The Building Materials Industry in China: An Overview

Feng Liu

Energy Analysis Program
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

and

Shumao Wang

Energy Research Institute
State Planning Commission
People's Republic of China

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Chapter I

Background, Objectives, and Analytical Approaches

Unprecedented construction in China since the late 1970s brought about a rapid expansion of the domestic building materials industries. Output of major construction materials tripled within a decade. By the late 1980s, China led the world in the production of cement, lime, bricks, and flat glass.

However, this rapid growth brought with it a particular set of problems. Inadequate investment capital, primitive technologies, and the proliferation of small factories further burdened an industry already clogged with inefficient and polluting small enterprises that produced low-quality goods. Such a rapid build-up of capacity, without much technological advancement, left behind costly long-term problems in energy efficiency and environmental protection. In the coming years a tremendous amount of work will be required to raise the industry's technological sophistication, improve its energy efficiency, and bring it into compliance with environmental regulations.

More than any other industry, building materials rely on energy for production.[1] Understanding energy use and energy efficiency offers major insights into production technologies and operations. Such information and knowledge are important for planning technical renovations and formulating investment policies in the industry.

This present energy study of China's building materials industry is a collaborative work between the Energy Research Institute (ERI) of the State Planning Commission of China and Lawrence Berkeley Laboratory (LBL) of the U.S. Department of Energy (U.S. DOE). Main objectives of this study are

• to investigate and evaluate energy consumption and energy efficiency of end-use processes and equipment in the major branches of the building materials industry;

• to estimate the potential energy savings attainable by introducing energy-conservation measures of different technical sophistication and to evaluate economic costs of such measures; and

• to identify barriers to energy conservation and propose policies that would both facilitate research and development and enable the industry to achieve a higher energy efficiency.

The guidelines of this study are to understand the energy uses of the production processes of major building materials and to identify opportunities to improve energy efficiency. This approach is best exemplified in Chapter 3, where the energy uses of each production stage in cement manufacturing are investigated. Other subsectors are not treated as thoroughly because of insufficient data.

We performed economic evaluations of energy-conservation measures in the cement industry and found that available data do not warrant any serious analyses of the cost effectiveness of energy-conservation investments. Problems arise from how the data were collected and the multiple objectives of such an investment. Energy-conservation investments in the cement industry have rarely focused on energy savings exclusively. Many renovation projects aim at increasing both production capacity and energy conservation. When energy is relatively cheap, additional cement production capacity is considered a quick way of paying back the investment because of the highly profitable sales. To assess the cost of saved energy, we need to obtain data that indicate net investments in energy conservation. Such data usually cannot be derived without ambiguity.

As a preliminary approach, we derived the net investment by subtracting from the gross investment the amount of capital required to build the increased capacity at new sites. For most measures, this method results in a negative net investment for energy savings. In other

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[1] The building materials industry has the highest energy-to-gross output value ratio among all industries in China.

words, compared with building new capacity on new sites, retrofitting existing capacity to the same efficiency level while also adding the same amount of new capacity would save capital. However, one can also argue that the increased capacity from retrofits is not fully comparable with the new capacity. In addition, adding capacity to existing facilities usually costs less than building new facilities. Thus, the estimate of net investment presented above overstates the costs of added capacity from retrofit.

Because the interpretation of minus capital cost can be ambiguous, we have chosen not to calculate the cost of conserved energy in cases where minus net investment occurs. In general, we used the simple payback time of a conservation project as a rough gauge of the cost effectiveness of the energy-conservation projects in the cement industry. The simple payback time is calculated by dividing the gross investment of a conservation project with the total net profits—mostly profits from increased cement sales and saved energy costs—resulting from the project.

This report consists of seven chapters. Chapter 2 is an overview of the building materials industry. It introduces the industry's sectoral structure, product mix and physical output, plant scale, technological sophistication, and energy use and efficiency. Serious environmental issues facing the industry are also discussed. Chapter 3 is the core of this report with detailed end-use energy analysis and estimates of conservation potential for the cement-manufacturing sector. At the end of the chapter we develop two scenarios for the cement industry to give a broad understanding of possible outcomes of the industry's future development.

Chapter 4 provides an overview on the flat glass manufacturing sector and discusses its energy efficiency issues on a general level. Chapters 5 and 6 discuss energy use and the efficiency of brick and lime manufacturing. These two chapters follow similar patterns of discussion as in Chapter 4. Chapter 7 concludes this study with policy suggestions for promoting energy conservation in the building-material industry.

This report uses the *metric system* for data recording and calculation. Because coal is the dominant commercial fuel used in China, energy units are expressed in tonnes of standard coal equivalent (1 tce = 7 million kcal).

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Chapter 2

General Perspectives of the Building Materials Industry

The building materials industry is made up of a variety of subsectors, including producers of cement, concrete products, flat glass, fiberglass, building ceramic products, bricks and tiles, lime, stone products, asbestos products, and refractory materials. As are the special cases of concrete and brick producers, these contributors can be small industries located in many different locations throughout the nation. The State Bureau of Building Materials Industry (SBBMI), which reports to the State Council, administers the industry on a national level.

2.1 ENERGY USE AND OUTPUT

The building materials sector is one of the major energy users of Chinese industry (including mining, manufacturing, and construction). Of a total 450 billion kWh of electricity consumed by industry in 1990, more than 7% was used in the manufacture building materials. Of the 400 million tons of coal equivalent (Mtce) fuel consumed by all of Chinese industry, 21% was expended in the building materials sector. The same sector, however, that contributed only approximately 4% of the total industrial gross output value (GOV) in 1990 [SSB, 1992].

Like other Chinese industrial sectors, building materials is dependent on coal for the greater share of its fuel supply. This dependency is only strengthened by the fuel-intensive nature of building materials manufacturing. Of the 97 Mtce energy used by the building materials industry in 1990, coal, oil, gas, and electricity contributed 79%, 7%, less than 1%, and 13% respectively.[2] For Chinese industry as a whole, respective energy-use shares are 58%, 8%, 5%, and 27% [SSB, 1992].[3]

According to SBBMI statistics, the subsectoral shares of energy use in 1989 were 48% for the brick and tile sector, 34% for the cement sector, 9% for lime, 3% for flat glass, and 6% for the rest. The manufacturing of brick and tile, cement, lime, and flat glass consumes 94% of the total energy use in the building materials industry.

Annual outputs of cement, lime, bricks, and flat glass are all ranked number one in the world, making the industry one of a few in China that leads the world in physical output of its major products. Table 2-1 reveals the rapid buildup of production from 1980 to 1990. Unfortunately, in many cases such a tremendous expansion of production was achieved without sound technologies and economies of scale. As a result, the industry became a vast collection of outdated small factories spread over the entire country. It is one of the least modern industrial sectors in China.

From 1980 to 1990, shares of both energy use and gross output value (GOV) of the building materials sector steadily increased. The rapid growth placed disproportionally more pressure on the energy system and the environment per unit of GOV generated. Much of this pressure could have been mitigated if higher energy efficiency had been achieved.

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[2]A total energy use of 97 Mtce in the official statistics might underestimate actual energy use in the building materials industry because energy used in thousands of rural plants might not be fully counted. The SBBMI estimated that about 120 Mtce energy was consumed in the building materials industry in 1990.

[3]In this report, electricity is converted into its fossil fuel replacement value, which was about 11.7 MJ/kWh in 1990.

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Table 2-1. Physical Output of Major Building Materials in China, 1980-1990

Year	Cement (Mton)	Bricks (Billions)	Flat Glass (Million Cases)[†]	Lime[††] (Mton)
1980	79.9	154	27.7	28.5
1981	82.9	164	30.6	28.2
1982	95.2	196	35.5	30.2
1983	108.3	206	41.7	37.2
1984	123.0	250	41.9	40.1
1985	146.0	294	49.4	46.0
1986	166.1	375	52.0	53.9
1987	186.3	399	58.0	66.6
1988	210.1	469	72.9	113.9
1989	210.3	472	84.4	110.2
1990	209.7	449	80.7	93.8

[†] One case is equal to 50 kg.
[††] 1980-87 figures are not comparable to 1988-90 figures because of the change in reporting coverage.
Source: SBBMI.

2.2 GENERAL CHARACTERISTICS

The building materials industry in China can be best described with three succinct phrases: uneconomical production scale, outdated technologies, and low energy efficiency. As a result, the industry is one of the major sources of air pollution.

2.2.1 UNECONOMICAL PRODUCTION SCALE

Cement manufacturing. According to SBBMI 1989 statistics, 210 Mt of cement output was produced by 65 state-owned key cement plants, 2100 county-level cement plants (either state-owned or collective), and 3500 rural cement plants.[4]   Table 2-2 gives more detailed information about the scale of China's cement plants.

The unit capacities of Chinese clinker kilns are much smaller than their Western counterparts. In 1990, average unit capacities of

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[4]*Key plants* are sometimes also called the medium or large plants and the rest are called *small plants.* The quantitative definitions are large plant—cement production capacity >600,000 ton/year; medium plant—cement production capacity between 200,000 and 600,000 ton/year; small plant—cement production capacity <200,000 ton/year. As seen in Table 2-2, the small plants (local and rural) are actually much smaller than in the standard definition.

Chinese rotary and vertical kilns were, respectively, about 90,000 and less than 30,000 tons of clinker per year, while the average unit capacities of Japanese and American rotary kilns in the mid-1980s were about 1,000,000 and 320,000 tons of clinker per year [Nakajima, 1990; Venkateswaran and Lowitt, 1988]. Vertical kilns, which produce more than 70% of China's cement, are not used in either the Japanese or the U.S. cement industries.

Although the thousands of small cement plants across China are an easy solution for meeting local demand and coping with severe transportation limitations, the present distribution of plants is not an economic way of organizing production, when the quality, productivity, energy efficiency, and pollution control issues of managing so many factories are considered.

Flat Glass Manufacturing. According to 1990 SBBMI statistics, there are approximately 130 flat glass producers in China. Among them, 22 were identified as key enterprises, 30 as medium enterprises, and 80 as small enterprises. Average annual output per plant for each category is 110,000, 35,000, and 10,000 tons of flat glass. The key enterprises, usually the more efficient ones, produce about 60% of the flat glass.

Table 2-2. Size Distribution of Cement Plants in China, 1989

	Total Output (Mton)	Number of Plants	Average Prod./Year (Thousand Tons/Plant)
Key plants	36	65	553
Local plants	130	2100	62
Rural plants	43	3500	12

Source: SBBMI

2.2.2 OUTDATED TECHNOLOGIES

Cement manufacturing. At present, China has 22 precalciner cement-production lines. In 1990, these lines provided about 9 Mton cement, which was less than 5% of total cement production. The domestically developed precalciner process is considered to lag 10 years behind comparable Western technology in terms of energy efficiency. While precalciner kilns have become the standard equipment in modern cement manufacturing, vertical kilns, many of them still manually operated, are the major production facilities, producing about 70% of the cement output (in 1990) in the Chinese cement industry. Other types of dry-process and wet-process rotary kilns produced about 25% the cement output [SBBMI, 1991].

Flat Glass Manufacturing. In 1990 China had 21 modern float-process lines, which produced approximately 40% of the total flat glass output. In addition, 71 sheet-process kilns, most of them built in the 1950s, manufactured about 50% of the total flat glass output. Forty-two plate-process kilns (the most backward technology of the three) fabricated about 10% of the flat glass output [SBBMI, 1991]. On average, the float process uses 60 to 70% less energy than the plate process and 20 to 30% less energy than the sheet process [Babcock, et al., 1988].

Brick and Tile Manufacturing. The brick and tile industry presents yet another example of the pervasiveness of primitive and inefficient production technologies in the building materials industry. The tens of thousands of village-operated brick factories claim some of the best farmlands around cities and towns. Pollution

control for simple kilns is almost impossible. Better equipped large plants provide improved environmental protection not only by using marginal resources (instead of farmland) but also by producing products more efficiently.

2.2.3 LOW ENERGY EFFICIENCY

A distinct indication of the outdated technologies used in the Chinese building materials industry is the low energy efficiency prevalent in all sectors. In 1990, the average fuel intensity of key dry-process cement plants was about 165 kgce/ton-clinker and for key wet-process plants, about 205 kgce/ton-clinker [SSB, 1992]. The fuel intensity of vertical kilns spans a wide range, from 110 to more than 220 kgce/ton-clinker, depending on the technological sophistication of such factors as levels of mechanization and electronic control, as well as operation skills. The average fuel intensity of mechanized vertical kilns, which produced 60% of China's cement in 1990, was about 165 kgce/ton-clinker. The industry-wide weighted fuel intensity was about 180 kgce/ton-clinker [estimate, Table 3-6]. In U.S. plants in 1985, average kiln fuel use per ton of clinker was about 157 kgce/ton-clinker (an average of both dry and wet processes), about 10% better than present Chinese practices [Venkateswaran and Lowitt, 1988]. The Japanese plants reached an average level of about 110 kgce/ton-clinker in the late 1980s [Nakajima, 1990].

Overall energy intensity (fuel plus electricity) of Chinese flat glass production in 1990 was 776 kgce/ton. The respective figure for the U.S. was about 600 kgce/ton, while the Japanese figure was already 370 kgce/ton in 1980 [Babcock et al., 1988; Gu, 1989].

Energy efficiency of brick making is considered very poor. While the large key enterprises (using tunnel kilns) can manufacture bricks at a fuel intensity of about 110 kgce/1000-piece, smaller local or rural enterprises usually have a fuel intensity of about 150 kgce/1000-piece. Primitive kilns can have fuel intensities as high as 200-400 kgce/1000-piece [Tao, 1988]. Comparison of fuel intensities of brick making between countries is somewhat problematic because of differences in brick sizes and physical characteristics. On the basis of equivalent brick volume (cubic meters), the advanced Chinese plants (110 kgce/1000-piece) seem to be comparable to tunnel-kiln plants in the industrialized countries [compared with the Australian experience, see Timothy, 1989].

According to a survey of 800 lime kilns in China, the average fuel intensity of lime production was 182 kgce/ton in 1989. Advanced domestic technology uses only 120 kgce energy to produce one ton of lime [SBBMI, 1991].

From these facts, we believe that a large potential for energy conservation exists in the Chinese building materials industry. Realizing such an energy-saving potential is important because it will not only reduce energy costs but also will help usher in new technologies that are badly needed for modernization. The entire economy also benefits from a more efficient building materials industry for reduced energy demand and air pollution.

2.3 MAJOR ENVIRONMENTAL CONCERNS

The most obvious environmental problem of the Chinese building materials industry is air pollution, both ambient and atmospheric. According to survey data of 82 major cities, the industry is the second largest SO_2 source after the thermal power industry, accounting for 10% of the total emissions. NO_x emissions are also considered high because cement, lime, brick, and tile production all require high-temperature pyroprocesses. The building materials industry emits the largest amount of particulates among all industries, accounting for 55% of the total industrial particulate emissions in the surveyed cities [SPC, 1991]. Most cement plants have insufficient dust-collecting equipment, and many have none installed.

Since building materials manufacturing is the largest industrial coal user (not including thermal power plants), it is a major target for CO_2 emissions reductions. Cement and lime production also generate additional CO_2 emissions because calcinating limestone frees carbon dioxide locked in limestone as calcium carbonate. Quarry activities in cement, lime, and brick and tile manufacturing also cause the destruction of land and vegetation.

2.4 PAST CONSERVATION WORK AND FUTURE OUTLOOK

A policy breakthrough in China in the 1980s was the industry-wide energy-conservation programs initiated by the central government. The building materials industry has been one of the

major targets of these programs. The following is a summary of what has been done.

Close Inefficient Factories

In the early 1980s, there were more than 6700 small cement factories in China. After official inspections for energy efficiency and production scale, more than 1100 of them were closed [Gao, 1990]. The central government also closed or restricted construction of flat glass production lines with unit furnace capacities of 200 ton/day or less. Primitive lime kilns were also targets of elimination.

Develop and Introduce Advanced Production Processes

Precalciner kilns of various countries were imported in the 1980s. In order to enable domestic production of precalciner kilns, 17 key manufacturing technologies of precalciner processes were also imported. By 1990, China was able to produce major components of the 1000 ton/day and 2000 ton/day precalciner kilns [Zhen, 1991].

In order to acquire advanced flat glass manufacturing technologies, in the 1980s China participated in two float-process flat glass joint ventures, one with the U.S. and another with Great Britain. By 1990, China already was capable of domestically constructing 500 ton/day flat glass float-process production lines. [Zhen, 1991].

Retrofit Existing Factories

As we have observed, the existing production capacity of the building materials industry consists largely of outdated technologies. Rather than simply abandoning them, retrofitting these old processes in many circumstances has proved to be a capital-saving approach to raise productivity and energy efficiency.

Most retrofit projects were co-sponsored by the SBBMI. From 1980 to 1989, through low-interest loans and appropriations, the government invested ¥500 million in energy-conservation demonstration projects, which paid off in 1.5 Mtce/year in energy-saving capacity, 60 MW electricity capacity (co-generation through waste-heat boilers), and 8.7 Mt/year of newly increased cement production capacity [SBBMI, 1991]. Investments from local governments and enterprises are considered to

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be at least three times as much as that of central government seed funds.

Based on experiences in the 1980s, the SBBMI has formed a new set of energy-conservation initiatives, thus demonstrating consistent government effort to improve the energy efficiency of the building materials industry. Major retrofit projects in the new plan include:

(1) Cement Sector

• Convert wet-process plants to dry-process plants if favorable conditions exist. Of the total 176 rotary kilns in the 65 key plants in 1989, 105 units were wet-process kilns [SBBMI, 1991].

• Continue the comprehensive renovation program for 14 old key plants. Special financial incentives are given to retrofit these plants. For example, the 14 plants are allowed to retain the increased revenue from raised cement prices. According to each situation, different retrofit approaches are used: some factories have constructed new precalciner production lines, while others have converted wet processes into dry processes. Minor retrofits such as adding waste-heat boilers (co-generation) are also installed. Upon completion of this program, these 14 plants are expected to increase their cement production capacity by 3.8 Mt/year, save 430,000 tce fuel per year, and generate 134 GWh electricity per year [Gao, 1990]

• Retrofit existing grinding systems and conserve electricity.

• Retrofit small cement plants. Of the 5600 plus existing small cement plants, about 2800 have mechanized vertical kilns. The remaining vertical kilns are manually operated, inefficient, and polluting. Converting good manual vertical kilns to mechanized ones is a priority of the technological renovation of small cement plants.

(2) Brick and Tile Sector

• Convert primitive kilns into annular kilns or tunnel kilns. In the late 1970s, most bricks and tiles were made by rural people in tens of thousands of manually operated, small, single-chamber kilns. In the 1980s, annular kilns were promoted in order to improve productivity (achieve a higher level of

mechanization) and the energy efficiency of brick and tile manufacturing.

• Promote the production of hollow bricks.

(3) Flat Glass Sector

• Apply imported technologies of the 500 ton/day float-process furnaces to retrofit existing 200-300 ton/day float-process furnaces.

• Retrofit existing sheet-process furnaces.

(4) Lime Sector

• Convert primitive vertical kilns into either semi-mechanized or fully-mechanized vertical kilns.

• Construct a few advanced lime-process lines.

The building materials industry experienced robust growth in the 1980s. Although a slowdown of the economy in the late 1980s caused downturns of the output of major building materials, the resumed growth in 1991 and 1992 was astonishing. Cement output, for example, increased over 40% from 1990 to 1992, showing the industry's capability of a quick response to a new demand. One major concern of such fast production growth is that much of the new capacity may come from low-cost, simple-to-build small plants. The construction boom in the 1980s was partially responsible for the proliferation of such plants, and the trend is continuing into the 1990s. Facing an expected period of rapid economic growth for the rest of the century, the building materials industry may have to invest extra capital to meet the rising demand without compromising product quality and environmental protection. Stricter regulations must be enforced to discourage the proliferation of inefficient and polluting small plants.

Identifying problems is always much easier than solving them. Many of the efficiency improvements achieved under the old administrative system may prove to be hard to repeat in the coming years, when free-wheeling local and private economies expand. Economic incentives for energy conservation may also be weakened when strong demand pushes up product prices and allows marginal plants to survive. It is our concern that the Chinese building materials industry may take an

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extended period of time to achieve the present level of modernization and energy efficiency already found in the industrialized countries.

Chapter 3

The Cement Manufacturing Sector

Cement is a material that binds together solids like sand or gravel by hardening from a plastic state. A cement that increases in strength under water after setting is said to be *hydraulic*. The predominance of portland cement, the major components of which are tri- and di-calcium silicates, in building and civil engineering is such that it is usually referred to simply as cement.

China is the world's leading producer and consumer of cement. Production surpassed 250 million tons in 1991, while in 1989 the second-ranked former Soviet Union's output was 140 million tons. China now manufactures about one fifth of the cement output in the world. Consumption was approximately 190 kg per capita in 1991, up from about 75 kg per capita in 1980 [SSB, 1992]. In comparison, cement consumption in the U.S. was about 340 kg per capita in 1989, having declined from a peak of 420 kg per capita in the early 1970s [BoC, 1991]. Per capita cement consumption in China is expected to increase in the future.

Construction is the primary use for cement in China. It is most often mixed at building sites for concrete foundations and mortar for bricks. About 28% is used by manufacturers of products such as slabs, blocks, and pipes, which are used for construction. Cement demand from infrastructure construction (roads, dams, and ports) is also high. In the U.S., manufacturers of concrete products use roughly 12% of total cement consumption. Most of the rest is used at construction sites.

Cement is typically produced locally, near the sources of raw materials and markets. Long-distance transportation of cement is considered inappropriate, but shipping by water can be effective. Cement is the classic example of a product with low value/ton ratio. Cement exports from China have increased rapidly in recent years, rising from 140 thousand tons in 1985 to about 11 million tons in 1991. This latter figure is approximately the output from existing precalciner kilns. The major destinations of Chinese cement exports are Asian and Pacific countries. Procuring hard currency is important for new investments in the cement industry, but exporting high-quality products may not be desirable if the domestic market is forced to use inferior ones. Such a tendency seems to be a pervasive feature of the trade policy in less developed countries.
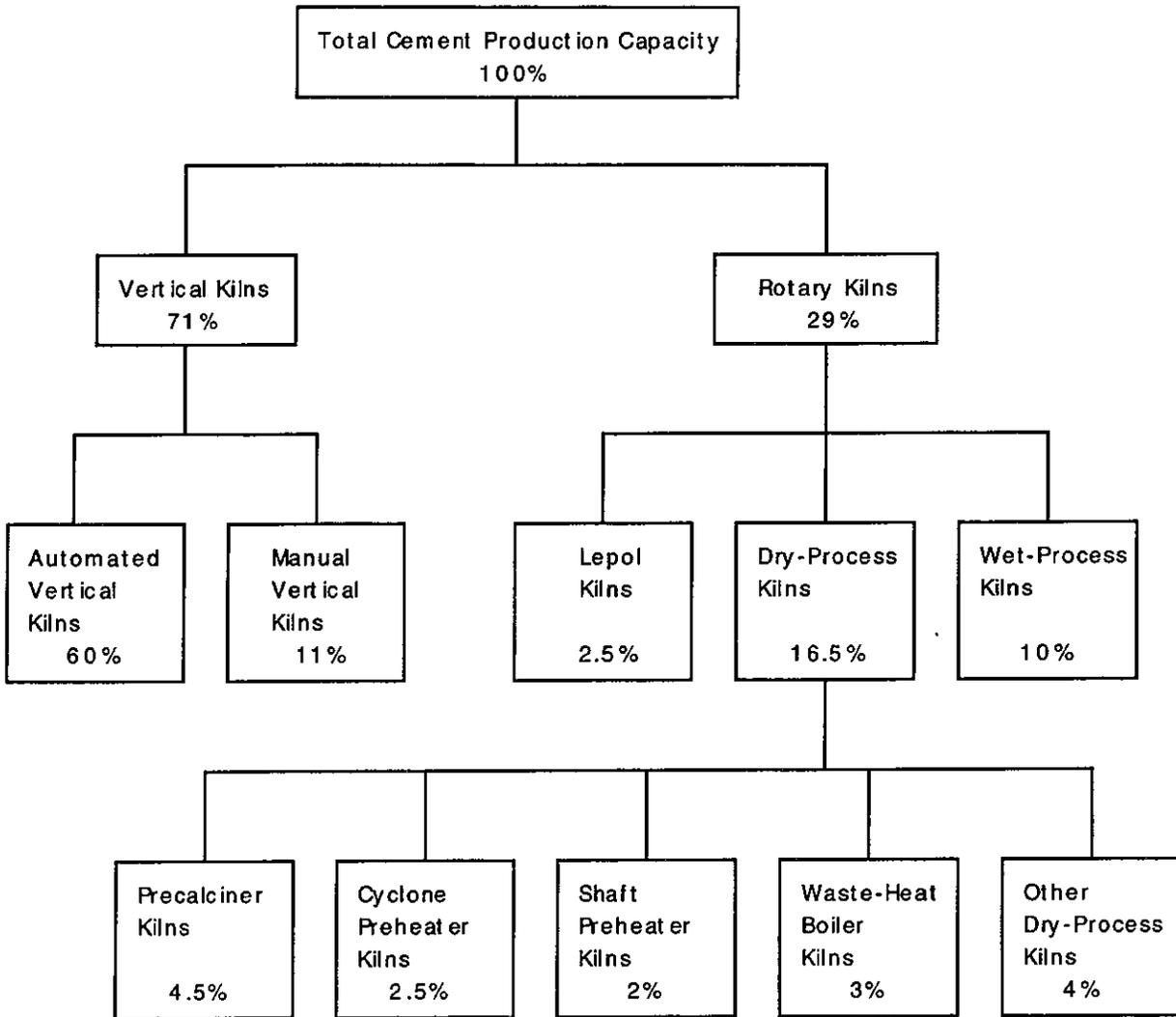
3.1 INDUSTRY STRUCTURE AND ENERGY CONSUMPTION TRENDS

The Chinese cement industry possesses the most diversified production technologies in the world. The industry has collected technologies of all ages—from wet-process production lines of 1940s vintage to advanced precalciner kilns, and from the most primitive vertical kilns to some very efficient mechanized vertical kilns. The industry now boasts some 5700 factories and about one million employees. Small plants, thriving on their low capital costs and easy access to local consumers, have gained a significant market share in the 1980s because of the strong domestic demand. Their share of total production rose to 83% in 1989 from 68% in 1980. The importance of small cement plants is expected to decline in the long run, but the recent revival of the economy will contribute to their growth for some years.

3.1.1 INDUSTRY STRUCTURE

Vertical kilns are the dominant production equipment of small cement plants. The number of mechanized vertical kilns increased, either by new construction or by converting manual kilns, from 467 units in 1980 to 3241 units in 1990. The number of more expensive rotary kilns increased from 305 units to 671 units in the same period [*Energy Statistical Yearbook of China*, 1991]. By importing equipment and technologies, the cement industry put 16 precalciner production lines (a few of them are domestically manufactured) into operation in the 1980s. But these modern units only produce about 5% of the total cement output at present. Figure 3-1 depicts the Chinese cement production structure in 1990 by the type of kiln employed.

Figure 3-1. Chinese Cement Production by Kiln Type, 1990

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                    ┌─────────────────────────────────┐
                    │  Total Cement Production Capacity│
                    │              100%                │
                    └─────────────────────────────────┘
                           │                    │
              ┌────────────────────┐   ┌────────────────────┐
              │   Vertical Kilns   │   │    Rotary Kilns    │
              │        71%         │   │        29%         │
              └────────────────────┘   └────────────────────┘
                   │         │            │        │         │
        ┌──────────┐  ┌──────────┐  ┌────────┐ ┌──────────┐ ┌────────────┐
        │Automated │  │ Manual   │  │ Lepol  │ │Dry-Process│ │Wet-Process │
        │ Vertical │  │ Vertical │  │ Kilns  │ │  Kilns   │ │  Kilns     │
        │ Kilns    │  │ Kilns    │  │        │ │          │ │            │
        │  60%     │  │   11%    │  │  2.5%  │ │  16.5%   │ │   10%      │
        └──────────┘  └──────────┘  └────────┘ └──────────┘ └────────────┘
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Precalciner Kilns	Cyclone Preheater Kilns	Shaft Preheater Kilns	Waste-Heat Boiler Kilns	Other Dry-Process Kilns
4.5%	2.5%	2%	3%	4%

Source: Wang, 1989; SBBMI Statistics.

3.1.2   ENERGY CONSUMPTION TRENDS

Cement manufacturing consumed about 41 Mtce energy in 1990, accounting for 34% of the energy used in the building materials industry. Most of the energy used in the cement sector is supplied by coal (77% of the total use), with electricity contributing 23%. Oil and gas consumption is negligible. Energy costs constitute 40% of the total production costs of cement manufacturing, indicating its energy-intensive nature [SBBMI, 1991 Statistics].

No simple description of the energy efficiency of the Chinese cement industry can be given because of its diverse production technologies. For example, plants with use rotary kilns have quite different energy aspects compared to plants that use vertical kilns. In addition, data and information are scarcest for the most important part of the industry: the small

cement plants. Published statistics show that fuel intensity of the key plants, consisting of both dry and wet processes, decreased from 207 kgce/ton-clinker in 1981 to 185 kgce/ton-clinker in 1990, a 11% reduction in 10 years. However, electricity intensity of key plants rose from 99 kWh/ton-cement in 1981 to 110 kWh/ton-cement, a 11% increase in 10 years [SSB, 1991]. The reduction in fuel intensity in the key plants is credited to the installation of new and advanced production lines as well as consistent energy-conservation work. Increases in automation and stricter pollution control requirements are considered to be the reasons for the increase in electricity intensity.

The average energy intensity of cement produced by small plants is believed to be lower than that of the key plants. Mechanized vertical kilns make up 83% of the production capacity of small plants and have an average fuel intensity of 165 kgce/ton-clinker, a figure significantly lower than the average 185 kgce/ton-clinker of the key plants. The best mechanized vertical kiln achieves 110 kgce/ton-clinker and rivals advanced precalciner kilns in energy efficiency [Gao, 1991]. Mechanized vertical kilns achieve high efficiency because of a combination of factors such as good kiln insulation, shorter pyroprocessing time, and precise control of the fuel/raw feed ratio. The electricity intensity of small plants is relatively low, usually under 100 kWh/ton-cement, because of low-level automation and fewer pollution-control devices. The lack of time-series data prevents tracking the trend of energy efficiency in small plants. The fuel intensity of small plants is considered to have decreased over the years because of the increasing number of more efficient mechanized vertical kilns. However, electricity intensity in the small plants is also gradually rising as automation increases and pollution controls tighten.

Mechanized vertical kilns seem to be an obvious choice for meeting local cement demand, since they are less capital-intensive than large rotary kilns and can be operated very efficiently. A major drawback to vertical kilns is that they produce inferior clinkers because of the difficulties in combustion control. Small plants also spread pollution to more areas and make pollution control and land preservation more difficult.

3.2 ENERGY CONSUMPTION BY PROCESS STAGE

Cement manufacturing can be divided into three production stages: raw material preparation, clinker production, and finish grinding. Each stage has its own set of equipment and different energy requirements. Raw materials preparation primarily uses electricity, although quarrying and drying may also consume fuel (in many cases, waste heat from the pyroprocess is used for drying). Most fuel is used in the pyroprocess of clinker production. Electricity is also used for feeding raw materials and other mechanical operations in the clinker-production stage. Finish grinding only uses electricity.

Energy consumption in the three production stages varies depending on the characteristics of the raw materials, the type of kiln, and the specific requirements of final products. In general, the pyroprocess consumes about 80% of the total energy used in cement production, while raw material preparation and finish grinding each consume about 10% of the total energy.

There are three distinctive clinker-production processes in use in China: wet process, dry process, and vertical-kiln process. The first two use rotary kilns differing primarily in the kiln feed.[5] In the wet process, the raw materials are introduced into the kiln in a slurry state with 24-48% moisture. In the dry process, the raw materials are introduced as powder with less than 7% moisture or as pellets with less than 14% moisture [Venkateswaran and Lowitt, 1988]. In the vertical-kiln process, the raw materials are introduced as pellets with moisture ranging from 12-14%. In this regard, the vertical-kiln process is similar to the dry process.

The difference between the vertical-kiln process and the rotary-kiln process is the kiln structure. A vertical kiln is a fixed, vertical cylindrical shell that receives raw materials at the top and discharges clinkers at the bottom by means of natural gravity. A rotary kiln, on the

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[5]Formerly the condition of the raw materials influenced the choice of clinker pyroprocess. If the initial moisture content of the raw materials was high (more than 15%) or the raw materials were too hard to be ground by the dry method, the wet process was usually adopted. The rise of energy-efficient dry processes in the past 20 years has eliminated wet processes in the industrialized countries. Raw materials with too much moisture must be dried to feed dry processes.

other hand, has a horizontally mounted cylindrical shell that inclines slightly toward the discharge end. The rotating shell provides better heat distribution (than in the case of a vertical kiln) and a moving force to discharge the clinker. The firing systems of the two types of kilns are also different. Fuel is mixed within the feed in the vertical-kiln process and a one-time ignition is needed to start the pyroprocess. In the case of the rotary kilns, a fire-gun is used to inject fuel into the kiln during the pyroprocess.

3.2.1 RAW MATERIAL PREPARATION

Limestone is the predominant source of calcareous rock used in cement manufacturing. Non-calcareous materials needed for producing clinkers include silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). These raw materials are quarried, crushed, ground, and blended to make a suitable raw feed for pyroprocesses.

The size and uniformity of the raw materials are important to the quality of clinker. In Chinese vertical-kiln plants, the fineness of the raw materials is usually controlled by an 88% passing through a 80-µm mesh sieve or a 98.5% passing through a 200-µm mesh sieve. For rotary kilns, the raw materials are reduced to a fineness that may range from a 75 to 90% passing through a 200-µm mesh sieve. Generally, the larger the raw-mix particles, the higher the temperature (and more energy) needed for clinker formation.

Preparation consumes the least energy of the three production stages. Dry-process plants use more energy because drying raw materials is often required. In the U.S., wet-process plants typically use about 6% of the total energy in raw material preparation, while dry-process plants use about 12% of the total energy [Tresouthick and Mishulovich, 1990]. Energy used for drying (about 5% of the total) is a significant addition in the dry-process plants. There is no similar information for the Chinese plants. Since the raw material preparation process tends to be generic, ordinary Chinese plants should not differ much from their American counterparts.

One process unique to small Chinese plants is *pelletizing,* which prepares raw material for vertical kilns. Ground raw materials are mixed with pulverized coal, usually anthracite, and are pressed into pellets with a diameter of 5–10 mm. Moisture content is controlled at 12-14%. Quality pellets also meet other standards, such as mechanical strength and thermal stability.

## 3.2.2 CLINKER PRODUCTION—THE PYROPROCESS

Clinker production is the key operation in cement manufacturing because the strength of the cement depends on the quality of clinker produced. Pyroprocess is also the most energy-intensive production stage, usually consuming more than 80% of total energy use. During pyroprocessing, raw materials are heated to 1400 °C and undergo a series of physical and chemical changes that eventually turn them into clinker. Clinker is then rapidly air-cooled to allow maximum heat recovery and to improve quality. In theory, if the initial temperature is 20 °C, producing one ton of clinker requires about 1.6 GJ of heat (amounts vary depending on the components of the raw materials). In practice, heat consumption is much higher due to heat losses. For example, the key plants produce clinker at an average heat consumption of 5420 MJ/ton-clinker. The best mechanized vertical kilns in China can achieve 3220 MJ/ton-clinker. Table 3-1 lists the theoretical heat required to produce one ton cement clinker.

Table 3-1.   Theoretical Heat Requirements to Produce Cement Clinker

Heat Absorbed	MJ/ton-clinker
Heating raw materials from 20 to 450 °C	639.2
Dehydration of clay materials at 450 °C	150.4
Heating materials from 450 to 900 °C	1786.0
Dissociation of $CaCO_3$ at 900 °C	733.2
Heating calcined feed from 900 to 1400 °C	470.0
Net heat of fusion	94.0
Subtotal	3872.8
Heat Evolved	**MJ/ton-clinker**
Crystallization of dehydrated clay	37.6
Heat of formation of cement compounds	376.0
Cooling clinker from 1400 to 20 °C	1353.6
Cooling CO_2 from 900 to 20 °C	451.2
Cooling steam from 450 to 20 °C	75.2
Subtotal	2293.6
Net theoretical heat required : 3872.8 – 2293.6 = 1579.2 MJ/ton-clinker	

Source: Venkateswaran and Lowitt, 1988.

Figure 3-2. The Basic Structure of Vertical Kilns

5%	Preheating Zone
10%	Calcination Zone
85%	Cooling Zone
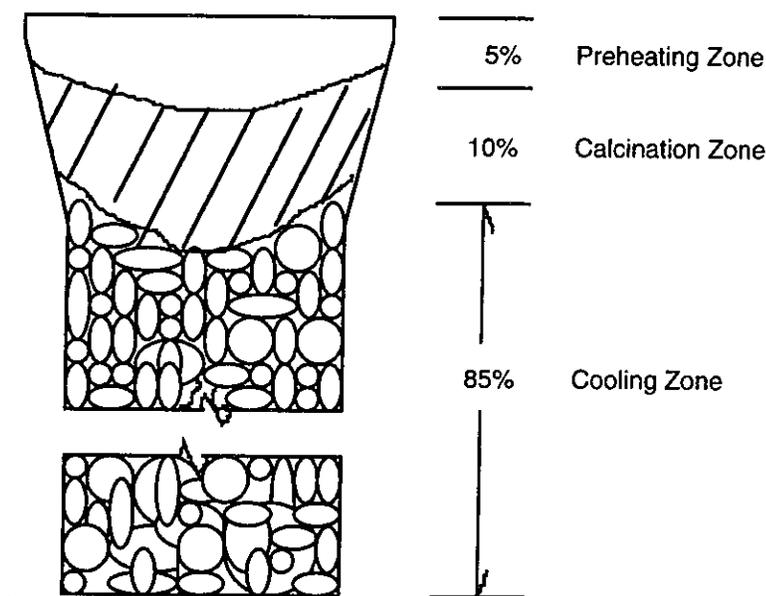
Vertical-Kiln Process. Approximately 70% of China's cement production is derived from small plants equipped with vertical kilns. A vertical kiln consists of a vertically positioned (and fixed) cylindrical steel shell with a refractory-lined inner wall and a layer of outside insulation. The top part of the kiln is cone-shaped to facilitate the feeding of raw materials. Sophisticated vertical kilns have mechanized feeding and discharging equipment and electronic control devices, while primitive vertical kilns are operated manually. Figure 3-2 depicts a stylized vertical kiln structure.

The size of a vertical kiln is indicated by the diameter of the cross section and is restricted by the difficulties in keeping the uniformity of air flow, combustion, calcination, and the sink of raw materials when the kiln volume gets larger. Suitable sizes of vertical kilns are 2.5–3.0 meters in diameter. The height of the kilns is determined by the time needed for raw materials to remain in the preheating, calcination, and cooling zones. Pellet composition, air-blowing power, and operation skills and procedures all influence the choice of kiln height. The popular 2.5-meter mechanized kilns usually have a height of 8–10 meters.

In the vertical-kiln pyroprocessing, the fuel-embodied raw material pellets are added at the top to meet with a counterflow of hot air. Combustion and calcination of the pellets

proceed from the surface to the inside. At the same time, a different stage of calcination is going on within a pellet.

The average surface temperature of pellets in the kiln and the on-going physical and chemical reactions divide the vertical kiln into three zones: the preheating zone, the calcination zone, and the cooling zone. The temperature of the preheating zone ranges from 20 to 1000 °C. Its length varies with on-site kiln operation and the height of the cone-shaped part of the kiln, but usually is 5–10% of the kiln's height. The calcination zone is controlled in the range of 0.5–1.0 meter, about 10–15% of the kiln's height. Temperatures in this zone range from 1000 to 1400 °C. Operation and control in this zone are the key to high-quality clinker and materials and energy consumption. In the cooling zone, clinker is cooled by air blown in from the bottom of the kiln. This process preheats combustion air and provides upward hot airflow for preheating pellets. The length of the cooling zone is about 75–85% of the kiln's height. Faster feeding of pellets tends to increase the length of the preheating zone and push the calcination zone downward, thus shortening the length of the cooling zone.

In terms of combustion control, operation of vertical kilns is more difficult than that of rotary kilns because the flow of raw materials is subject to the gravitational force, which is harder to

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manage than a rotating shaft. The predetermined mix of fuel and raw materials in the vertical kiln also reduces the flexibility of the firing system. Experience and operation skills are very important for energy efficiency, especially when electronic control devices are not installed. Such problems cause difficulties in quality control. Vertical kilns usually produce inferior clinker to that produced by rotary kilns.

Vertical kilns are operated continuously, as long as feeding and discharging facilities are adequate. Although mechanization improves productivity, low capacity is an inherent problem. Vertical kilns with an annual production capacity of 50,000 ton-clinker are already considered to be productive. The most productive vertical kilns in China have an annual capacity of about 100,000 ton-clinker, which is one tenth the capacity of a typical precalciner kiln.

Compared with the most efficient mechanized kilns (with a fuel intensity of 110 kgce/ton-clinker), the energy efficiency of the majority of the mechanized kilns can still be greatly improved. Table 3-2 is a comparison of the measured energy performance of two groups of mechanized vertical kilns. Differences in heat loss give clues for energy conservation.

As shown in the table, the more energy-efficient Group B kilns have advantages in waste heat recovery and combustion control, the areas that save the most energy.

Table 3-2. Heat Balance of Two Groups of Mechanized Vertical Kilns (in MJ/ton-clinker)

Kiln Process	Group A (7 units)	Group B (19 units)
Drying heat consumption	627.5	615.5
Heat loss via tail gases	417.9	230.3
Heat loss due to chemically incomplete combustion	1210.5	724.4
Heat loss due to physically incomplete combustion	247.6	79.6
Waste heat in clinker	171.7	163.3
Radiation heat loss	29.1	16.7
Clinker formation heat consumption	1711.1	1729.2
Other heat loss	86.5	142.4
Total heat balance	4501.9	3701.4
	(154 kgce/ton-clinker)	(126 kgce/ton-clinker)

Source: SBBMI, 1990

The single largest heat loss in both groups is from chemically incomplete combustion, which relates to the accumulation of CO. An inadequate air supply, uneven air distribution, and an oversupply of coal all contribute to CO production. Inadequate blower capacity and leakage are common causes of an insufficient air supply. Improvement in air distribution inside the kiln requires better pellets (in terms of strength, size, and porosity) and careful kiln operation. Oversupply of coal is usually caused by the mixed grinding of raw materials and coal, which results in overly ground coal powder and high fuel density in the raw feed. Under the conditions of low temperature and lack of oxygen, overly ground coal powder reacts with CO_2 and generates CO.

Incomplete combustion relates to uncombusted residual fuel in the pyroprocess. Poor pellet quality and operation misconduct often result in such waste. Pellets containing oversized coal grains, uneven mixing of raw materials and coal powder, and excessive discharging speed are a few examples.

Heat loss through tail gases is the second largest source of heat loss in vertical-kiln pyroprocesses. Preventive procedures, which include adjusting the length of the preheating zone and avoiding surface flame, are mainly operational tasks. It is unknown whether such heat loss can be economically recovered by waste-heat boilers.

From this discussion it is clear that, with other conditions remaining the same, operation skills and the training of kiln operators are of vital importance to the fuel intensity of vertical kilns. In addition, equipment to control pyroprocess, such as microcomputer monitoring systems, also improves operation quality.

Wet Process. In the wet process, a slurry of raw materials is introduced into a long rotary kiln where the entire pyroprocessing (preheating, calcining, and clinkering) takes place. The rotary kiln consists of a refractory-lined, cylindrical steel shell that rotates around an axis inclined about 2° from the horizontal line. The feed materials move slowly downward inside the rotating kiln to meet with countercurrent flames fired by a gun fueled with powdered coal at the discharge end of the kiln (oil and gas may also be used as the fuel). Hanging chains are installed in the evaporation part of the kiln to facilitate heat transfer.

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Wet-process rotary kilns are usually longer than dry-process kilns but are less productive because slurry feed materials require extra residence time for evaporation. For example, one large wet-process kiln in a Chinese plant is 3.5 x 145 m and produces 580 ton-clinker/day. By converting it into a ∅3.5 x 88 m cyclone preheating dry-process kiln, production capacity could be increased to 1050 ton-clinker/day [Chao, 1990].

In the wet process, most heat is consumed in the evaporation stage. Radiation heat loss is significant due to the large surface area of the kiln. Heat loss via tail gases is also great compared to that of the vertical-kiln pyroprocess. Table 3-3 reveals heat balances of typical wet processes used in China. Compared to vertical kilns, rotary kilns are much more efficient in terms of reducing incomplete combustion because of the direct burning of powdered coal.

Table 3-3. Heat Balance of Typical Wet Processes

	MJ/ton-clinker
Evaporation heat consumption	1989 – 2303
Heat loss via tail gases	921 – 1130
Radiation heat loss	586 – 921r
Heat loss due to incomplete combustion	146 – 251
Clinker formation heat consumption	1633 – 1842r
Waste heat in clinker	377 – 419r
Subtotal	5652 – 6866r
	(193 – 234 kgce/ton-clinker)

Source: Liu and Li, 1989

Wet process has been abandoned in most industrialized countries because of its inefficiency. In China, wet processes still comprise about 10% of total cement production capacity, with 34 key plants identified with this process. Average fuel intensity of these plants was about 205 kgce/ton-clinker in 1990, compared to about 200 kgce/ton-clinker of U.S. wet-process plants in the mid-1980s [SSB, 1991; Venkateswaran and Lowitt, 1988]. Since wet process is an inferior technology, conservation measures (which may include raw material moisture-content control, kiln shell insulation, waste heat utilization, and others) that do not change the basics of the process are usually temporary. More often, wet processes are

converted into dry or semi-dry processes or simply replaced by modern precalciner processes. We discuss some of these practices in Section 3.3.

Dry Process. The three types of dry process—long dry, preheater, and precalciner—have different degrees of energy efficiency, with precalciner being the most efficient.

Compared to the wet process, the long-dry process can shorten the rotary kiln by eliminating the evaporation zone, but fuel savings may not be substantial if waste heat is not recovered. Tail gas temperatures of the long-dry kilns are usually about 800 °C and can be effectively recovered to heat boilers for power generation. In 1985, the average fuel intensity for the long-dry process in the U.S. was about 170 kgce/ton-clinker, while similar processes in China in 1990 had fuel intensities over 200 kgce/ton-clinker [Venkateswaran and Lowitt, 1988; SSB, 1991]. There is no clear advantage of the long-dry process over the wet process in the Chinese key plants.

In the preheater dry process, a preheater, separate from the kiln, is installed at the feed end. This preheater essentially replaces the preheating zone of the long-dry process kiln. By enhancing the contact between the waste heat of tail gases and the feed materials, this arrangement reduces fuel consumption and also allows the use of a significantly shorter rotary kiln. In addition, the preheater dry process increases production capacity by calcining part of the feed materials before they enter the kiln. There are two types of preheater systems: grate-types and suspension (cyclone).

The grate-type preheater is related to the Lepol process, which uses pelletized raw materials. Pellets are preheated on a traveling grate before entering the kiln. In China, the Lepol process is also called the semi-dry process because the moisture content of pellets is higher than that of the powder-type dry feed. In 1990 Lepol-process kilns were used for about 2.5% of cement production . The fuel intensity of this process is typically about 160 kgce/ton-clinker.

The suspension preheater is a system of multistage cyclones and riser ducts in which the feed materials are heated in suspension. This system greatly enhances the heat exchange between the feed and the exhaust gases. Rapid and efficient heat transfer in the suspension preheater also allows calcination of 40-50% of feed and increases production capacity

significantly. Presently, about 2.5% of the Chinese cement production is derived from suspension preheater kilns. The average fuel intensity of cyclone preheater kilns was about 135 kgce/ton-clinker in 1990, comparable to the fuel intensity of U.S. preheater plants of the mid-1980s [Chen, 1992; Venkateswaran and Lowitt, 1988]. Cyclone preheaters are widely used in converting wet-process kilns and renovating inefficient dry-process kilns.

Another kind of preheater, called the shaft preheater, is used in many Chinese plants. The shaft preheater is a small vertical heater that evaporates wet feed materials by utilizing exhaust gases. These preheaters are used in converting small wet-process rotary kilns to dry-process kilns. There are about 100 such converted kilns in China, contributing about 2% of total cement production. Fuel intensity of such a process is typically about 180 kgce/ton-clinker, a 12% improvement compared to the average fuel intensity of wet-process kilns.

The precalciner process is a fairly recent invention, dating back only a couple of decades. The precalciner is a separate combustion chamber installed between the suspension preheater and the rotary kiln. The novelty of the precalciner process is that it divides fuel supply between two firing units: the precalciner and the rotary kiln. This process allows almost complete calcination of feed materials in the precalciner and further reduces thermal load on the kiln.

This reallocation of the heat load results in a further reduction of fuel intensity in the pyroprocess. The U.S. precalciner systems had an average fuel intensity of 123 kgce/ton-clinker in 1985 [Venkateswaran and Lowitt, 1988]. Kaiser Cement, one of the most advanced cement plants in North America, has achieved a fuel intensity of 104 kgce/ton-clinker for a kiln that produces about 4500 ton-clinker/day [data from Mark McKenna, Kaiser Cement, Cupertino, CA].

China can now design and construct small and medium (365,000 to 730,000 ton-clinker per year per kiln) precalciner kilns based on imported technologies. Such domestic designs are at the early 1980s level of their U.S. counterparts in terms of energy efficiency and other major technical indicators. The Jiangxi Plant (presented in Table 3-4) is an example. Jidong Cement Plant, a precalciner-process plant imported from Japan in the mid-1980s, now produces clinker at 116 kgce/ton-clinker and is improving [SSB, 1991]. A few other imported large precalciner kilns are now under construction and are considered an impetus to the modernization of China's cement industry.

Ceteris paribus, the fuel intensity of precalciner kilns varies with the kiln size. Larger kilns do not necessarily mean higher energy efficiency. The heat balances of several precalciner kilns in China and Japan are presented in Table 3-4 for comparison.

Table 3-4.   Heat Balance of Selected Precalciner Kilns, China and Japan

	Jiangxi Plant	Plant A	Jidong Plant	Plant B
	(China)	**(Japan)**	**(China)**	**(Japan)**
Kiln size (diameter x length, both in meters)	4 x 60	4.3 x 65	4.7 x 74	4.75 x 75
Kiln capacity (ton-clinker/day)	2092	2290	4209	4000
Clinker formation heat consumption (MJ/ton)	1737	1722	1721	1794
Heat loss in preheater exhaust gases (MJ/ton)	1023	692	860	607
Heat loss in cooler exhaust gases (MJ/ton)	490	533	339	472
Radiation heat loss (MJ/ton)	448	224	346	216
Waste heat in clinker (MJ/ton)	85	123	140	74
Total heat consumption (MJ/ton)	3783 (129 kgce/ton)	(112 kgce/ton)	3406(116 kgce/ton)	3163 (108 kgce/ton)

Source: Fu, 1990.

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For kilns with similar capacities, the Japanese models have lower heat loss through the preheater exhaust gases than those of China, while the heat loss through cooler exhaust gases shows the reverse pattern. But overall heat loss through exhaust gases from the Japanese kilns is 10-20% lower than that from the Chinese ones. One major problem identified with the Chinese kilns is the oversupply of air resulting from inaccurate airflow control. Leakage is also a cause of such heat loss. These problems can be solved through better operation control and routine maintenance. Another problem is the higher radiation heat loss of the Chinese kilns. Although, in general, larger kilns have lower radiation heat loss per ton of clinker than smaller kilns, high-quality refractory lining in the Japanese kilns is considered to be a major factor for their low radiation heat loss.

There are 17 dry-process key plants in China with an average fuel intensity of 164 kgce/ton-clinker in 1990. Except for the good efficiency of the Jidong Cement Plant, most of the dry-process plants do not even approach the average level (9 of the 17 plants have fuel intensities greater than 200 kgce/ton-clinker), which indicates serious energy efficiency problems [SSB, 1991] The semi-dry-process key plants (using Lepol kilns) are generally more efficient than the dry-process plants, but significant efficiency gains are still achievable by applying conservation measures to existing facilities. We discuss such measures in detail in Section 3.3.

3.2.3 FINISH GRINDING

Hot clinker is rapidly air-cooled and conveyed to a storage tank where it is ready for the final grinding process. Hot gases recovered from the cooler can be used for drying and preheating raw materials.

Portland cement is eventually produced by grinding clinker with 3-5% gypsum and a small amount of chemical additives. Gypsum is added to control the setting time of cement when it is mixed with water. Other materials such as blast furnace slag, power plant fly ash, and limestone can also be added in the final grinding to save clinker consumption. However, there is a limit to using these materials: adding too much reduces the quality of the cement. The portion of clinker in cement is about 85% in China and about 93% in the U.S. [SBBMI Statistics; Venkateswaran and Lowitt, 1988].

Electricity use in finish grinding usually comprises about 10% of the total energy use in cement production. On a worldwide basis, about 40 kWh are used to grind each ton of clinker [Venkateswaran and Lowitt, 1988]. Most cement plants in China use ball mills for finish grinding, while more efficient roller mills are the norm in the industrialized countries. Electricity intensity of finish grinding in the Chinese plants ranges from 35 to 45 kWh per ton of clinker [Cheng, 1992].

3.3 ENERGY-CONSERVATION MEASURES AND COST ANALYSIS

In the past ten years, the central government has sponsored many energy-conservation projects in the cement industry. Undertakings ranged from renovations of vertical as well as wet- and dry-process kilns to the introduction of advanced precalciner technology. These projects provided some information for the assessment of energy-conservation potential and the related direct costs to the Chinese cement industry. We look at the details of some projects in this section.

Renovation of Small Cement Plants (Equipped with Mechanized Vertical Kilns)

Increasing demand for cement in the 1980s stimulated a rapid increase in the number of mechanized vertical kilns. Although, on average, mechanized vertical kilns consume less coal per ton of cement clinker than the rotary kilns, many of them are inefficient. The fuel intensities of mechanized kilns range from 110 to 225 kgce/ton-clinker. The average fuel intensity of 165 kgce/ton-clinker indicates a great potential for efficiency improvement. Small plants that use mechanized vertical kilns also generate serious air pollution because of the lack of dust-collecting devices.

As revealed in our analysis of the energy use of the three-stage vertical kilns, most heat losses arise from chemically incomplete combustion and high-temperature tail gases. Evaporating (drying) feed materials also consumes a significant amount of heat. Renovation of the mechanized vertical-kiln plants is considered an overall retrofit that will not only increase energy efficiency and cement quality but also will improve air-pollution controls. Such a

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renovation usually consists of the following measures:[6]

(1) Retrofit the raw material grinding facilities: Automating the load control of grinders, installing high-efficiency classifiers, installing roller grinders, and retrofitting electric motors.

(2) Control the pre-mix of raw materials and fuel: Careful analysis of the chemical and physical characteristics of the raw materials and fuel to obtain an accurate raw-feed prescription.

(3) Control the raw-feed ingredients: Utilizing low-heating-value coal, using minerals that contain fluoride and sulfur as additives,[7] and computerizing the weighing process.

(4) Control the uniformity of the raw-feed mixture: Automating the blending process.

(5) Computerize pellet production: Controlling water content and raw-feed mixtures.

(6) Retrofit vertical kilns: Optimizing kiln size and shape, using high-quality refractory lining materials, and improving insulation.

(7) Computerize kiln operations: Optimizing air flow, temperature and temperature distribution, and the speed of feeding and discharging.

(8) Improve finish grinding efficiency: Pre-grinding clinker crushing, roller grinding process, high-efficiency classifiers, and uniformity control of cement.

(9) Control particulates emissions.

According to SBBMI data on the demonstration projects, applying these measures to mechanized vertical-kiln plants usually result in a 10-30% reduction in fuel intensity. Since renovation streamlines production processes and improves operation continuity, it always results in significant increases in production capacity.

Consequently, the avoided investment in new plants (equivalent to the newly increased capacity) often more than pays for the renovation investment, and the energy savings seem to be a costless by-product. The increased production capacity is also desirable because of the strong demand. The following is an example[8] of such renovation projects. Adopted measures include numbers 2, 3, 4, 6, and 7 (listed above) and the addition of an automated grinding-control system for raw materials [Cheng, 1992].

Pre-renovation condition:	
kiln capacity	88, 000 ton clinker/year
fuel intensity	152 kgce/ton-clinker
electricity intensity	87 kWh/ton-cement
Post-renovation condition	
kiln capacity	103, 000 ton clinker/year
fuel intensity	110 kgce/ton-clinker
electricity intensity	75 kWh/ton-cement
Total investment:	¥2 million (1990 prices)
Cost of new capacity (mechanized vertical kilns)	¥300/annual-ton-clinker (1990 prices).
Avoided new plant investment =	$¥(103, 000 - 88, 000) \cdot 300 - ¥2 \cdot 10^6 = ¥2.5$ million[9]
Energy savings at original capacity:	
Coal =	$42 \cdot 88, 000 \cdot 0.8 / 1000 =$ 2960 tce/year (assume 80% capacity factor)
Electricity =	$12 \cdot 88, 000 \cdot 0.8 \cdot 1.2 = 1 \cdot 10^6$ kWh/year.[10]

Considering profits from additional sales of cement (¥40/ton) and cost savings from energy conservation (¥150/tce for coal, and ¥0.20/kWh for electricity), the simple payback time (SPT) of this project is

$$SPT = ¥2 \cdot 10^6 / ¥(15,000 \cdot 0.8 \cdot 1.2 \cdot 40/yr + 2960 \cdot 150/yr + 1 \cdot 10^6 \cdot 0.20/yr) \approx 2 \text{ years.}$$

Renovating vertical kilns is usually justified in a straight economic sense because of the short payback period. Since economic benefits from increased cement production usually make up a

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[6]These conservation measures have been applied in the past. In a particular project they are not necessarily adopted all at the same time. Evaluating each measure is difficult because application of a *single* measure is also rare.

[7]This measure is for saving fuel, but may result in additional pollution. The authors consider that such measures should be used with caution.

[8]This is perhaps one of the best performance demonstration projects. On the average, retrofit results are probably less impressive.

[9]A rough estimate. The calculation is actually more complicated than this, since the increased capacity from the old facilities is not fully comparable with the newly built capacity in terms of capital value for reasons such as technology sophistication, plant life, and product quality.

[10] It takes one ton of clinker to produce about 1.2 tons of cement in China.

large portion of the total benefits (in the preceding case, about 50%), many experts have questioned the validity of classifying the renovation of vertical kilns as an energy-conservation undertaking. In fact, many cement plants carry out such renovations based more on the consideration of whether such procedures would bring them additional revenue than on the consideration of energy cost cutting. However, government policymakers should reconsider the investment channel of such projects in order to utilize limited energy-conservation funds most effectively. Since the return on such projects is large and rapid, economic incentives should be sufficiently attractive for the enterprises to share most of the required capital investment.

Converting manual vertical kilns to mechanized vertical kilns is also an important task of energy conservation. Manual vertical kilns still represent over 10% of China's cement production. The SBBMI plans to close all manual kiln plants with a capacity of less than 50,000 ton cement/year and convert others to high-efficiency mechanized kilns, i.e., with fuel intensity approaching 125 kgce/ton-clinker. This kind of project is similar in nature to the renovation of mechanized kilns and also banks its capital recovery on newly increased production capacity. Electricity intensity tends to increase after the conversion because of automation. The decentralized administration and the strong demand for cement in the last ten years have, to some extent, hindered this process. Stricter regulation and enforcement, as well as the simple element of time, are probably needed to eliminate the manually operated kilns.

Renovation of Wet-Process Kilns

Wet-process rotary kilns, contributing 10% of China's cement production, are largely imported technologies of the 1950s and early 1960s and produce clinker at fuel intensities of around 210 kgce/ton-clinker. Renovations of wet-process plants in the 1980s usually fell into three categories: comprehensive retrofits (keeping the wet process), semi-dry-process conversions, and dry-process conversions.

(1) Comprehensive Retrofits: Measures include the installation of heat-resistant steel chain (enhancing evaporation efficiency) and high-quality refractory lining; improving insulation and plugging leaks; retrofitting fuel injection and the firing gun; refining coal-pulverizing processes; applying mineral additives that enhance clinker formation at lower

temperatures; and retrofitting clinker-cooling systems.

These measures together usually result in a 30–40 kgce/ton-clinker reduction of fuel intensity with capital investment of about ¥30/ton-clinker at original capacity (1990 prices). It is not known whether electricity intensity is affected. Increased production capacity from such measures is small, usually about 3–4% [Cheng, 1992]. The following is an imagined project showing possible results of such a comprehensive retrofit (information about any real case is not available):

Example 1

Pre-renovation:	
kiln capacity	200, 000 ton-clinker/year
fuel intensity	210 kgce/ton-clinker
electricity intensity	105 kWh/ton-cement
Post-renovation	
kiln capacity	207, 000 ton-clinker/year
fuel intensity	170 kgce/ton-clinker
electricity intensity	assume no change
Total investment	¥6 million (¥30/ton-clinker at original capacity)
Energy savings at original capacity	
coal	40 • 200, 000 • 0.8/1000 = 6400 tce/year
electricity	SPT = ¥6 • 10^6 / ¥(7000 •1.2• 0.8 • 40/yr + 6400 •150/yr) ≈ 5 years

This example is a typical energy-conservation retrofit in which cost savings from energy contribute to about 80% of the economic benefits of the investment.

(2) Conversion to Semi-Dry-Process: One example of this measure preserves the routines of raw material preparation in the wet process but adds a water-extraction device that reduces the water content of the slurry-state to about 18%. The lumpy raw materials are then put into a drying and crushing process and are eventually fed into the dry-process kiln in powder form. A demonstration project of this kind in Bai Ma Shan Cement Plant has the following conditions and results [Chao, 1992]:

Example 2

Pre-renovation:	
kiln capacity	180, 000 ton-clinker/year
fuel intensity	214 kgce/ton-clinker
electricity intensity	101 kWh/ton-cement
Post-renovation:	
kiln capacity	255, 000 ton-clinker/year
fuel intensity	143 kgce/ton-clinker
electricity intensity	126 kWh/ton-cement
Total investment	¥30 million (1990 prices)
At original capacity	
Coal savings	180, 000 • 0.8 • 71/1000 =10224 tce/year
Increased electricity use:	180, 000 • 0.8 • 1.2 • 25 = 4.3 • 10^6 kWh/year
Increased clinker capacity	75, 000 ton/year

$$SPT = ¥30•10^6/¥(75, 000•0.8•1.2•40/yr + 10224•150/yr - 4.3•10^6 • 0.2/yr) \approx 8 \text{ years}$$

(3) Conversion to Dry Process: This measure is actually an overhaul of the original wet-process plant. The preparation process for raw materials is changed to fit the dry-process kiln, a suspension preheater is added, and the original long wet-process kiln is retrofitted into a short, preheater dry-process kiln. The cooling system is also renovated for better recovery of waste heat. There are also supplementary additions of equipment for handling increased production capacity. Since conversion to a dry process requires virtual rebuilding of a plant, the cost is the highest among the three measures. Example 3 is a summary of such a project [Chao, 1992]:

The simple payback times for Examples 2 and 3 seem to be too long for renovation projects. Using imported equipment might have contributed to the cost increases. Converting wet process to dry process also increases electricity consumption by about 25 kWh/ton-cement, which offsets some benefit from fuel savings, and consequently, may not be a favorable choice in certain situations. More data and information are needed for a better evaluation of such projects. The reason that the Chinese cement industry choose such conversion projects is very practical: additional capital for new plants is often not available and increasing capacity through conversions can save money. Relocating factories and workers is also difficult if old plants are closed. To restate, classifying such projects as energy-conservation activities may not be appropriate, but by doing so, cement

plants often procure bargaining power for renovation funds.

Example 3

Pre-renovation	
kiln capacity	174, 000 ton-clinker/year
fuel intensity	209 kgce/ton-clinker
electricity intensity	100 kWh/ton-cement
After-renovation	
kiln capacity	315, 000 ton-clinker/year
fuel intensity	118 kgce/ton-clinker
electricity intensity	126 kWh/ton-cement
Total Investment	¥65 million (1990 prices)
At original capacity:	
Coal savings	174, 000 • 0.8 • 91/1000 =12670 tce/year
Increased electricity use	174, 000 • 0.8 • 1.2 • 26 = 4.3 • 10^6 kWh/year
Increased clinker capacity	141, 000 ton/year
Cost of new capacity (precalciner kiln)	¥600/ annual-ton-clinker (1990 prices)[11]
Avoided new plant investment	¥141, 000•600 – ¥65•10^6 ≈ ¥20 million

$$SPT = ¥65•10^6/¥(141, 000•0.8•1.2•40/yr+12670•150/yr - 4.3 • 10^6 •0.2/yr) \approx 10 \text{ years}$$

Renovation of Lepol Kilns

The 16 Lepol kilns in the industry are among the large rotary kilns in China, each with an annual capacity of about 300,000 ton-clinker. Comprehensive energy-conservation measures identified include: pellet quality control, the use of calcination-aiding mineral additives, preheater retrofits (reducing breakage and increasing heat-transfer efficiency), firing gun retrofits, air leakage plugging, cooling system retrofits and waste heat recovery, and computer control of pyroprocessing. The demonstration project in Shao Tuen Cement Plant was able to reduce the fuel intensity from 160 kgce/ton-clinker to 130 kgce/ton-clinker and increase clinker production capacity by 16% with a capital investment of about ¥125/ton-clinker at original capacity (1990 prices) [SBMMI data, 1992]. The impact on electricity intensity is not known. Example 4 is an imagined project based on the above information, indicating possible results of such renovations:

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[11] Since the fuel intensity after renovation is close to that of the precalciner kiln, we choose the precalciner kiln as the alternative investment.

Example 4

Pre-renovation	
kiln capacity	300, 000 ton-clinker/year
fuel intensity	160 kgce/ton-clinker
electricity intensity	120 kWh/ton-cement
Post-renovation	
kiln capacity	348, 000 ton-clinker/year
fuel intensity	30 kgce/ton-clinker
electricity intensity	assume no change
Total investment	¥38 million (¥125/ton-clinker at original capacity)
Energy savings at original capacity	
coal	30 • 300, 000 • 0.8/1000 = 7200 tce/year
electricity	0
Net investment in energy savings	$38 \cdot 10^6 - ¥48,000 \cdot 600 \approx ¥9 \cdot 10^6$ [12]
Cost of energy saving capacity	$¥9 \cdot 10^6 / 7200 \approx$ ¥1250/annual tce

For comparison, the cost of bring one tce coal into market is about ¥700/annual tce in 1990

$SPT = ¥38 \cdot 10^6 / ¥(48,000 \cdot 0.8 \cdot 1.2 \cdot 40/yr + 7200 \cdot 150/yr)$ ≈ 13 years

According to these results, retrofitting Lepol kilns seems to be very costly and not worth the effort. Part of the reason is that such renovations do not increase clinker capacity. Adjustment of retrofit measures is needed to make such renovations attractive.

Renovation of Small Dry-Process Rotary Kilns

Small dry-process rotary kilns are some of the most inefficient kilns in the cement industry. Because of significant heat loss through high-temperature exhaust gases (some 800 °C), fuel intensities of these kilns are often as high as 280 kgce/ton-clinker. About half of the small dry-process rotary kilns have been eliminated since the mid-1980s, and present plans call for the renovation of the remaining kilns (about 100 units). In 1990, 4% of the total cement output was from these small dry-process kilns.

One demonstration project introduced the five-stage suspension preheater from Japan. This measure reduced fuel intensity from 286 kgce/ton-clinker to 136 kgce/ton-clinker and raised kiln capacity from 110 ton-clinker/day to 300 ton-clinker/day. However, the cost of this

renovation seems to be extremely high: the ¥60 million spent for the project is equal to the capital investment in a new precalciner-kiln plant of the same size [Cheng, 1992]. The simple payback time of such a renovation would be approximately 18 years. Closing similar small dry-process kilns is probably a better choice than retrofitting them. Five-stage suspension preheaters manufactured in China are now available and are reliable and effective. This development may significantly reduce the costs of such renovation projects.

Renovation of Shaft Preheater Rotary Kilns

Shaft preheater rotary kilns usually have a clinker capacity of 170–190 ton/day. They produced about 2% of the cement output in 1990. Fuel intensity ranges from 157–195 kgce/ton-clinker. Major energy-saving measures include: (1) improving the heat-exchange efficiency of the preheater by installing an additional feeding device, (2) installing a simple precalciner, and (3) installing heat-exchange-enhancing devices in the calcination zone of the kiln. The major results and simple evaluations of a demonstration project are presented as the following [Cheng, 1992]:

Example 5

Pre-renovation	
kiln capacity	51, 000 ton-clinker/year
fuel intensity	195 kgce/ton-clinker
electricity intensity	not available
Post-renovation	
kiln capacity	78, 000 ton-clinker/year
fuel intensity	145 kgce/ton-clinker
electricity intensity	assume no change
Total investment	¥12 million (1990 prices)
Energy savings at original capacity	
coal	50 • 51, 000 • 0.8/1000 = 2040 tce/year
electricity	0

$SPT = ¥12 \cdot 10^6 / ¥(27, 000 \cdot 0.8 \cdot 1.2 \cdot 40/yr + 2040 \cdot 150/yr)$ ≈ 9 years

Renovations of shaft preheater kilns are also marginal investment projects with too long a payback time. Conservation measures need to be adjusted in order to bring better returns on capital.

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[12] Assume precalciner kilns as the alternative.

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Renovation of Grinding Machines

Some 12,000 machines are utilized for grinding either raw materials or clinker. Grinders use 60-70% of the electricity of a Chinese cement plant. Ball mills dominate the grinding process but the more efficient roller mills could save about 20-30% electricity. Introducing high-efficiency classifiers can also effectively reduce electricity consumption. For example, the O-SEPA cyclone classifier imported from Japan reduces electricity use by 8% while it increases cement production by 6-8% compared with popular Chinese models.

Conservation measures in the grinding process are usually made up of a combination of devices. A system used in Xinjiang Cement Plant includes a roller grinding machine, a ball grinding machine, and a high-efficiency classifier. This system reduces electricity consumption of raw and finishing grinding by 30% and 25% respectively, compared to the ball mill system it replaced [Cheng, 1992]. Roller grinding machines and high-efficiency classifiers are now being produced domestically with imported technologies, and the cost of renovations is expected to decrease as a result. Estimates propose an industry-wide 25% reduction in electricity use for grinding if roller mills and high-efficiency classifiers are universally adopted. This decrease would result in an 18 kWh reduction per ton of cement production. However, increased electricity use in other production processes may offset much of this specific efficiency gain.

Because of process mechanization, the electricity intensity of cement production in China has been rising in the past 15 years. We expect it to continue to increase gradually in the coming years as the industry introduces more modern production lines and closes or converts existing manual vertical kilns.

3.4 ENERGY-CONSERVATION SCENARIOS OF THE CEMENT INDUSTRY

Domestic cement demand is expected to rise steadily in the remainder of the decade and beyond because of increased economic activity. Some antiquated kilns will be retired and new capacity increases can be met by combinations of production technologies with distinct socio-economic merits and short- and long-term cost-benefit trade-offs. Based on our projections of cement production by the year 2000, we present two development scenarios of the cement industry and examine their implications on energy demand and investment requirements.

3.4.1 CEMENT PRODUCTION CAPACITY BY 2000

From 1980 to 1988, increases in cement production and real gross output value had a very strong relationship. Annual growth rate for each, in turn, was 13% and 12%. While the economy was growing slowly, from 1988 to 1990, cement production leveled off. When the economy regained momentum (since 1991), cement production immediately resumed its strong growth. In 1991, output rose 20% over its 1990 level [SSB, 1992]. A similar growth rate is expected for 1992, and there were already reports of cement shortages in many areas [Wu, 1992]. We consider this unusually strong rebound a short-term phenomenon caused by a sudden spurt of new construction and the renewed work on projects that were stalled between 1989 and 1991. We would expect the demand for cement to keep pace with the GNP growth rate in the coming years. The major determinants of future cement demand are the scales of building and infrastructure construction as well as major water projects. These activities have already been intensive in the last decade and will remain so, or even be expanded, in the next 10-15 years.

The SBBMI projects an 8% annual growth rate for cement production from 1990 to 2000, a rate in line with the expected 8-9% annual GNP growth. Considering the already huge cement production capacity, this growth rate could be conceived of as a very ambitious goal. However, a cement output of *450 million tons in 2000* can be derived from the 8% annual growth rate. We assume that 10 Mt cement production capacity (from small dry-process kilns) will be retired before 2000. Thus, the net increase of cement production from 1990 to 2000 will be 250 Mt, an addition of 25 Mt per year. Similar growth was achieved from 1984 to 1988, when annual cement output increased about 22 Mt per year. So, it is not impossible that China could sustain another period of high growth in cement production.

One unpleasant implication for energy conservation is that if the demand remains high, many of the old plants may not be retired, and as long as cement prices justify the costs, still many more small plants may be built to feed burgeoning local demands. In a scramble to

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raise production, energy efficiency and environmental protection are often left less attended. Our scenarios below indicate what will be needed to achieve both the production goal and higher energy efficiency.

3.4.2 DESCRIPTION OF THE SCENARIOS

We consider that the projected 250 Mt increase in cement production from 1990 to 2000 is fulfilled by the increased capacity from renovating existing plants and constructing new plants. We assume that the additional capacity from renovation is a constant amount in our two biased scenarios—"Cheap" Solution and "Expensive" Solution—where the meaning of "cheap" and "expensive" is based on one-time investment costs. Assessing the total social costs is beyond the scope of this report and the capability of the authors.

Scenario I: "Cheap" Solution

In this scenario, capacity increases from new plants is achieved by building advanced vertical kilns (VK), a less expensive and matured domestic technology. Construction of modern precalciner kilns (PK) will take a moderate role. The ratio of VK capacity/PK capacity in new construction is assumed to be 3:1.

Scenario II: "Expensive" Solution

In this case, PKs contribute most of the capacity increase from the construction of new plants and VKs will be the complement. The VK capacity/PK capacity ratio in new construction is assumed to be 1:3.

3.4.3 RESULTS AND IMPLICATIONS

In 1990, the total cement output was 210 Mt and the shares of production by different kiln type were 60% for mechanized VKs, 12% for manual VKs, 2.5% for Lepol kilns, 4.5% for PKs, 11% for other dry-process kilns, and 10% for wet-process kilns. Based on experiences from the 1980s, renovations of existing facilities will have the following results (data obtained from SBBMI; for special cases, see discussions in Section 3.3):

• Comprehensive measures for mechanized VKs: Capacity increases 30% over the pre-renovation level; fuel intensity decreases from 165 to 125 kgce/ton-clinker; gross capital

investment is ¥70 per ton of pre-renovation cement capacity, or ¥230 per ton of newly increased cement capacity (in 1990 yuan).

• Converting manual VKs to advanced mechanized VKs (fuel intensity reaches 125 kgce/ton-clinker): We assume that by closing and converting existing manual VKs, the resulting mechanized VK capacity will be at the present manual VK level, i.e., 23 Mt cement. Investment cost is (optimistically) assumed to be the same as the cost data for retrofitting mechanized VKs.

• Converting wet process to dry process (the cyclone preheater case): Capacity increases 80% over the pre-renovation level; fuel intensity decreases from 210 to 135 kgce/ton-clinker; gross capital investment is ¥285 per ton of pre-renovation cement capacity, or ¥360 per ton of newly increased cement capacity (in 1990 yuan).

• Lepol kiln renovation: Capacity increases 16% over the pre-renovation level; fuel intensity decreases from 160 to 130 kgce/ton-clinker; gross capital investment is ¥100 per ton of pre-renovation cement capacity, or ¥625 per ton of newly increased cement capacity (in 1990 yuan).

• Renovation of shaft-preheater kilns: Capacity increases 55% over the pre-renovation level; fuel intensity decreases from 180 to 145 kgce/ton-clinker; gross capital investment is ¥170 per ton of pre-renovation cement capacity, or ¥310 per ton of newly increased cement capacity (in 1990 yuan).

• Renovation of other dry-process kilns is usually very expensive and considered not practical. We assume that about 10 Mt cement capacity of such facilities will be retired.

These renovations will generate about 60 Mt of additional cement capacity, which leaves a gap of 190 Mt to be filled by construction of new plants. According to SBBMI estimates, new PK plants require gross investment of about ¥600/ton-clinker in 1990 prices, or about ¥500/ton-cement at present clinker/cement ratios. We assume that new advanced VK plants require half that amount as gross investment, i.e., ¥250/ton-cement in 1990 prices. We assume that new PK plants will achieve a fuel intensity of 115 kgce/ton-clinker and new VK plants will achieve a fuel intensity of 125 kgce/ton-clinker. Table 3-5 gives a full description of these scenarios.

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Table 3-5. **Cement Production Structure in 2000 and Estimated Gross Incremental Costs (over 1990 Output)**

	1990 Base Year	2000 Scenario I			2000 Scenario II		
		Renovation	New Plants	Subtotal[†]	Renovation	New Plants	Subtotal[†]
Cement Output (Mt)							
Manual vertical kilns	23 (250)[††]	0	0	0	0	0	0
Mechanized vertical kilns	126 (165)	61 [(a)]	143	330(125)	61	48	235(125)
Wet-process kilns	22 (210)	0	0	0	0	0	0
Lepol kilns	5 (160)	1	0	6(130)	1	0	6(130)
Shaft-preheater kilns	4 (180)	2	0	6(145)	2	0	6(145)
Cyclone-preheater kilns	5 (135)	40 [(b)]	0	45(135)	40	0	45(135)
Other dry-process kilns	15 (220)	0	0	5 (180)[(c)]	0	0	5(180)
Precalciner kilns	10 (120)	0	48	58(115)	0	143	153(115)
Subtotal				450			450
Gross Costs (Bn¥)							
Manual vertical kilns		0	0	0	0	0	0
Mechanized vertical kilns		14 [(d)]	36	50	14	12	26
Wet-process kilns		0	0	0	0	0	0
Lepol kilns		1	0	1	1	0	1
Shaft-preheater kilns		1	0	1	1	0	1
Cyclone-preheater kilns		6 [(e)]	0	6	6	0	6
Other dry-process kilns		0	0	0	0	0	0
Precalciner kilns		0	24	24	0	72	72
Subtotal				82			106

[†] 1990 output + renovation + new plants, unless noted.

[††] Figures in the parentheses are the average fuel intensity (kgce/ton-clinker) for each type of kiln in the corresponding year.

(a) Increased production from renovation, including 23 Mt converted from manual kilns.

(b) Increased production resulted from converting wet-process kilns (original plus increased output).

(c) Assume that 10 Mt capacity has been retired. The cost of intensity reduction for the remainder is assumed to be negligible.

(d) Capital investment for renovating mechanized VKs and converting manual VKs.

(e) Capital investment for converting wet-process kilns (increased output is 18 Mt).

From a simple comparison of numbers, the cheap scenario, which achieves much of the fuel-intensity reduction and uses significantly less money than the expensive solution, appears to be more favorable. However, the expensive scenario will provide more high-quality cement, which benefits society in the long term. Large modern plants have more effective pollution control than small plants. Many of the technologies and equipment needed to make the cement industry more efficient and less polluting are still imported. As we have discovered in the evaluation of the demonstration projects, imported equipment makes retrofit projects expensive. Costs could be significantly reduced if equipment were manufactured domestically. This raises the issue of the important role of Western assistance in facilitating technology transfers that are urgently needed for the Chinese cement industry.

Chinese industry was historically very good at producing high growth with massive low-cost small enterprises. If strong cement demand is sustained in the next 10 years, it is likely that Scenario I will be the case, but with less capital input and less improvement in energy efficiency. Direct governmental financial support for energy conservation is expected to decline in the coming years. How the market will work its magic on energy conservation is still an unknown matter in China. As shown from U.S experiences, the energy efficiency of the cement industry is sensitive to energy prices. One significant difference between the U.S. past and the Chinese present is that the former was facing a stable and slightly shrinking cement market

while the latter is confronting a buoyant and fast-growing market.

In both scenarios we assume the elimination of manual and wet-process kilns, which may be somewhat optimistic. In terms of the share of vertical kilns in total output, Scenario I does not differ much from the 1990 base year. Scenario II indicates a large reduction in vertical kilns, with precalciner kilns assuming a significant share of the cement output. From the market experience in the 1980s, we expect a continued strong growth in demand for high-quality cement. This trend will inevitably stimulate the construction of modern precalciner kilns.

Even in the "cheap" solution case, the gross investment seems to be very high. The total investment in the entire building materials industry in 1991 was only about ¥7 billion (probably an underestimate because data from rural enterprises are difficult to collect) [SSB, 1992]. The annual investment of ¥8 billion in Scenario I and about ¥11 billion in Scenario II is probably too much for the cement industry to pay. Even the "cheap" solution is not a realistic solution from an historical perspective.

On the other hand, the proposed investment would significantly improve the industry's energy efficiency. Average fuel intensity would be reduced from the 1990 average 180 kgce/ton-clinker to 126 kgce/ton-clinker in Scenario I and 124 kgce/ton-clinker in Scenario II by 2000. Fuel intensity of clinker production diminished about 10% in the 1980s. If we assume business as usual, fuel intensity would achieve about 160 kgce/ton-clinker, instead of the figures given in the two scenarios. Compared with the business-as-usual case, the resulted fuel-saving capacity is estimated at 13 and 14 Mtce/year in Scenario I and Scenario II respectively. Saved one-time front capital investment in coal supply would thus be ¥11 billion in Scenario I and ¥12 billion in Scenario II.[13] Table 3-6 summarizes the general results of our scenarios.

3.5 CONCLUSIONS

With an average fuel intensity of 124 kgce/ton-clinker in Scenario II, the Chinese cement-manufacturing industry will be a moderately efficient industry. Significant further

improvement is achievable even with today's technologies. Well-operated mechanized vertical kilns have achieved fuel intensities as low as 110 kgce/ton-clinker and advanced precalciner kilns produce clinker at 104 kgce/ton or even lower fuel consumption.

Precalciner kilns have been the worldwide trend in the cement industry in the last 20 years. In the 1980s, the American cement industry completed the transition from conventional wet-process and dry-process kilns to modern precalciner kilns. The Chinese industry may take longer time to make such a transition. We consider that the most likely course of cement industry restructuring in China in the next 10 to 15 years is toward a mix of high-efficiency vertical kilns and modern precalciner kilns with the former meeting local, small volume and the lower end of the cement demand, and the latter meeting regional (and international), large volume and the higher end of the cement demand.

Clinker production only theoretically requires about 1.6 MJ energy per ton of clinker, or 55 kgce/ton-clinker. Reaching that limit may never be possible, but new technologies can further reduce the fuel intensity of clinker production. According to Venkateswaran and Lowitt [1988], advanced pyroprocessing technology under development in the mid-1980s can bring clinker fuel intensity below 100 kgce/ton-clinker.

Of course, kilns are not the only target for energy conservation and new technologies. There are a host of measures and techniques to reduce energy consumption in cement manufacturing [Venkateswaran and Lowitt, 1988]. Only approaches that take into consideration all the links of cement production will realize the greatest energy conservation and achieve the best pollution control.

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[13]Capital cost of bringing one tce coal into market in 1990 is estimated to be ¥700/annual-tce-coal. The saved capital investment in coal supply is equal to saved coal capacity times unit cost of coal supply.

Table 3-6. General Results of Scenarios

	Cement Output (Mt)	Technology Mix [a]	Fuel Intensity [b] (kgce/ton-clinker)	Fuel Demand [c] (million tce)	Capital Cost [d] (billion 1990¥)
1990	210	71% VK [f], 5% PK	180	32	
BaU [e]	450	no projection	160	60	no projection
Scenario I	450	73% VK, 13% PK	126	47	82
Scenario II	450	52% VK, 34% PK	124	46	106

[a] Output from different types of kilns. Table 3-5 has more detailed information.

[b] Weighted average of different types of kilns.

[c] Estimated coal consumption for making clinker (cement/clinker≈1.2).

[d] Investment requirements for achieving the production goals with different mixes of technologies.

[e] BaU stands for "business as usual," a reference case for the two scenarios. What will happen under such a condition is not projected. The only assumption is that fuel intensity will be reduced at the same pace achieved in the 1980s. Investment cost in this case is considered to be significantly lower than in Scenario I.

[f] Includes 21% manual vertical kilns. In Scenarios I and II, all vertical kilns are the advanced type.

Chapter 4

The Flat Glass Manufacturing Sector

The manufacture of flat glass, regardless of any specific technology, consists of four processes: preparing raw materials, melting and refining, product formation, and finishing treatments. In this continuous process, most energy is consumed in the melting and refining furnaces where raw materials (silica, limestone, and soda ash) are liquefied at a temperature of around 1550 °C. The float process,[14] invented in England in the late 1950s, is the predominant worldwide technology for producing flat glass, while plate and sheet processes,[15] technologies of the 1930s, are still used in China as well as in some other countries. In the finishing treatment, procedures such as annealing, tempering, laminating, and coating are applied in order to make quality products to meet various end-use requirements.

In the U.S. flat glass industry, melting and refining account for about 68% of the energy used, while raw materials preparation, glass formation, and finishing each account for 18%, 12%, and 2% respectively [Babcock, et al., 1988]. The Chinese factories use significantly higher shares of energy for melting and refining—80% for float-process factories and 95% for sheet-process factories—suggesting inefficient furnaces and less sophisticated production procedures (less treatment and refining, fewer product types) [SBBMI, 1991].

The uses of flat glass differ in the U.S. and China. While most flat glass is used in the construction sector in China, only one-third of the U.S. flat glass shipments goes to construction. Close to 60% is consumed by the automobile industry, which has yet to become a manufacturing force in China.

4.1 CURRENT STATUS

Some 130 flat glass manufacturers in China produced 84 million standard cases (50 kg/case) in 1989. In that same year, total energy consumption was about 3.5 Mtce, a very small figure compared with the amounts used for cement, brick, or lime manufacturing [SBBMI, 1991]. Many plants use coal for melting, an unusual practice for an industry that demands high-quality fuels such as oil and gas. In the U.S., flat glass manufacturing depends almost exclusively on natural gas for its fuel supply.

Although the Chinese flat glass industry has made significant progress through the introduction of new technologies, the industry as a whole still remains underdeveloped and inefficient compared to its Western counterpart. We can summarize the major drawbacks in three aspects:

- *Low Productivity.* Small furnaces and outdated processes are responsible for this condition. In 1989 the industry's average labor productivity was about 150 ton flat glass per person-year, compared to the 1985 U.S. average of about 280 ton flat glass per person-year.

- *Low Product Quality and Few Varieties.* Quality has always been a serious problem of the flat glass industry which, in 1989, still produced two-thirds of its output below the state quality standard. With the introduction of the modern float process, this situation has been improving, but the variety of products is still limited. The bulk of the output (about 60%) is used for

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[14]In the float process, molten glass flows horizontally from the furnace under a tweel and over a lip (or spout) into the float chamber, which is a molten tin bath approximately 50 to 60 meters long and 4 to 9 meters wide. During its passage over this expanse of molten tin, the hot glass assumes the perfect flatness of the tin surface and develops excellent thickness uniformity.

[15] In the sheet process, molten glass is drawn from a submerged chamber between a system of double rollers arranged in a vertical plane. The glass is given a preliminary annealing in its upward travel. It is then cut into large sizes and passed through another layer for final annealing.

In plate process, molten glass is drawn from the furnace horizontally and passes between iron or steel rollers. The glass ribbon formed is then carried on conveyor rollers through the annealing lehr. The plate process consumes more energy than the sheet process because of the grinding and polishing processes involved.

window glazing in buildings. However, even these products are insufficient to meet end needs because of the limited thicknesses or types of flat glass.

• *Low Energy Efficiency.* Although the flat glass industry uses little energy compared to other major building-material industries, the energy-saving potential in the industry is considered to be significant. For example, the overall energy (fuel plus electricity) intensity of flat glass manufacturing was about 42 kgce/case, according to the output and energy data in 1989, while the equivalent U.S. figure was about 30 kgce/case in 1985. This efficiency gap indicates a conservation potential of about 1 Mtce/year at present production levels. That amount is equivalent to more than one-quarter of the present energy used in flat glass production.

4.2 CONSERVATION MEASURES AND ENERGY-SAVINGS POTENTIAL

Energy conservation was not impressive in the 1980s. Industry-wide fuel intensity was reduced from 43 kgce/case in 1980 to 38 kgce/case in 1988 because of more and larger factories (such as the construction of 21 float-process lines). Ironically, the average fuel intensities of the medium and large factories increased in the same period from 33 to 36 kgce/case because of the relative decline in average furnace size in this category. The lowest fuel intensity achieved is about 25 kgce/case, a figure still higher than the mid-1980, average U.S. level of 22 kgce/case and the average Japanese level of 18 kgce/case. These domestic or international efficiency gaps indicate significant energy-saving potential.

Furnace size is the most important factor influencing fuel intensity. Larger furnaces not only lose less unit radiation heat but also increase the economic feasibility for heat recovery. Modern float processes are usually supported by furnaces with unit capacities of more than 500 ton/day. Among the 21 float-process lines built in the 1980s, seven have furnaces with a melting capacity of 400-700 ton-glass/day; others are in the range of 200-300 ton-glass/day. The most inefficient small factories, which use furnaces below 100 ton-glass/day (average fuel intensity at about 90 kgce/case flat glass), have not been effectively phased out due to shortages of glass during most of the 1980s. Because of capital shortages, the investment emphasis has been on less expensive (per unit of

manufacturing capacity), medium-capacity furnaces or retrofits. The majority of furnaces used in the Chinese flat glass industry have a unit capacity of around 200 ton/day, which is far below the common sizes (more than 500 ton-glass/day) found in industrialized countries.

Another important factor influencing the fuel efficiency of furnaces is the quality of the interior refractory lining. The poor refractory material in Chinese glass-melting furnaces not only lowers heat efficiency (due to excessive heat losses) but also shortens the operating life. Major furnace maintenance, which interrupts production, must be scheduled every two or three years instead of every seven or eight, as in the West. Frequent "cold" maintenance (draining out all molten glass and installing new refractory lining) usually interrupts production for about two months and wastes an estimated 1500-1800 tce for furnaces with unit capacities around 250 ton-glass/day [Guo, 1989]. Furnace insulation is one of the major energy-conservation measures since higher furnace temperatures enhance glass melting and increase productivity. But factories in China have been hesitant to adopt this measure for fear that higher inner temperatures may damage refractory linings and significantly shorten the life of furnaces. Refractory quality has improved in recent years, and some factories have begun to experiment with total furnace insulation. Reductions in fuel intensity of 15-20% and 12% were achieved for furnaces that use oil and coal respectively.

Other conservation measures include improving firing techniques and glass-melting boost techniques (such as the installation of bubblers in the bottom of melters to enhance the convection flow of molten glass), installing higher efficiency motors (for furnace blowers), computerizing control systems, preheating raw materials, and utilizing waste heat (for example, co-generation).

Future energy-conservation efforts in the Chinese flat glass industry will need to rely on the introduction of large modern float-process lines and, at the same time, the closure of the extremely inefficient small factories. Production should not only become more energy efficient, but also expand to include energy-efficient goods. To diversify the industry, new product technologies, such as low-E windows, that improve the end users' energy efficiency as well, should be introduced.

Chapter 5

The Brick Manufacturing Sector

Brick manufacturing is made up of four processes: raw material preparation, molding, drying, and baking. Clay or shale is usually mixed or crushed to make a plastic feed for brick molding. Soft bricks are then either pressed or extruded by a molding machine. These soft bricks need to be dried either in the open air or in a dryer before baking.[16] The most energy-intensive process is baking, where raw clay bricks are vitrified into hard pieces under temperatures as high as 1200 °C.

Three types of kilns are used in China. The least efficient are the batch-wise vertical kilns, which have single firing chambers with brick or refractory lining. The firing cycle for this type of kiln usually lasts longer than four days. The annular kilns, which have multiple firing compartments, are now popular. The multi-compartment structure facilitates continuous production since each compartment contains bricks in different firing stages. But the process is still labor-intensive because bricks have to be loaded or removed from each compartment by hand. Modern large-scale brick production utilizes tunnel kilns where steel cars carrying bricks pass through a long tunnel with different firing zones. Depending on the design of the tunnel kilns, a car can pass through in 30 to 60 hours.

Our discussion will focus on clay bricks, which make up about 98% of China's brick production.

5.1   CURRENT STATUS

Bricks are the dominant wall material in Chinese buildings, encompassing about 65% of new construction and 95% of residential buildings [Tao, 1988]. Like other building materials, brick production experienced a high-speed growth period from 1980 to 1988 and declined somewhat in 1989 and 1990. Production was about 160 billion pieces in 1980 and rose to 450 billion pieces in 1990, the latter, an equivalent of 640 million cubic meters in volume (1 m^3 is equivalent to about 700 pieces of bricks). According to SBBMI statistics, energy use in brick manufacturing was about 55 Mtce in 1990,[17] the largest energy consumption in the building materials industry.

About 96% of the brick production in China is solid clay pieces (standard dimension: 240 x 115 x 53 mm). Hollow clay bricks account for less than 1% of brick production. Production of bricks made of other materials is likewise small [Tao, 1988].

Facile access to raw materials, low technological requirements, and dispersed local demand have made brick manufacturing yet another massive collection of small-scale operations. Production of bricks is shared among 11 key enterprises (SBBMI-controlled), approximately 1800 local enterprises (local government-controlled plants or urban collectives), and more than 90,000 rural enterprises. Their average production level per factory is about 430, 43, and 5 million pieces per year respectively. The rural enterprises contribute about 84% of the total production while the key enterprises' share is less than 1% [SBBMI, 1991].

Brick-manufacturing technology in China has experienced great changes since the late 1970s. Automatic or semi-automatic molding has replaced the popular manual molding of 15 years ago, and over 95% of the bricks made by the rural enterprises are now baked in annular kilns instead of primitive single-chamber kilns. However, the industry still remains labor-intensive, energy-inefficient, technologically outdated, and environmentally destructive. In most rural enterprises, every process is operated manually except molding. Soft clay bricks are naturally dried and occupy large storage areas.

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[16] Drying bricks in a separate dryer is found to be more efficient than in the baking kiln.

[17] The brick plants also manufacture a small amount of roofing tiles. This energy-use figure may include both brick and tile production.

Serious destruction of farm lands because of brick making is reported in important agricultural regions such as Hebei, Henan, and Shandong provinces. Bricks made by the rural enterprises usually do not meet quality standards for rigidity and exterior appearance. While the large key enterprises can produce bricks at about 110 kgce/1000-piece fuel consumption, smaller local or rural enterprises usually have fuel intensity of about 150 kgce/1000-piece. Primitive vertical kilns have fuel intensity as high as 200-400 kgce/1000-piece [Tao, 1988].

5.2 CONSERVATION MEASURES AND ENERGY-SAVINGS POTENTIAL

Learning from the experiences in the 1980s, the SBBMI considers the following measures to be important to improve the energy efficiency in the brick industry:

(1) Promoting Hollow Bricks

Hollow bricks (with symmetric and parallel holes across the brick body) save both clay and energy. It is estimated that bricks with 30-45% hollow space save 25-30% fuel compared to equal volume solid bricks. Walls made of hollow bricks also insulate better than walls made of solid bricks. Even with such appealing features, however, production of hollow bricks is negligible and expansion is troublesome because of quality problems and technical difficulties for China's many small producers. At present, hollow bricks account for less than 1% of total brick production in China, which indicates potential for both a large market and huge energy savings.

Judging from experience, without strong support from the government hollow brick manufacturing may still have difficulties surviving. Poor physical strength (not necessarily an inherent property of hollow bricks) and fierce competition from cheap solid bricks have made demand for hollow bricks extremely low. Such a situation also makes the diffusion of hollow brick manufacturing very difficult because of higher capital costs and greater technical sophistication than the traditional brick making. The market has failed to select a superior technology and government intervention may be necessary to facilitate the introduction of hollow bricks into the market.

(2) Promoting the Economies of Scale

Large and continuously operating brick factories have many advantages for energy efficiency and product quality. In large urban areas where brick demand is large and relatively concentrated, large-scale production is often justified. However, promoting large-scale modern facilities in China usually has the side effect of displacing workers from small factories.

(3) Renovating Brick Kilns

Although most rural enterprises have switched from primitive single-chamber kilns to more efficient annular kilns, there is still much to do to improve energy efficiency. Available retrofit measures are able to reduce unit fuel consumption by about 20% and increase productivity as well. Energy-efficient annular kilns can bake bricks at fuel intensity as low as 100 kgce/1000-piece [Qiu, 1989 and Cheng, 1992].

(4) Utilizing Low-Grade Coal and Industrial Solid Waste

Mixing pulverized low-grade coal and solid industrial waste such as fly ash into the raw material (clay or shale) helps reduce fuel use in the baking process. Factories located in regions where conditions exist are encouraged to adopt such procedures.

Timothy [1989] has some revealing observations about energy conservation in the Australian brick industry. We consider them useful for conservation promoters in the Chinese brick industry. Two major points are:

• Kiln type and fuel source do not necessarily affect the energy efficiency of the baking process. Single-chamber kilns can be operated as efficiently as tunnel kilns, although the former are more labor-intensive. The skill of operation and determination of the management are crucial factors to achieve good energy efficiency. Thus the kiln type and fuel can be chosen to suit the local conditions and market.

• Shortened firing times and heat recovery are two important measures to achieve low fuel

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intensity for baking with intermittent kilns (as opposed to continuous tunnel kilns). The critical factor in achieving a reduction in firing time appears to be a sufficient number of carefully positioned burners to fire uniformly throughout the stack. A separate dryer can be used to dry bricks with recovered waste heat. This procedure also tends to increase output.

The official estimate of residential building construction is 1.1 billion square meters per year for the rest of the century, compared with about 900 million square meters per year in the 1980s [Tao, 1988]. Adding the construction activities in the commercial and industrial sectors, the demand for bricks is expected to be great. Significant substitutions of other kinds of wall materials are considered unlikely in the near future because of higher costs and insufficient manufacturing infrastructure. brick manufacturing is already the largest energy user in the building materials industry and will probably remain so for quite some time. By closing the gap between the large enterprises and the rural enterprises alone, the brick industry will be able to save about 18 Mtce per year at present production.[18] The cost of such efforts is expected to be moderate since all technical expertise is domestically available.

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[18] About 99% of present brick output is produced at 150 kgce/1000-piece, 40 kgce more than the key enterprises' level. Potential for energy savings by closing the gap at present production level = 450 billion pieces x 99% x 40 kgce/1000-piece = 17.8 Mtce.

Chapter 6

The Lime Manufacturing Sector

Lime manufacturing is a simple process in which quarried limestone pieces are fired under temperatures around 1000 °C for calcination. Kilns with similar structure to that of vertical cement kilns, either manually operated or mechanized, are used in China.

Because lime is a cheap substitute for cement in building construction, China is probably the only country in the world that has massive lime production. According to the 1989 SBBMI survey, more than 5000 enterprises produced a total of 110 million ton lime. In 1990, lime production decreased to 94 million tons because of nation-wide construction retrenchmment. Total energy consumption in lime manufacturing was 13 Mtce in 1990, the third largest among building materials industries after cement and brick production. Coal is the exclusive firing fuel, while a small amount of electricity is also used in the operation of mechanized kilns and for driving fans and milling machines. In 1989, energy costs were about 51%—probably the highest among all manufacturing industries—of the production cost of lime.

Lime production is another industry in which rural enterprises have the lion's share, contributing about 85% of the output. The majority of existing lime kilns are manually operated vertical kilns. According to a survey of 173 factories (including a total of 801 lime kilns), fuel intensity varies greatly among different types of kilns, as well as within the same type of kilns. Manually operated kilns have an average fuel intensity of 183 kgce/ton-lime and the lowest fuel intensity achieved is 138 kgce/ton-lime. On the other hand, mechanized kilns average 134 kgce/ton-lime and can reach a fuel intensity as low as 100 kgce/ton-lime. The average fuel intensity of the industry is estimated at 182 kgce/ton-lime [SBBMI, 1991]. It is clear that mechanization could bring significant energy-efficiency improvements to lime manufacturing. Improved control of operations and better productivity are major contributing factors to better fuel efficiency in mechanized kilns.

Various conservation measures have been practiced in the past. Except for converting manually operated kilns, other measures are of the basic housekeeping type, which demands skill, experience, and patience. Such measures include optimizing the size-mix of limestone;[18] optimizing the coal/limestone ratio for better firing efficiency; increasing air flow; improving fuel-feeding techniques; stablizing the temperature zones (preheating, calcination, and cooling) in the kiln; optimizing kiln size (proper kiln height and preheating volume for better waste heat utilization); insulation; as well as utilizing coal with a low heating value [Yuan, 1992].

The recent construction boom is once again sure to push up the demand for lime. Since lime manufacturing is much less organized than cement manufacturing, orchestrated efforts for energy conservation will be difficult. Furthermore, since the industry has already been largely regulated by the market (85% output from rural enterprises), we would not expect a large impact on energy efficiency from the proposed coal price deregulation. Converting manual kilns to mechanized ones is the most effective way of improving energy efficiency, but it is a financial burden for a industry that has a slim profit margin. Extensive government support is probably needed for such a conservation effort. In the long run, as less lime is used in favor of cement, we may expect a gradual consolidation of lime manufacturing toward bigger scale modern plants.

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[18]This operational procedure requires careful feeding in order to distribute the larger size limestone in the middle of the kiln and the smaller size limestone arond the edge. Such practice enhances heat convection and increases lime yield.

Chapter 7

Conclusions and Policy Recommendations

The Chinese building materials industry experienced unprecedented growth in the 1980s and appears heading for another boom period. The massive production scale of the industry and its high dependency on direct coal burning for energy make it a prime target for energy conservation and pollution controls.

Capital shortages and demand pressure, especially in cement, brick, and lime manufacturing, have contributed to the tremendous growth of inefficient small enterprises that produce low-quality products in the building materials industry. The government has been actively promoting energy efficiency. Energy intensities of major products have had various levels of reduction in the 1980s. But limited investments and tolerant regulations have not been able to change the industry's backwardness, inefficiency, and polluting.

Facing the pressures of renewed demand and tightened efficiency and environmental standards, the industry has difficult tasks ahead in both expansion and renovation. Of all problems, capital shortage is considered the greatest challenge for the industry. In light of what occurred in the 1980s, without sufficient funding, fundamental improvements in production technology, energy efficiency, and pollution control are unlikely to occur during the last years of the remaining century.

Low-cost conservation opportunities abound in the Chinese building materials industry. Most of such conservation measures apply to domestic technologies such as vertical cement kilns, annular brick kilns, and vertical lime kilns. Conservation technologies for these facilities are considered most important for the industry in the short to medium term, since large-scale modern facilities are unlikely to become the main-stream production technologies in the near future.

From experiences with energy conservation in the building materials industry, we consider that future efforts should be directed to the following areas:

- Technical Training. Given facility and equipment, energy efficiency is very much in the hands and minds of factory operators. The skills of workers have proven to be a very important factor in energy efficiency. Since the building materials industry requires extensive fuel and material handling, skillful furnace or kiln operators make a difference in product energy intensity. In addition, knowledgeable technicians and managers can help to identify system problems promptly and prevent inefficient practices. Technical training is especially important for the Chinese building industry, which mainly consists of unsophisticated small plants, many of them in rural settings.

- Financial Incentive, Efficiency Standards and Environmental Regulations. We combine these three elements because we feel that they need to be related. Renovation investment and financial incentives should be used for two purposes: (1) to improve the conditions of inefficient and polluting plants, and (2) to expand the production of efficient and least polluting plants. Government financial support in the renovation projects has been focusing on purpose number one. Much is being said now about whether the low efficiency plants are worth helping. Permanently closing them may benefit society more. The second option is certainly worthwhile because it takes full advantage of the expertise in energy and production management of the existing plants. Such performance-oriented funding criteria send positive feedback to enterprises and encourage the best to do better.

- Research and Development. Facing serious capital shortages, the building materials industry must rely on domestic technologies to achieve its expansion and renovation goals. The 1980s have shown that domestically developed technologies could save a great amount of money compared to similar imported technologies. The government should support not only the development of systematic conservation technologies for present

mainstream domestic production facilities but also the transfer of advanced foreign technologies. Large-scale precalciner-kiln cement production and float-process flat glass production are the two most important building material technologies that China needs to master during the rest of the century.

• Product Diversification and Quality Control. The building materials industry affects energy demand and the environment not only because it is a heavy energy user but also because its products have important impacts on energy use in buildings. In both aspects, the present Chinese building materials industry is doing poorly. The industry needs to consider investing in energy-efficient products, such as low-E windows, and various insulation materials.

As we have seen, promoting energy efficiency and product quality in the Chinese building materials industry deserves great attention, not only because of its scale of energy use and pollution generation, but also because of the difficulties of making progress in an industry that contains so many small enterprises.

Finally we want to emphasize the need for more critical and aggressive approaches to restructuring the building materials industry, especially the cement sector. Retrofitting particularly out-of-date production capacities and promoting marginal energy-conservation projects can be a waste of resources while more major changes or plant closure may be more appropriate. Financial and technological assistance from the industrialized countries is very important in this regard. The modernization of the largest building materials industry in the world is sure to benefit the global society.

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