areas with potential for energy savings.

(2) Heat Loss by Radiation

4.05 The heat loss by radiation is controlled by the insulating materials shielding the pyroprocessing vessels from the high internal temperatures. Usually this material consists of refractory brick and it is important to select bricks which are both durable and insulating. During daily operation, there are hardly any means of controlling the radiation loss. However, since the radiation loss is proportional to the exterior surface, which is constant for a given installation, the radiation loss per unit of production will diminish as the production rate of the system is increased.

(3) Heat Content of Clinker

4.06 Basically two types of clinker coolers are used, the planetary cooler and the reciprocating grate cooler. In both types the granulation of the clinker is important for proper heat transfer (it can neither be dust nor large size balls). During daily operation, relatively little can be done to control the heat transfer in the planetary cooler, while in the case of the reciprocating cooler sophisticated controls are available to achieve maximum heat exchange, i.e., maximum cooling of the clinker.

4.07 Selected Measures: Some of the more basic energy saving measures which can be readily implemented in the short-term without major capital expenditures are:

(a) Heat Transfer Improvements: Better heat transfer resulting in lower exhaust gas temperature can be accomplished in some kilns by addition of internal heat exchange devices such as chains and lifters. A reduction of about 100°C in the exit gas temperature can reduce fuel consumption by about 120 kcals per kg of clinker. 9/

(b) Reductions in Slurry Moisture: Slurry moisture, a major factor influencing fuel consumption in wet process plants, can be reduced by use of chemical admixtures (slurry thinners) and by modification of the piping system. Reducing the moisture content of the slurry from 40% to 35% could save about 80 kcals per kg of clinker.

(c) Improvements in Burnability of the Raw Mix: A hard-burning raw mix is a major cause of high energy usage in kiln operations; as a general guideline, about 22 kcals per kg of clinker can be saved by lowering the sintering temperature by 100°C in the kiln. Good burnability can be achieved by appropriate alterations in the chemical composition of the mix, and by improvements in the homogeneity and fineness of the mix. However, the potential energy savings from improving the existing raw mix must be weighed against the additional costs from adopting a more expensive raw material composition.

(d) Reductions in Dust Losses: Loss of kiln dust implies an energy loss of about 10 kcals per kg of clinker for each percent loss of material, mostly due to the extra raw material that has to be processed. Modifications resulting in a reduced dust loss simultaneously improve energy efficiency and pollution control.

(e) Reductions in Primary Air and in Air Leakages: Modifications to reduce use of primary air in combustion from about 25% to 15% (measured as percent of required combustion air) help to reduce fuel consumption, and between 8 to 20 kcals per kg of clinker can thereby

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9/ Fuel consumption of clinker is typically 750 to 2,100 kcals/kg of clinker depending upon the specific process used (para 2.08).

be saved. By reducing air infiltration at the kiln inlet and outlet seals by 10%, about 10 to 20 kcals per kg of clinker can be saved.

(f) Reductions in Radiation Loss: Use of appropriate insulating bricks will permit a 10-15% reduction of these heat losses.

(g) Improvements in Clinker Cooler Recuperation Efficiency: By improving cooler efficiency, the secondary air temperature is maximized resulting in a corresponding decrease in consumption of primary fuel.

(h) Recuperation of Waste Heat from Cooler and the Kiln Shell: Installation of indirect heat exchangers around the kiln and cooler shells permits utilization of radiated waste heat for, inter alia, preheating fuel or providing heat to auxiliary buildings.

(i) Improvements in Electrical Energy Consumption: Energy consumption in raw material grinding (typically 20-40 kwh/ton) can be improved by coarser grinding as long as it does not impair the burnability of the raw mix; the resulting savings may amount to between 6 to 7 kwh (.0015 to .0017 toe/ton) per ton of cement. The utilization of roller mills instead of tube mills can reduce electrical energy consumption in raw material grinding by upto 25%. In cement grinding, the use of close-circuited cement grinding, optimization of the ball mill charge, use of segregating liners, precrushing of clinker, and use of grinding aids where applicable cement standards permit it, can yield important savings in electrical energy consumption. The use of grinding aids alone may provide savings of between 4 to 12 kwh (.0010 to .0030 toe/ton) per ton of cement depending upon the type of cement to be produced. The grinding mills are by far the largest consumers of electric power with the next largest being the fans and compressors in the kiln system and the homogenization area. The remaining electrical energy is consumed by a large number of smaller motors, mostly for material handling. Most of the potential energy savings relating to these units is more a matter of good plant and process design.

4.08 As seen from the foregoing, there is a great potential for saving energy by analyzing and modifying the process step by step. Such modifications in conjunction with a carefully designed management system for continuous optimization of operation can yield savings of up to 10-15% without large capital investments. Such measures have been very successfully implemented in ICs

(Annex 4-2). However, appropriate training of personnel and qualified and motivated supervision are a prerequisite. Longer-term measures are discussed in the following paragraphs.

Longer-Term Conservation Measures

4.09 The principal longer-term measures discussed here are: (i) wet to dry process conversions; (ii) cogeneration; (iii) production of blended cements; and (iii) other possible measures.

4.10 Wet to Dry Conversions: Wet to dry process conversions may be either full or partial depending upon the characteristics of the available raw materials. In full conversions, both the raw material preparation facilities and the kiln are converted to the dry process, while in partial conversion only the kiln is converted to dry or semi-dry process and the raw mill remains wet. The main advantage of such conversions are: a) the substantial thermal energy savings per kg of clinker produced (typically 400 to 700 kcals/kg), and b) increased kiln output which can be substantial (doubling of capacity or more in some cases) depending upon the type of conversion. Such conversions require large capital expenditures [10] and, entail in most cases, substantial kiln downtime with resulting loss of production during the conversion period (typically between 2 to 6 months). The high capital expenditures are due to the fact that, in many cases, not only the kiln department will be modified but also interrelated facilities, such as raw material preparation, clinker cooler and cement grinding must be modified or enlarged in order to be compatible with the increased kiln capacity [11]. The high cost of such conversions can usually only be justified on the combined effects of the energy savings and

10/ Typically ranging from US$10 to 80 million depending upon the type of conversion and plant size. Conversion of a 1,500 tpd wet kiln to a long dry kiln may cost upto US$21 million while a conversion to a preheater/precalciner system may cost upto US$80 million. These cost estimates are, however, indicative estimates only of the broad order of magnitudes involved in such cases and are not site- or country-specific. They are, therefore, adequate for purposes of general comparison only rather than for the evaluation of the appropriateness of estimated capital costs in specific projects.

11/ In some cases, a plant may operate a number of relatively small wet kilns that may be old and inefficient requiring substantial annual expenditures just in order to maintain production. In such cases, the several small wet kilns could be replaced by a single large modern dry process kiln that could make use of the existing plant infrastructure and facilities, e.g., for cement grinding, bagging, etc., suitably modified and expanded as necessary.

substantially increased production and revenues resulting from the conversions, which in turn are dependent upon the prevailing levels of energy and cement prices, i.e., the higher the prevailing prices, the greater the benefits and the economic justification of the conversion.

4.11 (a) Full Conversions: In full conversion from wet to dry process, modifications are carried out not only to the raw mill and the kiln but also to the handling and storage facilities for the raw materials kiln feed. As mentioned earlier (para 2.11), usually a conversion will result in a higher kiln production rate. With the higher clinker production rate, it may become necessary to increase the capacity in process areas both upstream and downstream of the kiln. The greater sensitivity of a dry kiln (and particularly a higher capacity kiln) to variations in kiln feed composition may require the installation of special preblending and reclaiming installations for raw materials quite apart from the homogenizing silos for dry kiln feed. Depending on the physical characteristics of raw materials involved, it may be necessary, inter alia, to install new blending stockpiles, crushers capable of handling clay, clay dryers to facilitate handling and storage of clay, and large limestone crushers to match the enlarged kiln capacity. In conjunction with these various specific process requirements, a certain amount of modernization and updating of the plant in general will take place.

4.12 (b) Partial Conversions: In some cases, raw material characteristics may create constraints for the conversion from the wet to the dry process. Such constraints include: (i) extremely high raw material moisture content (over 20%) which requires significant amounts of primary source heat for drying; (ii) handling characteristics of specific raw materials like certain chalks or clays, which can best be handled in a wet process; (iii) beneficiation of raw material by flotation; (iv) remote quarries and/or lack of conventional transport infrastructure, leaving transport by pipeline as the only alternative. In such cases, the wet process may remain the best option for raw material preparation, and only the kiln will be converted to the dry or semi-wet processes.

4.13 (c) Costs/Benefits of Conversion Alternatives: Three basic alternatives for converting a wet kiln to the dry process are discussed here: (i) long dry kiln; (ii) 1- or 2-stage preheater kiln; and (iii) 4-stage preheater or precalciner kiln. In addition, there are the partial conversions from the wet to the semi-wet process using grate preheaters in conjunction with filter presses.

(The technology of each kiln type has been discussed earlier in Chapter II, paras. 2.05 to 2.12 and in Annex 2-2). The cost/benefit comparisons for each alternative are summarized in the following table:

4.14 (i) Long-Dry Kiln: Full conversion from a wet to a long-dry kiln can yield energy savings upto 30-35% while kiln capacity is typically increased by about 10%. Additional installations required may include a new blending stockpile, raw meal silo and modifications to the kiln internal heat transfer devices like chains. The capital costs of conversion involved may typically range between US$7 to 20 million.

Table 4.1: Comparative Costs/Benefits of Alternative Conversions

	Wet	Long Dry	2-Stage Preheater	4-Stage Preheater/ Precalciner	Grate Preheater with Filtration
For Original Wet Kiln of 750 Tons Per Day					
Capacity (tpd)	750	800	960	1,350	1,125
Energy Consumption (kcals/kg)	1,500	1,050	950	800	1,080
Typical Conversion Capital Cost Range (US$ mil.)	-	7-10	12-16	30-40	26-35
For Original Wet Kiln of 1,500 Tons Per Day					
Capacity (tpd)	1,500	1,600	1,920	2,700	2,250
Energy Consumption (kcals/kg)	1,500	1,000	950	800	1,060
Typical Conversion Capital Cost Range (US$ mil.)	-	15-21	17-23	45-60	41-55

Notes: All capital cost estimates are indicative estimates only of the broad order of magnitudes involved for the different cases and are not site- or country-specific. In any given case, the costs could be different from those indicated on account of factors and circumstances specific to the case.

Electrical energy conversion ratio assumed: 1 kwh = 2,500 kcals.

Source: Based on data from Lafarge Consultants.

(ii) Preheater/Precalciner Kiln: Conversion to 1-stage, 2-stage preheaters or to 4-stage preheater/precalciner kilns yield even greater energy savings (upto about 45% as compared to the wet kiln) while greatly expanding kiln capacity, typically by between 30 to 80% as compared to the original wet kiln. The additional installations and equipment involved may include new preblending stockpile, raw mill, raw meal silo, new 1-stage, 2-stage or 4-stage preheater/precalciner, substantial modifications to the kiln and to the clinker cooler, and increase in cement grinding capacity. The investment involved may range between US$12 to 80 million depending upon the kiln size and equipment configuration. Satisfactory rates of return on the investment require substantially increased production rates. In general, such a conversion can only be justified if the kiln to be converted is of a certain minimum size, such as, for instance, a minimum kiln diameter of 12 feet.

(iii) Grate Preheater with Filtration: The choice between conversion to the grate preheater (semi-wet process) or 2 stage/4 stage preheater (dry process) systems depends upon certain characteristics of the raw materials such as, for instance, whether the slurry is easy or not to handle in a filtering process, whether it exhibits high plasticity and will form strong nodules, etc. Under the grate preheater system, slurry is filtered to reduce moisture content and then dried and preheated on travelling grate preheaters (Annex 2-2) before entry into the kiln. Additional installations and equipment required may include a new slurry mill, filter presses, silo, extruder, grate preheater, modifications to the kiln and to the clinker cooler and increase in cement grinding capacity. As compared to the wet kiln, such conversions may typically yield energy savings upto 30% while production may increase by upto 50%.

4.15 (d) Return on Investment: The capital costs of necessary modifications could vary significantly depending upon the degree of modifications necessary for the facilities upstream and downstream of the kiln itself, with corresponding effects on the rates of return (RORs) on investment. In addition, RORs are sensitive to energy and cement prices and are generally higher for the larger sized kilns to be converted (e.g., 1,500 tpd). RORs based on economic energy and output prices (fuel oil $200/toe, cement $70/ton corresponding to the landed cost of sustained cement imports) for the different alternatives generally vary between 9 to 14% depending upon the kiln size, specific equipment and infrastructure configurations, and the extent of the required modifications therein.

Higher RORs may be obtained where the existing facilities are old and inefficient, entailing high recurrent expenditures in order to maintain capacity and production, and consequently, are suitable candidates for phasing out by more modern efficient facilities, e.g. replacement of a number of old wet process lines by a single modern large dry process line.

4.16 (e) Recent Experience: The necessary technology for both full and partial wet to dry conversion has been available for a number of years and has become progressively better established. Many such conversions have therefore been carried out, primarily in the ICs, but also in some DCs, e.g., Brazil, Malaysia and Gabon. The experience suggests that justifiable returns on the investment can be achieved (Annex 4-3) particularly where the projects are carefully designed and implemented.

4.17 Cogeneration: Cogeneration represents a very interesting approach to energy savings in connection with the conversion of a kiln from wet to dry operation. The temperature of the kiln exhaust gases is increased from 180-260°C in the wet kiln to around 550-760°C of the long dry kiln. With the higher temperature, it becomes possible to use the heat of the gases for generation of electrical power.

4.18 In such a project, a waste heat boiler is installed at the kiln feed end and the hot gases are drawn through the boiler. The resulting steam is utilized for driving a turbine generator. In some cases, a power generation of 50-100 kwh per ton of clinker may be feasible.

4.19 The production rate of the wet kiln is usually increased by around 10% when converting to a long dry kiln, and since the output does not increase substantially, relatively minor modifications are required upstream and downstream of the kiln. Consequently, the capital requirements are relatively low.

4.20 A few such projects have been carried out in the ICs. The projects were justified economically on the basis of savings in cost of purchased power. (In most ICs, the cost of electricity has increased faster than the cost of fuel.) For DCs with an overloaded powergrid system resulting in frequent breakdowns and interruptions of power, cogeneration may become an attractive option for the following reasons:

(i) It facilitates uninterrupted kiln operation since cogeneration usually produces far more power than the kiln department and raw mill require. The ensuing continuity of operation will result in the following benefits:

(a) better fuel efficiency;

(b) lower consumption of refractories;

(c) better clinker quality;

(d) higher kiln utilization (higher clinker production); and

(e) low capital costs compared to conversion to a preheater system.

(ii) Costs for purchased power are significantly reduced. In certain installations, the cement plant could even sell surplus power to local power companies.

4.21 However, cogeneration also has some disadvantages, namely:

(i) It entails rather sophisticated operation both in respect of operating the boiler and the generator, and in tying in to the power grid for the disposal of surplus power during the intervals when the plant cannot consume all the energy generated;

(ii) It results in higher specific fuel consumption of the long dry kiln as compared to a preheater kiln; and,

(iii) The resulting clinker production rates are lower as compared to a preheater system.

4.22 The decision of whether to introduce cogeneration or not depends on the local conditions and requires a very detailed feasibility study, and it also involves negotiations with the local power companies for selling surplus power.

4.23 Production of Blended Cements: The blending of certain materials like granulated slag, fly ash and pozzolans with cement makes it possible to produce more cement from the same amount of clinker and as a result the fuel consumption per ton of cement will be reduced. Experience in several countries has shown that upto 20% of the clinker can be replaced by fly ash and upto 25% by blast furnace slag without changing the character of ordinary portland cement as a general purpose cement. Such blending is a well-known and widely accepted practice especially in Europe, and has permitted an estimated 20 to 40% savings in fuel consumption in certain countries, e.g., France and the Netherlands. Certain DCs, e.g., Brazil, Mexico and India produce cement utilizing industrial byproducts like fly ash and granulated slags depending upon the availability from economical local sources and adequate transportation. Blended cements can probably be used for 80 to 90% of most jobs where a normal portland cement would have been specified. However, further research must be carried out on the effects of additives on concrete properties, before proper formulation of specifications for the additives and for the blended cements, and universal acceptance of blended cements.

4.24 The higher cement production per kg of clinker produced through blending may require additional cement grinding and storage facilities. Typically, necessary investments may range between US$2 to US$5 million. However, the 20-25% increase in cement production enabled by blending assures attractive pay-back periods and high rates of return for such investments.

4.25 Other Possible Measures: (a) Fineness of Cement: Cement standards specify certain maximum and minimum levels for various physical and chemical properties of the cement which will assure satisfactory performance of the end product. Approximately seventy countries have established cement standards, half of them DCs. Many DCs with national standards have based them on standards from ICs and in many cases such standards do not allow lower quality cements (e.g., blended cements) which would be acceptable for a majority of applications in the DCs. Cement standards affect energy consumption significantly, particularly in respect of fineness of the cement (approximately 5% more power is needed for each increase in surface area of 100 cm^2/g Blaine[12/]). In the US, the cement is ground finer than in most other countries, resulting in a specific power consumption per kg of cement 20% higher than found in most other countries. The high fineness is as much a result of an excessively competitive market as a product quality requirement.

4.26 Most standards for portland cement call for tests for strength at 1, 3, and 28 day periods. Very finely ground cement is needed when early strength development is essential. For longer-term (e.g., 28 day) strengths, high fineness is not so critical. This has been recognized in many parts of Europe where greater reliance is placed on performance specifications rather than on cement composition criteria, e.g., if a blended cement meets the same standards as a pure portland cement, it is given an equivalent grade. The use of performance specifications encourages the use of blended cements and makes energy savings possible.

4.27 (b) Recycling of Kiln Dust: Energy savings can be achieved through the reutilization of kiln dust by intergrinding it with cement in small quantities, e.g., in the FR of Germany, up to 5% fines can be used with cement in grinding.

12/ Cement fineness is usually indicated as specific area in square centimeters per gram measured by a method known as the Blaine Method.

Such recycling of the kiln dust also alleviates the problem of disposing waste dust.

4.28 (c) Reductions in Transportation Costs: Since cement has a low value to weight ratio, transportation costs, both of raw materials and of the finished product, account for a significant part of the delivered price of cement. Because transportation is a major energy consumer, all transportation modes must be considered, such as: shipping by truck, by rail, by ship. All of these may include cement in bags, bulk cement or clinker, with terminals for bulk cement and packing facilities, or clinker grinding stations with packing at the various major consumption centers. The economics of these alternatives depend upon the particular circumstances of the given plant/market configuration and available infrastructure.

V. CONVERSION TO ALTERNATE FUELS

Introduction

5.01 During the early days of cement manufacture, coal was burned as a fuel in the cement kilns since it was so readily available in the ICs. As the DCs began to manufacture cement, they tended to use oil which was easier to use, and at prices prevailing at the time, actually cheaper to use than imported coal. The energy shock of 1973 caused changes in the pattern of fuel use because of the manifold increase in oil prices. On a kilocalorie basis, coal is now cheaper than oil not only in the ICs which in many cases have domestic coal deposits, but also in many DCs where imported coal can be landed at a reasonable cost. Consequently, ever since 1973 there has been a worldwide move toward converting cement plants to coal usage.

5.02 The basic requirement of a kiln fuel is that it must have a high enough calorific content to produce a burning zone temperature of 1,500-1,600°C. In addition it must be able to ignite and reignite easily so that the flame is sustained even during temporary imbalances in the burning zone. In the precalciner kiln it is possible to utilize low quality fuel such as oil shale, inferior coal, and, under certain conditions, alternative fuels like industrial wastes, shredded tires, wood chips, etc., which would not serve in a conventional kiln where the lower limit for energy content of fuel is approximately 4,500 kcals/kg. This flexibility of the precalciner becomes very important because there are so many deposits of fuels which have limited application, and the precalciner systems allow the cement industry to lower cost by using these inferior grade fuels, and thereby permit the scarcer high grade fuels to be preserved for higher technology applications where their use is more appropriate.

Conversion to Coal

5.03 Coal is ground and simultaneously dried in special mills to a certain minimum fineness prior to being blown into the kiln. There are two basic coal grinding systems: direct fired and indirect fired coal firing systems and two variants: semi-direct and semi-indirect. (Diagrams are provided in Annex 5-1). In the direct fired system, the finely ground coal is blown into the kiln directly from the coal mill. In the indirect fired system, the ground coal is separated from the coal mill exhaust gases and stored in a silo and the ground coal is then metered into the primary air at a controlled rate as required by the pyroprocess. The relative capital costs of the systems are: direct (100%), semi-indirect (150%), and indirect (190%). Direct fired systems have lower capital costs (typically US$1.5 million to US$3 million, depending upon the plant size), but slightly higher fuel consumption. Indirect fired systems (capital costs typically between US$2 to 6 million) are generally preferred in cases of large plants with several production lines where a centralized grinding system will result in lower operating costs.

5.04 Converting to the use of coal requires many more installations than just the coal mill. Coal exhibits considerable variations in calorific value, moisture content and ash content, and by installing suitable stockpiling/reclaiming facilities such variations can be evened out through homogenization prior to use in the kiln. Special facilities are required for transporting, handling, storing and reclaiming of coal prior to its use in the pyroprocess. Where existing installations are not adequate, additional investments in supporting infrastructure for transportation and storage may therefore become necessary. Unloading and storage facilities for coal can increase the capital costs drastically. For example, if transport by deep sea vessels is the only means of bringing the coal, the cost of port loading, handling and storage facilities could amount to US$ 15 million.

5.05 The primary consideration in the economics of substituting oil by coal is the difference between their prices. The following table shows the alternative rates of return obtainable for a range of price differentials between coal and oil by converting from an oil fired to an indirect coal fired system. [13/] Three kiln sizes are considered: 750, 1,500 and 3,000 tpd, with average energy consumption of 1,000 kcals/kg of clinker.

Table 5.1: Approximate Rates of Return on Oil to Coal Conversions

Kiln Capacity	Oil/Coal Cost Differential (in US$/toe)									
(tpd)	30	40	50	60	70	80	90	100	110	120
750	8	14	18	23	27	32	36	40	44	48
1,500	20	28	35	43	50	57	64	72	79	86
3,000	33	45	57	69	81	93	105	117	129	141

Source: Based on data from Lafarge Consultants.

13/ Based on an oil price of US$ 200/toe and the assumption that no significant additions to infrastructure are involved. Where substantial infrastructure investments are involved, the rates of return can be drastically affected.

As seen, depending upon the kiln size, oil to coal conversions can yield acceptable rates of return even at relatively low price differentials (between US$30 to 40/toe).

Conversion to Other Alternate Fuels

5.06 The commonly used fuels in cement manufacture are oil, coal, natural gas, petroleum coke, coal, charcoal, and oil shale. Natural gas and oil have increasingly been replaced in most ICs by coal (para. 3.08). Natural gas is available in large quantities in some DCs and it continues to be a significant energy source for cement production, particularly in Pakistan, Egypt, Tunisia, Nigeria, Argentina, and Mexico. However, use of natural gas is limited to areas serviced by gas pipelines. Charcoal has been used in cement plants principally in Brazil and Uganda, and is being considered for use, e.g., in the Philippines, Bhutan and Papua/New Guinea. Petroleum coke mixed with coal up to 50% is commonly used for firing in the kiln. Oil shale has been successfully utilized in preheater/precalciner systems where use of low grade fuels is possible. Depending upon the particular system, between 20-25% of the total fuel can be fed in the form of oil shale between the preheater and the kiln.

5.07 Selected industrial wastes are being increasingly utilized in many ICs, and in some DCs, as supplementary fuels in precalciner kilns. Old rubber tyres (with a calorific content of 5,000 to 9,000 kcals/kg) are being successfully used particularly in the shredded form. Research to date has generally indicated that, apart from causing some change in the color of the cement, such use does not unduly affect cement quality or significantly increase pollution. Problems are still being encountered, however, in developing appropriate storage, conveying and feeding systems, leading thereby to higher use of manual labor. Though this is a problem in the ICs, it is less of a deterrent in the DCs in view of the availability of inexpensive labor in DCs. Certain chemical wastes like liquid organic wastes are also being increasingly experimented with as supplementary kiln fuels (e.g in Norway), in view of the twin benefits of energy savings and waste disposal.

5.08 Other less commonly used supplementary fuels which have been successfully tried, though in a limited number of cases, are: peat (e.g. in Ireland); processed household garbage (e.g. in UK, FR of Germany); wood chips, coconut shells; peanut shells (e.g. in Niger); rice hulls (e.g. in Uruguay); agricultural refuse and animal waste (e.g. in India).

5.09 A prerequisite for the increased use of all such supplementary fuels is the development of efficient and economic collection and distribution systems, the absence of which has acted as a deterrent in many cases.

VI. PROMOTION OF ENERGY CONSERVATION AND FUEL SUBSTITUTION

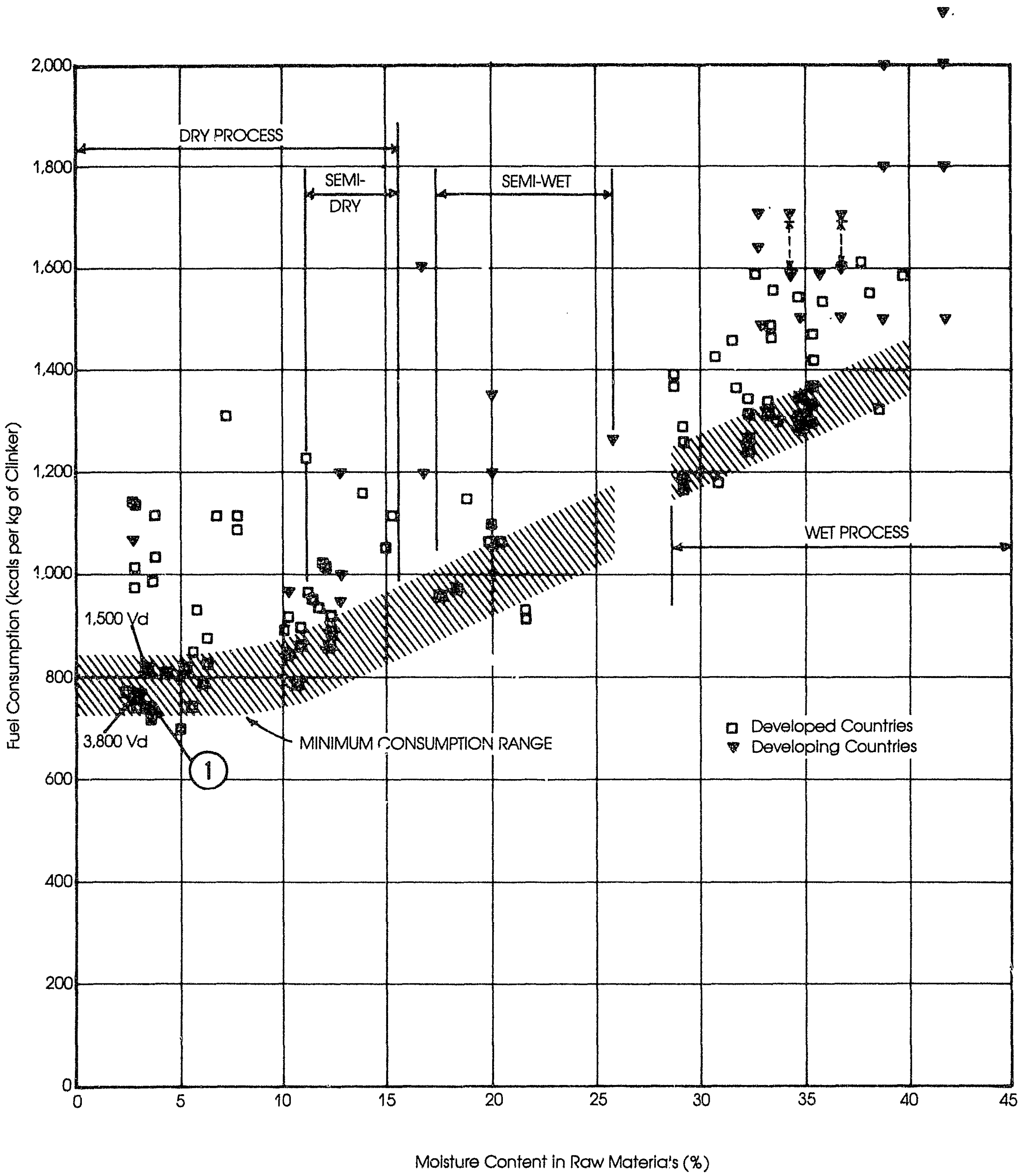
Existing Constraints

6.01 There is an urgent need for improving energy efficiency in the DC cement industries. For a variety of reasons, some of which are within, and others, outside the control of the individual plant, the DC plants, with some exceptions, generally tend to have higher specific energy consumptions for a given process and kiln size than plants in the ICs. This is illustrated in the chart on the following page which shows, for different processes, specific energy consumption in a sample of IC and DC cement plants. Some of the reasons for the higher specific energy consumption are: (i) an insufficient awareness of the potential benefits that can be derived from energy savings programs; (ii) a lack of the necessary technical and managerial know-how required for preparing and implementing projects; (iii) a lack of incentives leading to lack of motivation both in plants and in management; (iv) improper focus on short-term objectives within responsible government institutions; (v) inappropriate pricing of energy inputs and of cement; (vi) insufficient attention to possible energy savings in connection with design of expansion projects; and (vii) financial constraints. Any program aimed at promoting energy conservation has therefore to address these problems through appropriate measures at the country, industry and plant levels. A number of such measures are discussed below. They provide a framework for the successful implementation of energy conservation programs.

Measures at Country and Industry Levels

6.02 A rational pricing policy, both for energy inputs and for cement, is an essential tool for energy demand management and energy conservation. The price of energy for all uses should reflect its real economic or opportunity costs. A government can tax some or all of its energy inputs to encourage energy conservation or inter-fuel substitution. Experience in the ICs in this area has shown that cement producers respond to changes in energy prices by

Chart 5.1: Comparative Specific Energy Consumption



Source: Based on Data from Lafarge Consultants

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undertaking major operational improvements that have significantly lowered specific energy consumption in cement (paras. 3.04 to 3.08). In many DCs, the achievement of economic pricing of energy inputs requires either the removal of inappropriate government-imposed pricing restrictions or adjustments in government policies.

6.03 Rational pricing of energy inputs should be accompanied by appropriate pricing of cement. Often, cement prices in DCs are controlled by the government, in many cases at levels that do not permit adequate returns on the invested capital. The inappropriately low prices discourage cement firms from undertaking necessary investments including those that could substantially improve energy efficiency. In particular, increases in energy prices have substantial impact on operating costs (para. 3.10) and, in most cases, would necessitate suitable upward adjustment of existing cement prices to enable the firms to remain profitable.

6.04 Fiscal and financial incentives can help cement plants to prepare for higher energy prices and thus accelerate the introduction of energy saving equipment and technology. Various such measures have been successfully introduced in the ICs and include: (i) grants/subsidies for energy saving investments or energy research; (ii) tax incentives like investment tax credits, tax write-offs, advance or accelerated depreciation, elimination of sales tax on energy-saving equipment, etc.; and (iii) access to credit on preferential terms, e.g. lower interest rates, longer grace periods.

6.05 To obtain the full potential benefits from any major energy conversion investment (e.g. wet to dry, oil to coal), it is essential that the technical and technological considerations be carefully assessed in order to determine the most appropriate alternative. In this respect, in DCs with little or limited experience in such conversions, the governments should enable and even encourage cement firms to have access to the requisite technology and know-how from suitably qualified sources through technical collaboration and consultancy arrangements.

6.06 Targets can be useful in motivating both management and workers to save energy. Governments should encourage the setting of targets and their achievement at both the industry and company levels.

6.07 In order to monitor progress in achieving energy efficiency improvements, mandatory periodic reporting schemes have been introduced in several countries (e.g. USA, Canada, Japan, and Italy) for companies in energy-intensive industrial sectors.

6.08 Energy audits (para. 4.02) go beyond reporting and require the collection of information on energy flows within industries. In some countries, energy auditing is used as a means of controlling the relative energy consumption in a specific branch of industry. Such audit schemes exist in several countries (e.g. USA, Canada, Japan, UK, Sweden, Spain and Greece) to varying degrees of comprehensiveness. Among DCs, Portugal introduced an Energy Management Decree in early 1982 under which about 1,000 enterprises with energy consumption levels over a specific limit will have to engage independent energy auditors to (i) undertake a comprehensive energy audit of each enterprise, and (ii) prepare for each enterprise a five-year energy conservation plan.

6.09 The success of any energy conservation program depends largely on the extent to which people are involved in meeting the goals of the program. Suitable information, advisory and assistance schemes offered through appropriate institutional agencies can assist in this respect. Specific institutional arrangements vary from country to country. In some cases, specific energy management, audit and training centers involving inter-agency collaboration are being set up whose functions would, inter alia, include, (i) training and promotional seminars, and (ii) providing technical and advisory services and performing selected enterprise audits.

Measures at the Plant Level

6.10 Clearly defined responsibilities within the plant organization must be established in order to develop and implement energy conservation programs. The establishment of an energy department is the first step. This department should be staffed to provide the expertise in evaluating projects from an energy standpoint. In addition, company management should encourage the energy department to obtain technical expertise from the outside when needed and to keep the plant staff continuously updated on new developments in the field. Company management must delegate a certain amount of authority to the energy department to permit it to obtain the desired results.

6.11 The energy department, together with the operating departments of the plant and with the assistance of independent energy auditors, should arrange for a comprehensive energy audit of the enterprise and then establish short-term and long-term (e.g., five-year) plans for energy conservation. In consultation with the operating departments, specific operational goals should be developed for each major energy-consuming process area. Periodic monitoring should follow with feedback to the operating departments. If possible, bonus arrangements by departments should be established as incentives for achieving specified energy consumption levels in the plants.

ANNEX 1-1: CEMENT RAW MATERIALS AND DIFFERENT TYPES OF CEMENT

Cement Raw Materials

1. Reserves of raw materials for making cement have not been quantified but are abundant in most countries, although not always located near market areas. The main materials are:

2. Calcareous rock, principally limestone, is composed primarily of calcium carbonate ($CaCO_3$) and is mined from sedimentary formations of marine origin from virtually every geologic age. Limestones of different origins show variations in physical characteristics, texture, hardness, color, weight, and porosity, ranging from loosely consolidated marls through chalks to compact limestones and hard crystalline marbles. The maximum magnesium oxide (MgO) allowed in portland cement is 5%; therefore, limestones containing significant amounts of MgO are not suitable for making cement.

3. Noncalcareous materials necessary for manufacturing clinker are silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). Many limestone deposits contain chert, a form of silica, and some contain iron minerals. Sand, quartzite, and sandstones from sedimentary deposits are used to maintain the proper silica ratio, but silica in the form of aluminum silicate is preferable to quartz. Alluvial and residual clays and sedimentary deposits of shale and schist are common sources of alumina and silica. Slate, andesite, and granite are other sources of silica and alumina. Some igneous rocks such as pumice, tuff, and other volcanic materials are used for silica and alumina to a lesser extent. Bauxite is commonly used for high-alumina cements. Staurolite and aluminum dross are other sources of alumina. Iron ore is the predominant source of iron oxide, followed by pyrite cinders and mill scale. Blast furnace slag is utilized not only for silica and alumina but for the iron content. Laterite also supplies alumina and iron oxide. Fly ash has become of increasing interest as an argillaceous raw material.

4. In addition to the raw materials used for making clinker, calcium sulfate ($CaSO_4$) in the form of gypsum and anhydrite, is added during the grinding of clinker, in quantities up to 5%, to impart set-retardant properties to the finished cement.

5. Pozzolan is a cement additive comprising siliceous or siliceous and aluminous material that in itself possesses little or no cementitious value but that will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. Fly ash is a pozzolanic material obtained from industry as the finely divided residue collected from flue gases produced from combustion of ground or powdered coal. Natural pozzolans are materials occurring in some diatomaceous earths, opaline cherts and shales, tuffs, volcanic ash, and pumicites. Calcined pozzolans are produced by calcination of natural siliceous or alumino-siliceous earths for the purpose of activation of pozzolanic properties. Cements containing up to 35% pozzolan have been used extensively.

Cement Products

6. Part 13 (Part 9 until 1974) of the Annual Book of ASTM Standards contains all current, formally approved ASTM standards and tentative test methods, definitions, recommended practices, classifications, and specifications for cement, lime, and gypsum. The European Cement Association, CEMBUREAU, compiles and periodically updates its publication on "Cement Standards of the World." The main types of hydraulic cement products, and the materials from which they are made, are:

7. Clinker is produced by heating a properly proportioned mixture of finely ground raw materials containing calcium carbonate, silica, alumina, and usually iron oxide in a kiln to a temperature at which partial fusion occurs. Chemically, clinker comprises four main phases of various proportions of tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A), tetracalcium aluminoferrite (C_4AF), minor amounts of calcium sulfate ($CaSO_4$), and usually, but not necessarily magnesia (MgO), lime (CaO), and various

alkalies, depending on raw materials used and type of cement being manufactured. Clinker, ranging in particle size from fine sand grains to walnut size, is ground with a small amount of calcium sulfate, usually gypsum of anhydrite (2% to 5%), to make portland cement.

8. Portland Cement is produced by pulverizing clinker consisting essentially of hydraulic calcium silicates and usually containing one or more of the forms of calcium sulfate as an interground addition. ASTM specification C150 covers five types of portland cement, based mostly on the proportions of C_3S, C_2S, and C_3A in the cement. Type I, for use when special properties specified for any other types are not required; Type II, for general use, more especially when moderate sulfate resistance or moderate heat of hydration is desired; Type III, for use when high early strength is required; Type IV, for use when a low heat of hydration is desired; and Type V, for use when high sulfate resistance is required. ASTM specifications include three additional types of portland cement designated Type I A, Type II A, and Type III A that are respectively air-entraining cements for the same uses as Type I, Type II, and Type III. Air-entraining portland cement is produced in essentially the same way as portland cement but with the addition of an interground air-entraining agent.

9. White Cement is made from iron-free materials of exceptional purity, usually limestone, china clay or kaolin, and silica. Clinker is burned with a reducing flame in the kiln and rapidly quenched in a water spray to keep any iron in the ferrous state to avoid coloration by ferric irons. Clinker is ground with high-purity white gypsum using ceramic balls and liners in grinding mills; recently high-chromium alloys have been used for liners and grinding media. White cement conforms to portland cement specifications for the various types and is used in decorative concrete including terrazzo, highway lane markets, and architectural concrete.

10. Masonry Cement is a hydraulic cement for use in mortars for masonry construction, containing one or more of the following materials: portland cement, portland-pozzolan cement, slag cement, or hydraulic lime, usually with hydrated lime, limestone, chalk, calcareous shale, talc, slag, or clay interground for plasticity.

11. Portland-Blast Furnace Slag Cement is essentially an intimately interground mixture of portland cement clinker and granulated blast furnace slag, or an intimate and uniform blend of portland cement and fine granulated blast furnace slag in which the amount of the slag constituent is between 25% and 65% of the total weight of blended cement. Type I S portland-blast furnace slag cement is for general concrete construction.

12. Portland-Pozzolan Cement, an intimate and uniform blend of portland cement or portland-blast furnace slag cement and fine pozzolan, is produced by intergrinding portland cement clinker and pozzolan, by blending portland cement or portland-blast furnace slag cement and finely divided pozzolan, or a combination of intergrinding and blending in which the amount of the pozzolan constituent is between 15% and 40% of the total weight of blended cement. Type I P portland-pozzolan cement is for use in general concrete construction, and Type P is for use in concrete construction where high strengths at early ages are not required.

13. Pozzolan-Modified Portland Cement - The constituents in this type of cement are the same as those for portland-pozzolan cement, and the methods of production are also the same. However, the amount of pozzolan constituent is less than 15% of the total weight of blended cement. Type I (PM) pozzolan-modified portland cement is for general concrete construction.

14. Slag Cement is a finely ground material consisting essentially of an intimate and uniform blend of granulated blast furnace slag and hydrated lime in which the slag constituent is at least 60% of the total weight of blended cement. Type S-slag is for use in combination with portland cement in making concrete and in combination with hydrated lime in making masonry mortar.

15. Oil-Well Cement was developed to seal oil and gas wells under pressures up to 18,000 pounds per square inch and temperatures up to 350° F. These cements are required to remain fluid up to about 4 hours and then harden rapidly. Setting time is controlled by reducing C_3A to nearly zero or adding to portland cement some retarder such as starches or cellulose products, sugars, and acids or salts of acids containing one or more hydroxyl groups.

16. Expansive Cement tends to increase in volume after setting during the early hardening period, due to the formation of chemical substances such as calcium sulfoaluminate hydrate which cause expansion equal to or greater than the shrinkage that would normally occur during the hardening process.

17. Regulated-Set Cement has a setting time which can be controlled from a few minutes to 30 minutes or more. Rapid-hardening modifed portland cement develops very high early strengths. Promising applications include highway resurfacing and paving patching, underwater patching, manufacturing concrete pipe, blocks, and prestresed precast forms, and use in slip form structures.

18. Aluminous Cement, sometimes known as calcium aluminate cement, high-alumina cement, or "Ciment Fondu", is a hydraulic non-portland cement containing monocalcium aluminate ($CaO \cdot Al_2O_3$ or CA) as thepredominant cementitious compound that sets at about the same rate as portland cement but hardens very rapidly, attaining high strength in 24 hours. Aluminous cements are produced mainly from relatively high-purity bauxite and limestone with very low silica and magnesia content within the temperature range of 2,700° to 2,900° F. Special applications of aluminous cement are based on its rapid-hardening qualities, resistance to sulfate action, and refractory properties when used as "castable refractories" and mortars for furnaces and kilns.

19. Concrete. A proportioned mixture of inert mineral aggregates of sand and gravel or crushed stone, concrete is bound together by a paste of hydraulic cement and water into a monolithic mass when the binder sets and hardens through the chemical action of cement and water. A mixture of cement, water, and fine aggregate is called mortar; concrete contains coarse aggregate in addition.

Source: US Bureau of Mines, Mineral Facts and Problems

ANNEX 2-1: CEMENT PRODUCTION AND CONSUMPTION IN SELECTED COUNTRIES

	Production (Million Tons)				Consumption (Million Tons)				Per Capita Consumption (Kg)		
	1950	1973	1981	% Share of World Prod. in 1981	1950	1973	1981	% Share of World Cons. in 1981	1950	1973	1981
Industrial Countries (ICs)											
- France	7.2	31.9	29.5	3.4	6.4	28.9	27.0	3.0	155	573	501
- FR of Germany	10.9	40.9	30.2	3.4	9.6	39.7	29.3	3.3	200	640	475
- Italy	5.0	36.7	43.1	4.9	5.2	35.7	42.7	4.8	111	648	746
- Japan	4.5	77.7	84.4	10.2	4.0	77.7	77.9	8.8	48	715	659
- USA	38.0	73.9	65.0	7.4	38.0	78.4	66.5	7.5	251	374	289
- Spain	2.1	22.6	30.5	3.5	2.0	21.6	18.5	2.1	73	619	491
- Others	26.9	85.1	63.4	6.5	21.9	88.7	69.5	8.1			
Subtotal	94.6	368.8	346.4	39.3	87.1	370.7	331.4	37.5			
Centrally Planned Economies (CPEs)											
- USSR	10.2	109.4	127.0	14.4	10.2	106.7	124.6	14.1	53	427	465
- Czechoslovakia	1.8	8.3	10.6	1.2	1.6	9.1	10.7	1.2	132	624	702
- Poland	2.5	15.5	14.2	1.6	2.4	17.0	13.9	1.6	95	510	388
- Others	2.1	16.1	21.6	2.4	2.1	15.8	19.5	2.2			
Subtotal	16.6	149.3	173.4	19.6	16.3	148.6	168.7	19.1			
High Income Oil Exporting Countries (HIOECs)											
- Kuwait	-	0.3	1.5	0.2	-	0.7	1.9	0.2	-	769	1,300
- Saudi Arabia	-	1.0	3.4	0.4	-	1.5	15.6	1.7	-	178	1,670
- Others	-	0.2	5.0	0.6	-	2.6	8.0	0.9			
Subtotal	-	1.5	9.9	1.2	-	4.8	25.5	2.9			
Developing Countries (DCs)											
Oil Importing DCs (OIDCs)											
- Argentina	1.6	5.2	6.7	0.8	2.0	5.2	6.5	0.6	120	215	240
- Brazil	1.4	13.4	26.0	2.9	1.8	13.5	26.0	2.9	34	133	204
- Burma	-	0.2	0.4	-	-	0.2	0.3	-	-	7	7
- China	-	40.8	82.0	9.3	-	39.8	81.1	9.2	-	49	80
- Greece	0.4	6.5	13.1	1.5	0.4	6.1	6.5	0.7	52	581	670
- Hungary	0.8	3.4	4.6	0.5	0.8	4.6	5.1	0.6	84	444	480
- India	2.6	15.0	20.1	2.3	2.7	14.8	22.3	2.5	7	26	33
- Korea	-	8.2	15.6	1.8	-	7.2	12.4	1.4	-	215	321
- Morocco	0.3	1.6	3.6	0.4	0.6	1.7	3.6	0.4	63	102	176
- Pakistan	0.4	2.7	3.7	0.4	0.4	3.4	4.1	0.5	6	53	49
- Philippines	0.3	4.0	4.0	0.4	0.3	2.8	3.5	0.4	17	71	71
- Portugal	0.6	3.2	6.0	0.7	0.5	3.2	6.4	0.7	63	368	636
- Romania	1.0	9.8	14.8	1.7	1.0	8.1	12.0	1.4	60	387	532
- Thailand	0.2	3.7	6.3	0.7	0.2	3.1	6.1	0.7	10	77	126
- Togo	-	0.1	0.4	-	-	0.1	0.2	-	13	56	82
- Turkey	0.4	9.2	15.1	1.7	0.5	8.3	11.8	1.3	25	216	259
- Yugoslavia	1.2	6.2	10.1	1.1	0.9	6.7	10.0	1.1	56	321	444
- Others	n.a.	33.5	53.6	6.2	n.a.	31.0	54.7	6.4			
Subtotal	n.a.	166.7	286.7	32.4	n.a.	159.8	272.6	30.9			
Oil Exporting DCs (OEDCs)											
- Algeria	0.3	1.0	4.5	0.5	0.5	2.2	5.5	0.6	56	162	279
- Ecuador	0.1	0.5	1.2	0.1	0.1	0.6	1.6	0.2	20	96	181
- Egypt	1.0	3.6	3.4	0.4	1.0	3.0	6.9	0.8	47	86	159
- Indonesia	0.1	0.8	6.8	0.7	0.2	2.1	6.7	0.7	3	17	44
- Mexico	1.4	9.7	18.0	2.0	1.4	9.6	18.1	2.0	54	171	255
- Nigeria	-	1.2	2.5	0.3	0.2	1.9	7.2	0.8	5	32	91
- Tunisia	0.2	0.5	2.0	0.2	0.2	0.7	2.1	0.2	56	125	319
- Others	n.a.	13.9	28.1	3.2	n.a.	13.5	36.6	4.1			
Subtotal	n.a.	31.2	66.5	7.5	n.a.	33.6	84.7	9.6			
Subtotal for all DCs	n.a.	197.7	353.2	39.9	n.a.	193.4	357.3	40.5			
World Total	133.0	717.5	882.9	100.0	133.0	717.5	882.9	100.0	55	188	190

Source: Based on CEMBUREAU data.

ANNEX 2-2: CEMENT MANUFACTURING PROCESSES

1. The principal steps in manufacturing portland cement are: crushing, grinding, mixing, and burning raw materials; and cooling and grinding clinker.

Crushing

2. Most rock is transported by truck from the quarry to gyratory or jaw crushers where it is crushed, screened, and further reduced in size in cone crushers or hammer mills to mill feed size.

3. Crushed rock is transported to the grinding mills by barge at many plants on waterways, by rail at some inland plants, and by conveyor belts several miles long at other plants.

4. About 1.8 tons of raw materials are required to manufacture one ton of finished portland cement; 1.7 tons are used to make clinker, and the remaining 0.1 ton is added during the clinker-grinding process.

Raw Material Grinding and Preparation

5. The two main processes used in cement manufacture are the wet and dry processes. In the wet process, the crushed and proportioned raw materials are ground with water, thoroughly mixed and fed into the kiln in the form of a slurry. Slurry feed has typically about 35% moisture (normal range 24-48%) and is the result of an entirely 'wet' preparation process. The minimum moisture content of the slurry is determined by the maximum viscosity permissible for efficient pumping of the slurry. In the dry process, the raw materials are ground, mixed and fed into the kiln in their dry state. The powdered feed (raw meal) has typically about 0.5% moisture (normal range 0-7%) and is the result of an entirely 'dry' preparation process. In other respects, the wet and dry processes are essentially the same. There are also less common variations of these two basic processes, such as the semi-wet and semi-dry processes.

In the semi-wet process, the slurry feed is partially dewatered before introduction to the pyroprocess through a filtration and subsequent extrusion process. The moisture content is typically 17-22% and as a result of extrusion, the feed is transformed into cylindrical slugs of plastic material. The minimum moisture content is determined, apart from raw material properties, by filtration time and the extent of filtration equipment. In the semi-dry process, powdered feed is subsequently mixed with typically 11-14% water to achieve better homogenization of the raw mix before introduction to the pyroprocess. The water is added to the dry feed on a rotating dish (pelletizer) in such a manner as to form small pellets possessing a certain minimum mechanical integrity. The required water addition is determined by the minimum amount necessary to achieve adequate pelletization.

6. The choice between the different processes is dictated primarily by the characteristics of the available raw materials. Despite its relatively high specific energy consumption, the wet process may be necessary for raw material preparation in certain cases, e.g., those involving: (i) extremely high moisture content (over 20%) the drying of which requires large amounts of auxiliary heat to supplement the kiln waste heat; (ii) characteristics of specific raw materials like certain chalks or clays that can best be processed as a slurry; (iii) necessity of limestone beneficiation by a wet process; (iv) remote quarries and lack of viable raw material transport alternatives other than existing pipelines; and (v) raw material chemistry unsuited to use in high efficiency preheater kilns.

7. Until recently, two types of mills were used, based on grinding media: ball mills and rod mills. Both are horizontal rotating drums with alloy steel liners ranging from 8 to 18 feet in diameter, 10 to 73 feet in length, with 300- to 8,700-horsepower motors. The ball mill is charged to about 45% of the volume with steel balls up to 5 inches in diameter, and the rod mill is charged with steel rods 2 to 5 inches in diameter and nearly equal to the inside length of the mill. Raw materials are reduced in size by impact and attrition by the grinding media in cascading and cataracting motions while the mill is rotating 15 to 18 revolutions per minute.

8. In wet process milling, water is added with the mill feed to produce a slurry containing about 65% solids. A few plants install beneficiation facilities using froth flotation to remove excess silica from the limestone.

9. Raw materials must be dried, usually in a rotary dryer, for dry-process grinding in ball mills and rod mills. In many new dry-process plants, roller mills are replacing ball mills and rod mills. In roller mills, the material is dried during pulverization using waste heat from the kilns.

Pyroprocessing

10. Burning is the most important operation in manufacturing cement because: (i) fuel consumption is the major expense in the process; (ii) capacity of a plant is measured by kiln output, and (iii) strength and other properties of cement depend on the quality of clinker produced. Two types of kilns are used in the industry: vertical or shaft kilns (accounting for only about 5% of world production) and rotary kilns. Vertical kilns, common in Europe and some developing countries, are generally only efficient at capacities of up to 100,000 tons per year, whereas rotary kilns are efficient at capacities well beyond one million tons. Rotary kilns have replaced shaft kilns completely in the United States. A rotary kiln is a refractory-lined steel cylindrical shell that rotates around an axis inclined at 3/8 to 1/2 inch per foot. Kilns in the United States range in size from 6 feet in diameter and 120 feet long to 25 feet in diameter and 760 feet long, and rotate at 50 to 90 revolutions per hour.

11. Rotary kilns are amenable to both wet and dry processes (attached diagram 1), whereas vertical kilns are limited to the dry process only. Blended dry mix or slurry enters the upper or feed end of the rotary kiln and is conveyed by the slope and rotation to the firing or discharge end of the kiln. In the wet process, exit gas temperature is about 500°F to 700°F and the moisture in the slurry is evaporated in a heat exchanger, usually a system of hanging chains about one-fourth the length of the kiln. Next, in a temperature zone up to 1,800°F, alkalies vaporize, combustion of any organic material takes place, and calcium carbonate is calcined to CaO. Clinkering takes place in the burning zone at about 2,700°F. Presence of iron oxide as a flux in the raw mix lowers the temperature required to form clinker.

12. Suspension Preheater Systems: These systems are similar to the long dry rotary kiln in that the feed is a free-flowing powder, but the initial heating takes place in a stationary unit composed of a sequence of from one up to six cyclones (usually four or five). The feed enters the top stage and gradually moves through the cyclones until it enters the rotary kiln. The hot kiln exit gases are simultaneously moving in the opposite direction and the highly turbulent mixing action between the feed and gases promotes efficient heat exchange sufficient to induce 40-50% calcination of the raw feed by the time it enters the rotary kiln. Thus, the kiln itself is shorter than a long dry kiln of equivalent production. Since the feed is already partly calcined before entry into the kiln, its duration of stay in the kiln is shortened and kiln productivity is increased. More than 500 suspension preheaters have been installed in the world in the last 20 years.

13. Although preheater systems improve fuel economy, they can have the disadvantage that certain impurities like alkali metal compounds, which are vaporized in the kiln and would usually be removed from the process in the hot kiln exit gases, can be introduced into the raw mix as it is preheated with the recycled kiln gases. These alkalies thus reenter the kiln where they are again vaporized and sent back to the preheater, thereby setting up an 'alkali cycle' leading to alkali build-ups in the preheater. Eventually, an equilibrium is reached, with large quantities of alkali being removed in the clinker. This can cause problems in the resultant concrete, leading to severe cracking in concrete structures. To avoid the problem of alkali build-up, the suspension preheater design may include a gas-bypass system. If the alkali content of clinker rises too high, typically 5 to 10% of the kiln gases is bypassed, and with this gas, some of the alkali components are removed. However, there is a penalty in terms of energy consumption, since bypassing of 10% of the gas generally represents an extra heat consumption of the order of 60 kcals/kg of clinker.

14. Grate Preheater Systems (Semi-Wet/Semi-Dry Processes): An external preheater is used in these systems as well (attached diagram 2). The feed is processed into pellets in a special equipment called a pelletizer using finely ground feed and about 12-22% water. The pellets are discharged onto a

travelling grate which conveys them toward the kiln inlet. At the same time, the kiln exit gases are passed through the bed of pellets which effects efficient heat exchange to dry, preheat and partially calcine the feed before entry into the kiln.

15. Precalcining or Secondary-firing Systems: The advent of preheater equipment, either grate or suspension, has allowed the development of two-point fuel firing or precalcining. Precalciner systems (attached diagram 3) have one common basis - the degree of calcination of the raw mix entering the rotary kiln is increased by burning a substantial portion (up to two-thirds) of the total fuel requirements in a precalciner vessel which is part of the grate or suspension preheater. In a conventional preheater system, 50% of the heat transfer occurs in the preheater and the raw mix enters the kiln 20-30% decarbonated. With the addition of precalcination, decarbonation is increased to 85-90% and as a result a higher kiln capacity is attained with given kiln dimensions, or for a new installation, the required kiln volume can be reduced by as much as 50%. Since a substantial part of the fuel is burnt outside the kiln, precalciner systems have the major advantage of being able to use low-grade fuels. Other advantages claimed for precalciner systems are: improved brick life for the kiln lining; reduced alkali and sulphate build-up; improved control and kiln stability; more efficient alkali bypass; and reductions in dust emissions.

16. Clinker Coolers: The temperature of clinker discharged from the kiln is reduced in a clinker cooler, serving the dual purpose of lowering the clinker temperature and recuperating the clinker heat for reuse as combustion air inside the kiln. In the United States, most clinker is air-quenched in a traveling or reciprocating grate cooler where cooling air passes through a slowly moving bed of hot clinker.

17. Kiln exit gases pass through electrostatic precipitators or glassbag collectors where entrained dust particles are collected. Dust collected may be returned to the kiln feed or insufflated near the burner, unless the alkali content is too high.

Clinker Grinding

18. Finally, clinker is fine ground with gypsum (2-5%) in the case of portland cement, plus other additives such as pozzolan, fly ash, slag, etc., when a different type of cement is being produced.

Source: US Bureau of Mines, Mineral Facts and Problems, and various other sources.

Diagram 1: Dry and Wet Process Flows

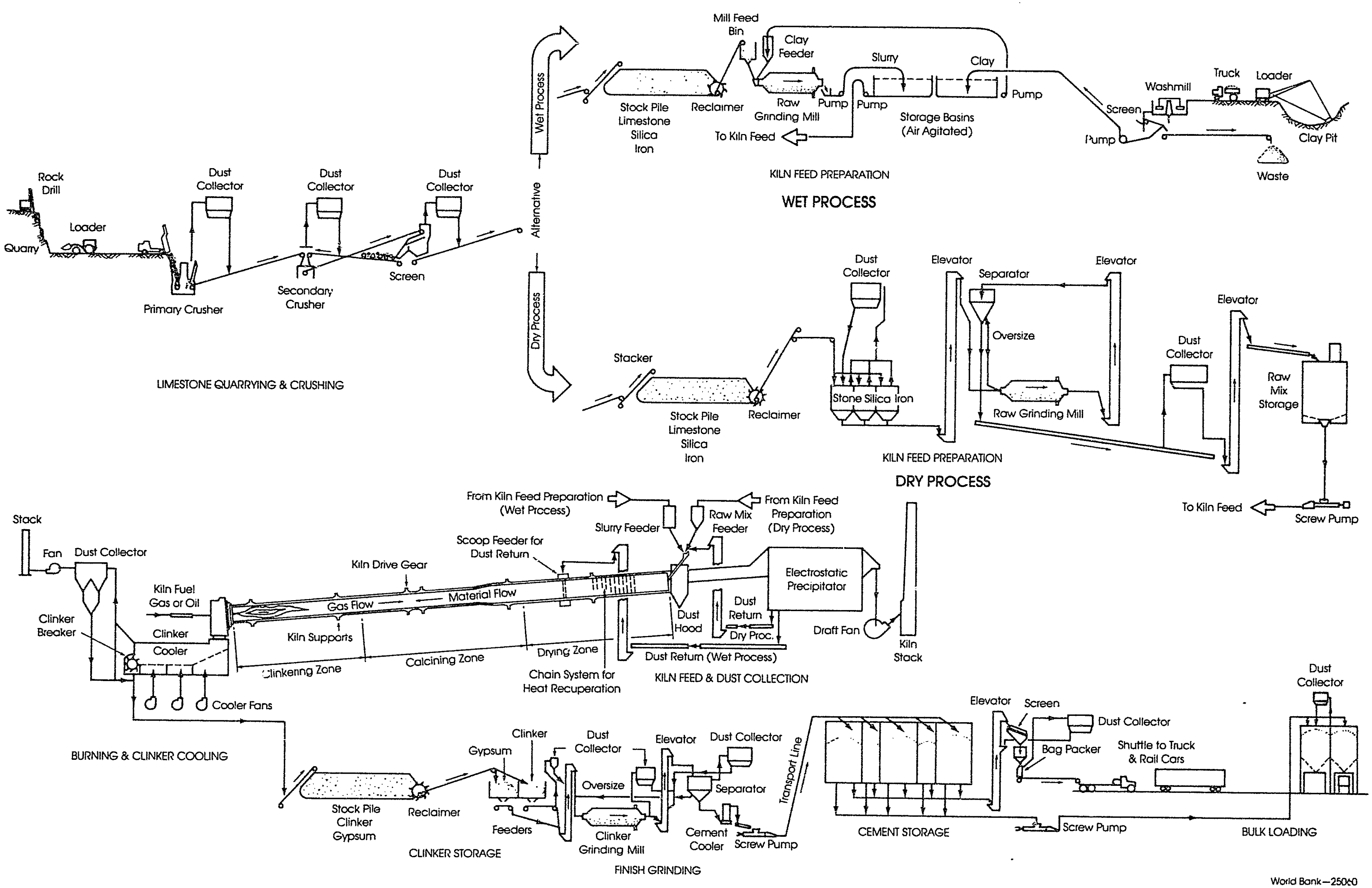

Diagram 2: **Semi Wet Process Flow**

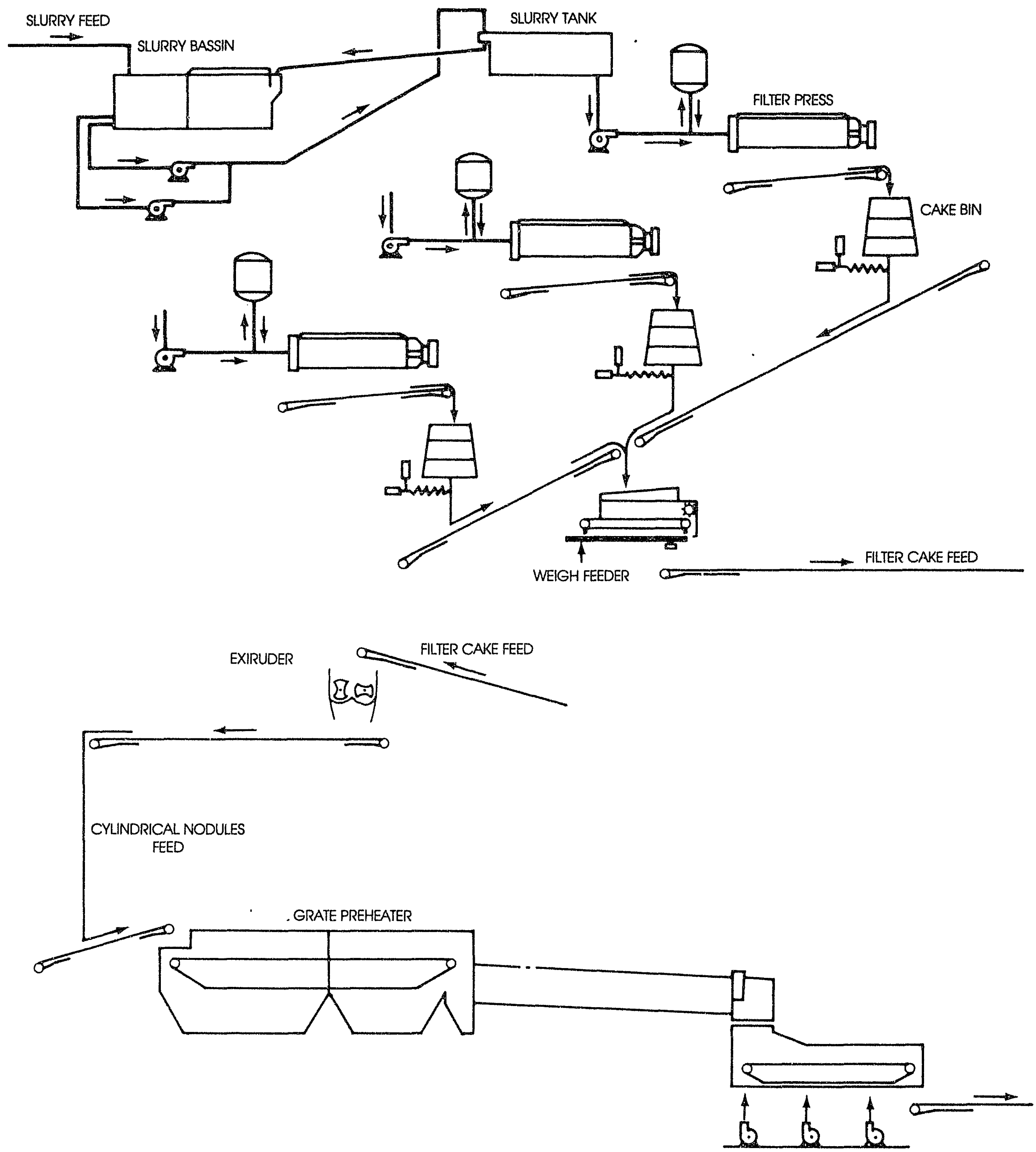

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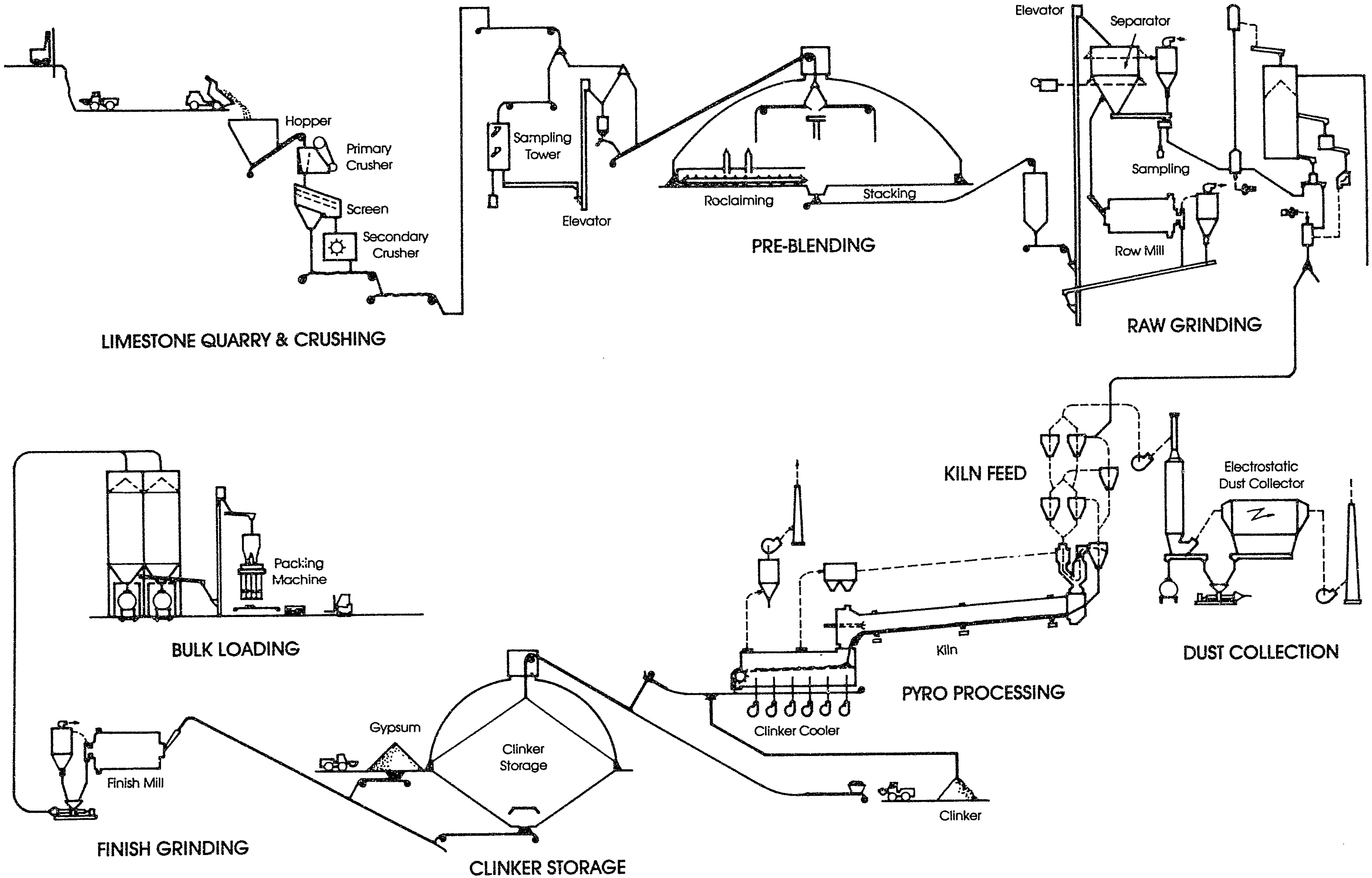
Diagram 3: Precalciner Process Flow



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ANNEX 2-3: VARIOUS FORECASTS OF GROWTH OF WORLD CEMENT CONSUMPTION
(million tons)

Source	1980 (Actual)	1985 ---(Forecasts)---	1990
A. Lafarge Consultants (1981)	879	-	1,200-1,380
B. Blue Circle (1981)	879		1,100

ANNEX 3-1: ENERGY CONSUMPTION IN THE CEMENT INDUSTRY IN SELECTED DCs

	Annual Energy Consumption in Cement (10^{12} kcals)	Percentage of Commercial Energy Consumption	Percentage of Energy as Fuel	Average Kiln Heat Consumption (kcals/kg cl.)
Argentina	9.13	2	79	1030
Bolivia	0.81	5	77	930
Brazil	36.80	5	76	1040
Cameroon	0.11	n.a.	83	1100
Caribbean	4.00	4	85	1485
Chile	2.17	3	72	1140
Colombia	10.41	8	85	1620
Ecuador	2.02	5	78	1075
Ethiopia	0.24	5	85	1120
Gabon	0.26	3	86	1450
Indonesia	9.18	3	77	970
Malawi	0.18	8	80	950
Malaysia	3.75	5	80	1110
Mali	0.10	7	87	1900
Morocco	6.12	15	79	1085
Mozambique	1.40	10	80	1045
Niger	0.06	4	83	1300
Nigeria	6.51	12	81	1135
Pakistan	6.93	7	93	1670
Panama	1.05	8	82	1350
Paraguay	0.37	9	85	1500
Senegal	0.57	8	82	1120
Sri Lanka	0.83	7	77	905
Togo	0.73	41	76	830
Tunisia	3.54	14	81	990
Uruguay	1.33	6	84	1385

Source: Based on data from Lafarge Consultants

ANNEX 3-1 (Continued)

DISTRIBUTION OF ENERGY CONSUMED BY TYPE OF FUEL (1978)
(%)

	Oil	Gas	Coal	Total
Oil Importing DCs (OIDCs)				
Argentina	34	63	3	100
Brazil	100	-	-	100
Chile	16	-	84	100
Colombia	27	17	56	100
India	2	-	98	100
Korea	100	-	-	100
Morocco	100	-	-	-
Pakistan	-	100	-	100
Philippines	97	-	3	100
Portugal	100	-	-	100
Thailand	100	-	-	100
Turkey	75	-	25	100
Yugoslavia	78	6	16	100
Oil Exporting DCs (OEDCs)				
Indonesia	83	-	17	100
Malaysia	100	-	-	100
Mexico	77	23	-	100
Nigeria	73	-	27	100
Peru	100	-	-	100
Syria	100	-	-	100

Source: Estimates based on CEMBUREAU data.

ANNEX 3-2: DC CLINKER CAPACITY BY TYPE OF PROCESS - 1979 a/

	Rotary Dry			Rotary Semi-Dry			Rotary Wet			Vertical Shaft			Total		
	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)
A) AFRICA															
- Algeria	10	G	3,850	-	-	-	5	G	1,100	-	-	-	15	G	4,950
- Angola	-	-	-	-	-	-	4	0	900	-	-	-	4	0	900
- Cameroon	1	0	70	-	-	-	-	-	-	-	-	-	1	0	70
- Congo	1	0	80	-	-	-	-	-	-	-	-	-	1	0	80
- Egypt	-	-	-	3	0	840	18	0,G	6,900	-	-	-	21	0,G	7,830
- Ethiopia	2	0	130	1	0	38	-	-	-	-	-	-	3	0	168
- Gabon	-	-	-	-	-	-	1		350	-	-	-	1		350
- Kenya	2	0,C	/50	-	-	-	2	0	350	6	0,C	500	10	0,G	1,600
- Libya	9	0	3,930	-	-	-	-	-	-	-	-	-	9	0	3,930
- Madagascar	-	-	-	-	-	-	1	C	115	-	-	-	1	C	115
- Malawi	1	C	70	1	C	70	-	-	-	-	-	-	2	C	140
- Mali	-	-	-	-	-	-	1		45	-	-	-	1		45
- Morocco	4	0	1,870	4	0	960	8	0	1,600	-	-	-	16	0	4,430
- Mozambique	1	C	600	1	C	90	1	6	300	-	-	-	3	C	990
- Niger	1	0	37	-	-	-	-	-	-	-	-	-	1	0	37
Nigeria	6	0	1,570	2	0	430	8	0	2,700	-	-	-	16	0	4,700
- Senegal	3		380	-	-	-	-	-	-	-	-	-	3		380
- Sudan	3	0	600	-	-	-	-	-	-	-	-	-	3	0	600
- Tanzania	2	0	545	-	-	-	-	-	-	-	-	-	2	0	545
- Togo	2	0	1,200	-	-	-	-	-	-	-	-	-	2	0	1,200
- Tunisia	6	0	3,430	-	-	-	3	0	470	-	-	-	9	0	3,900
- Uganda	4	0	300	-	-	-	-	-	-	-	-	-	4	0	300
- Zaire	3	0	710	1	0	105	3	0.C	115	-	-	-	7	0,G	930
- Zambia	2	C	270	-	-	-	3	C	200	-	-	-	5	C	470
- Zimbabwe	1	C	427	3	C	250	-	-	-	-	-	-	4	C	675
Sub total for Africa	64		20,817	16		2,783	58		15,235	6		500	144		39,335
Distribution by Type of Process (%)															
- No. of kilns	45			11			40			4			100		
- Capacity			53			7			39			1			100

0 = Oil; C = Coal; G = Gas.

a/ Capacity refers to rated capacity and includes plants under construction in 1979.

DC CLINKER CAPACITY BY TYPE OF PROCESS - 1979

	Rotary Dry			Rotary Semi-Dry			Rotary Wet			Vertical Shaft			Total		
	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of kilns	Type of Fuel	Capacity ('000 tons)	No. of kilns	Type of Fuel	Capacity ('000 tons)	No. of kilns	Type of Fuel	Capacity ('000 tons)
B) **AMERICA**															
- Argentina	28	O,C,G	7,830	3	O,G	300	11	O,G	1,895	-	-	-	42	O,C,G	10,025
- Bahamas	-	--	-	-	-	-	2	O	690	-	-	-	2	O	690
- Bolivia	4	O	610	-	-	-	-	-	-	-	-	-	4	O	610
- Brazil	43	O,C	18,265	3	O	755	51	O,G	7,965	-	-	-	97	O,C	26,985
- Chile	5	C	920	-	-	-	2	C	430	-	-	-	7	C	1,350
- Colombia	6	O	955	-	-	-	36	O,C,G	5,415	-	-	-	41	O,C,G	6,370
- Costa Rica	3	O	985	-	-	-	-	-	-	-	-	-	3	O	985
- Dominican Republic	1	O	540	-	-	-	6	O	760	-	-	-	7	O	1,300
- Ecuador	6	O	940	-	-	-	2	O	120	-	-	-	8	O	1,060
- El Salvador	1	O	290	-	-	-	3	O	610	-	-	-	4	O	900
- Guatemala	4	O	1,020	-	-	-	-	-	-	-	-	-	4	O	1,020
- Haiti	-	--	-	-	-	-	2	O	270	-	-	-	2	O	270
- Honduras	4	O	450	-	-	-	-	-	-	-	-	-	4	O	450
- Jamaica	-	-	-	-	-	-	3	O	400	-	-	-	3	O	400
- Mexico	68	O,G	23,050	-	-	-	4	O	490	-	-	-	72	O,G	23,540
- Nicaragua	-	-	-	-	-	-	5	O	330	-	-	-	5	O	330
- Panama	1	O	120	-	-	-	3	O	330	-	-	-	4	O	650
- Paraguay	-	-	-	-	-	-	2	O	200	-	-	-	2	O	200
- Peru	8	O	2,835	-	-	-	4	O	235	-	-	-	12	O	3,070
- Puerto Rico	-	-	-	-	-	-	8	O	2,030	-	-	-	8	O	2,030
- Trinidad and Tobago	-	-	-	-	-	-	3	O	425	-	-	-	3	G	425
- Uruguay	1	O	255	-	-	-	7	O	470	-	-	-	8	O	725
- Venezuela	9	O,G	3,400	-	-	-	14	O,G	4,400	-	-	-	23	O,G	7,800
Subtotal for America	192		62,465	6		1,055	168		27,465	-			365		90,985
Distribution by Type of Process (%)															
- No. of kilns	53			2			46			-			100		
- Capacity			68			1			31			-			100

DC CLINKER CAPACITY BY TYPE OF PROCESS - 1979

	Rotary Dry			Rotary Semi-Dry			Rotary Wet			Vertical Shaft			Total		
	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)
C) ASIA															
- Afghanistan	-	0	-	-	-	-	3	C	860	-	-	-	3	C	860
- Bangladesh	-	-	-	-	-	-	1	G	120	-	-	-	1	G	120
- Burma	1	-	240	-	-	-	3	0	300	-	-	-	4	0	540
- China	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	90,000
- India a/	35	0,C	10,160	6	0,C	1,828	95	C,G	12,464	-	-	-	136	0,C,G	24,452
- Indonesia	9	0	7,020	-	-	-	10	0,C	1,450	-	-	-	19	0,C	8,470
- Iran b/	34	0,C	11,890	-	-	-	10	0	4,455	-	-	-	44	0,C	16,345
- Iraq	3	0	1,250	-	-	-	24	0	5,825	-	-	-	27	0	7,075
- Jordan	1	0	440	-	-	-	3	0	660	-	-	-	4	0	1,100
- Korea	21	0	24,790	7	0	2,200	4	0	570	-	-	-	32	0	27,560
- Lebanon	-	-	-	-	-	-	10	0	2,330	-	-	-	10	0	2,330
- Malaysia	3	0	1,100	2	0	450	4	0	1,640	-	-	-	9	0	3,190
- Nepal	-	-	-	-	-	-	1	C	44	-	-	-	1	C	44
- Pakistan	-	-	-	5	G	495	21	C,G	2,865	-	-	-	26	C,G	3,360
- Philippines	20	-	5,075	12	0	1,620	2	0	205	-	-	-	34	0	6,900
- Sri Lanka	4	0	915	-	-	-	-	-	-	-	-	-	4	0	915
- Syria	4	0	1,360	-	-	-	9	0	1,020	-	-	-	13	0	2,380
- Taiwan	21	0,C	11,460	10	0,C	1,910	-	-	-	-	-	-	31	0,C	13,370
- Thailand	7	0	3,990	2	0	400	9	0	2,710	-	-	-	18	0	7,100
- Yemen Arab Republic	-	-	-	-	-	-	1	0	65	-	-	-	1	0	65
Subtotal for Asia - Excluding China	163		79,690	44		8,903	210		37,583	-		-	417		126,176
- Including China	n.a.		n.a.	n.a.	n.a	n.a.	n.a.	n.a	n.a	n.a	n.a	n.a	n.a.		216,176
Distribution by Type of Process (%)															
- No. of Kilns) Excluding	39			11			50			-			100		
- Capacity) China			63			6			31			-			100

a/ Does not include mini-cement plants and some new plants under construction.
b/ Cement capacity.

DC CLINKER CAPACITY BY TYPE OF PROCESS - 1979

	Rotary Dry			Rotary Semi-Dry			Rotary Wet			Vertical Shaft			Total		
	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)
D) EUROPE															
- Cyprus	2	0	385	-	-	-	3	-	780	-	-	-	5	0	1,165
- Greece	24	0	10,953	-	-	-	-	0	-	2	0	515	26	0	11,468
- Hungary	5	0,C,G	2,500	5	0	740	14	0,C	1,130	-	-	-	24	0,C,G	4,360
- Portugal	11	0	4,150	1	0	70	6	0	1,750	-	-	-	18	0	5,970
- Romania	n.a.		n.a.	n.a.		n.a.	n.a.		n.a.	n.a.		n.a.	n.a.		n.a.
- Turkey	50	0,C	17,400	-	-	-	8	0,C	2,150	-	-	-	58	0,C	19,550
- Yugoslavia	31	0,C	9,945				6	0,C	860	22	0,C	725	59	0,C	11,530
Subtotal for Europe	123		45,333	6		810	37		6,660	24		1,240	190		54,043
Distribution by Type of Process (%)															
- No. of Kilns	65			3		1	19			13			100		100
- Capacity			84						12			2			
TOTAL FOR ALL DEVELOPING COUNTRIES															
- excluding China	542		208,305	72		13,551	473		86,943	30		1,740	1,117		310,539
- including China	n.a		n.a	n.a		n.a	n.a		n.a	n.a		n.a	n.a		400,539
Distribution by Type of Process (%)															
- No. of Kilns)Exclu-	49						42						100		
- Capacity)ing China, Romania			69	6		4		28		3		1			100

Source: Based on CEMBUREAU data.

ANNEX 4-1: AN ILLUSTRATIVE OUTLINE OF AN ENERGY AUDIT FOR A CEMENT PLANT

1. An energy audit is a formalized review of the operating parameters within a cement plant, with special emphasis on the kiln/raw mill/clinker cooler system. It attempts to establish a balance sheet with energy inputs on one side and energy outputs on the other side. Such an audit is usually conducted over a reasonably long period of time (typically 48 hours) in order to assure that the collected data are representative of a balanced uniform operating condition. The basic tools consist of a material balance and an energy balance.

2. Material Balance: The feed rates to kiln and raw mill are carefully monitored. In most cases the instrument feed rate is checked by physically collecting and weighing the material flow within a carefully measured time interval in order to verify whether the instrument readings are correct. The input fuel rate is checked in the same manner. Simultaneously, all gas flows within the system are determined by measuring gas velocities and temperatures with regular intervals. The material output rate is found by weighing and measuring the raw meal and clinker production. Most of these measurements are cumbersome and require experience and care. It involves not only readings of temperatures and velocities, but also measurement of oxygen, combustibles and moisture contents of the exhaust gases in order to determine things like rate of air infiltration and possible incomplete combustion. A material balance is required before an energy balance can be constructed.

3. Energy Balance: A number of individual sources of heat loss or energy consumption can be calculated rather directly from mass flow and temperature readings, but others, as for instance, radiation losses require some interpretation. Once the heat balance has been put together it becomes possible for the experienced operator to diagnose the process areas where excessive heat losses occur and thereby to prescribe procedures for improvements.

4. The whole exercise can be done in approximately 2-4 weeks, and it requires a number of special measurement devices. A somewhat similar approach is followed for reviewing the consumption of electrical power. All inefficiencies in the kiln system cause the gas volume per unit of production to be higher than design, and since the bottleneck in most kiln systems is located within the gas handling equipment, such inefficiency will prevent the system from reaching its full clinker production potencial.

ANNEX 4-2: SELECTED EXAMPLES OF IMPROVEMENT IN ENERGY CONSERVATION AND IN SPECIFIC ENERGY CONSUMPTION

Plant Type/ Location	Energy Savings	Measures Taken	Approximate Capital Cost (US dollars)	Payback Period (Years)
A. Energy Conservation				
Wet Process	Savings of 150 kcals/kg equivalent to US$300,000/year.	Adding a vent air recirculation system to clinker cooler thereby reducing dust wastage and increasing heat recuperation.	130,000 430,000	1-2
Long Dry Pocess	Savings of 512 toe/year, equivalent to US$102,400/year.	Preheating of fuel oil by using clinker cooler waste heat from heat exchanger inside the cooler.	55,000	1-1.5
Preheater Dry Process	Savings of 625 toe/year, equivalent to US$192,000/year.	Use of coal mine tailings as substitute for fuel oil.		2-2.5
Semi-Dry Process	Savings of 625 toe/year, equivalent to US$125,000/year.	Use of clinker cooler vent air as primary air to hot air furnace.	500,000	
Dry Process	Savings of 14 kcals/kg, equivalent to US$50,000/year.	Addition of new kiln seal at discharge end to cut out air infiltration.		1
B. Lowering Specific Energy Consumption				
Wet Process (Canada)	10% (from 1,416 kcals/kg to 1,280 kcals/kg)	Recirculating clinker cooler air.		n.a.
Wet Process (Canada)	9% (from 1,441 kcals/kg to 1,280 kcals/kg)	Slurry thinner to lower slurry moisture from 35.8% to 31.2% with increase in clinker production by 9%.	n.a. n.a.	n.a. n.a.
Wet Process (USA)	17% (from 1,876 kcals/kg to 1,560 kcals/kg)	Reduction in slurry moisture, new seals and closing holes, new cooler grates, and fans, new chain system.	n.a.	n.a.
Wet Process (Brazil)	11% (from 1,841 kcals/kg to 1,637 kcals/kg)	Changing clay component, modifying chain system, increase in production.	n.a.	n.a.
Wet Process (USA)	15% (from 1,617 kcals/kg to 1,381 kcals/kg)	Slurry water reduction, adding lifters, insulating bricks, raw feed chemistry control, chain maintenance, and cooler modification.		

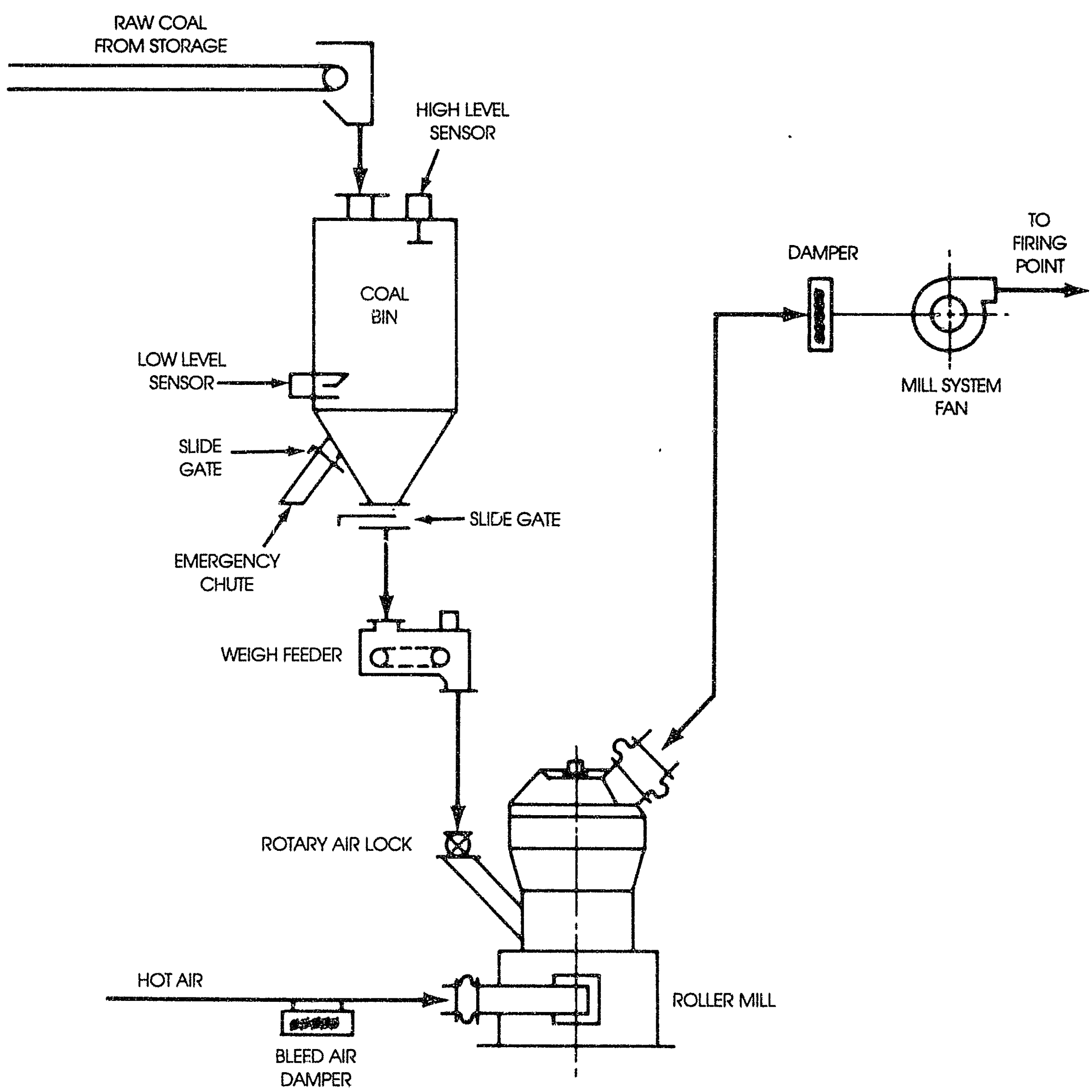
Source: Based on data from Lafarge Consultants.

ANNEX 4-3: ESTIMATED RESULTS IN RECENT CONVERSIONS IN SELECTED COUNTRIES

	Project Completion Date	Project Outline	Project Cost (US$ Million)	Plant Capacity (tpd) Before	Plant Capacity (tpd) After	Fuel Consumption (kcals/kg) Before	Fuel Consumption (kcals/kg) After	Estimated Financial Rate of Return (%)
A. WET TO DRY PROCESS CONVERSIONS								
FRANCE	- 1977	One wet kiln to pre-calciner, other closed	25	1,500	1,500	1,400	750	17%
CANADA	- 1980	Two wet kilns replaced by 4-stage preheater	70	1,400	1,200	1,400	800	15%
BRAZIL	1982	Wet kiln to 4-stage preheater	10	440	550	1,450	900	17%
MALAYSIA	1982	Wet kiln to 4-stage preheater/precalciner	95	1,500	4,300	1,335	830	20%
B. OIL TO ALTERNATE FUEL CONVERSIONS								
FRANCE	1979	4-stage preheater from oil to 70% coal/30% oil	n/a	3,000	3,000	900	900	14%
URUGUAY		Four wet kilns. Oil to direct coal/rice hulls	1.5	800	800	1,560	1,685	57%
USA		4-stage preheater-gas	3	1,450	1,450	850	870	42%

Source: Based on data from Lafarge Consultants

ANNEX 5-1:
Coal Firing — Direct Fired System



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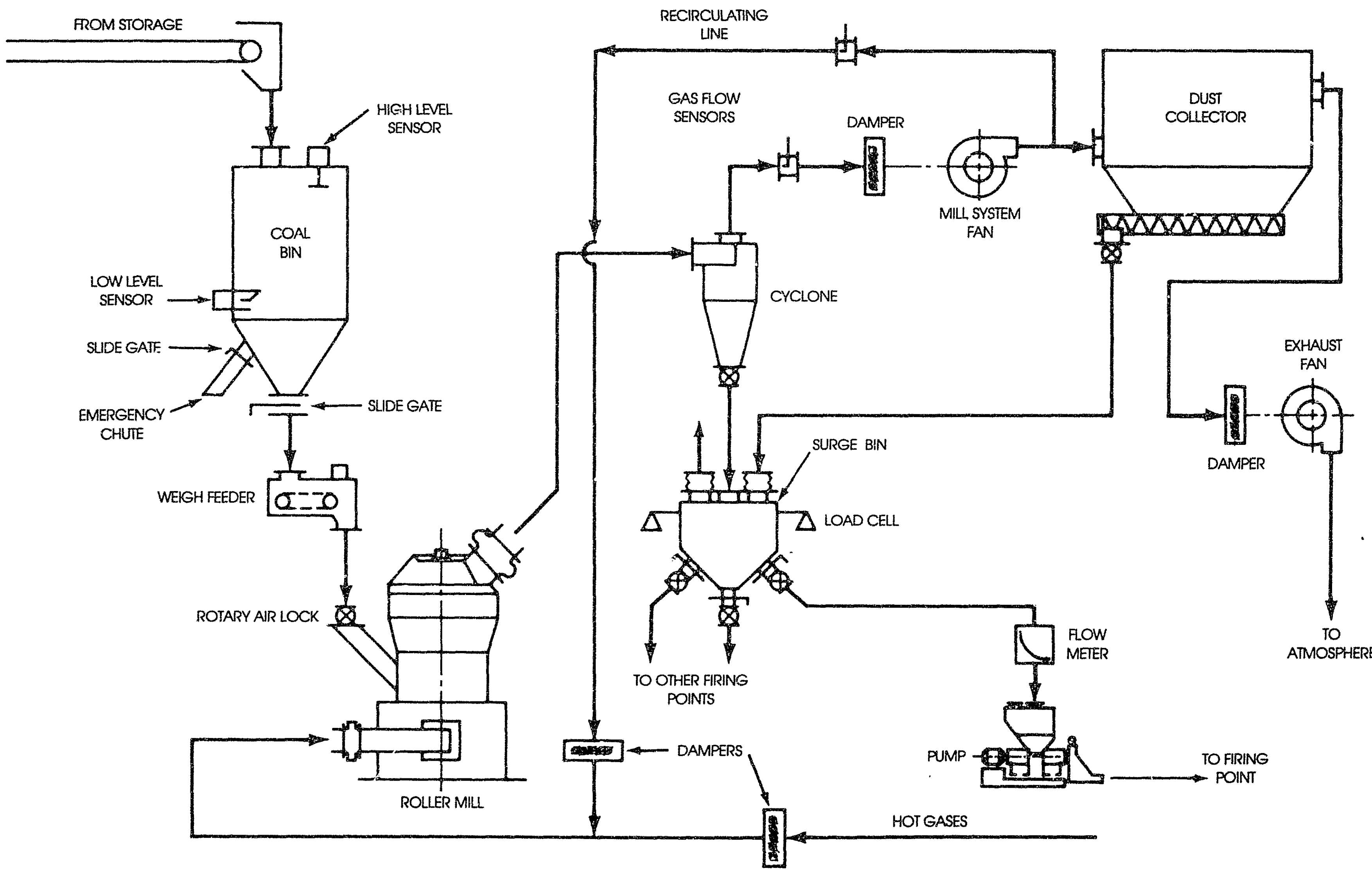
ANNEX 5-1:
Coal Firing — Indirect Fired System



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French: L'économie de l'électricité: essais et études de cas. *Economica, 1979.*

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Spanish: Electricidad y economía: ensayos y estudios de casos. *Editorial Tecnos, 1979.*

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