The Building Materials Industry in China:
An Overview

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mainstream domestic production facilities but also the transfer of advanced foreign technologies. Large-scale precalcerine-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 Retrofitting particularly out-of-date production capacities and promoting marginal energy-conservation projects can be a waste of resources while more major changes or plant closure may be more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.

Chapter 1

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 buildup 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. 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 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
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
net total profits—mostly profits from increased
clay 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
sectors and the demand for energy and
building materials. Chapter 3 describes the
energy efficiency issues faced by the cement
industry. Chapter 4 provides a detailed
overview of the cement manufacturing sector
and discusses its energy use and efficiency.

Chapter 5 and 6 discuss the efficiency in brick
and lime manufacturing. These two chapters
cover similar patterns of discussion as in Chapter 4.
Chapter 7 concludes this study with policy
suggestions for promoting energy conservation in
the cement-manufacturing sector.

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 ton = 7 million kcal).

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 pollution.

Facing the pressures of renewed demand and
tightened efficiency and environmental
standards, the industry has faced a daunting
challenge. 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,
assorted 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 clean 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
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. For Chinese industry as a whole, respective energy-use shares are 58%, 8%, 3%, and 27% [SSB, 1992].

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 build up of production from 1980 to 1990. Unfortunately, in many cases such a tremendous expansion of production was achieved without sound technologies and economics 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 disproportionately 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.

¹A 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 130 Mtce energy was consumed in the building materials industry in 1990.
²In this report, electricity is converted into its fossil fuel replacement value, which was about 11.7 MWh/KWh in 1990.
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 SSBMI 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 rectrenchment. 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 80 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 (SSBMI, 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, optimizing the coal/limestone ratio for better firing efficiency; increasing air flow; improving fuel-feeding techniques; stabilizing 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 an 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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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 SSBMI 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. 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 cement 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 SSBMI 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.

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1 Source: SSBMI.
Table 2-2. Size Distribution of Cement Plants in China, 1989

<table>
<thead>
<tr>
<th>Total Output (Mton)</th>
<th>Number of Plants</th>
<th>Average Prod./Year (Thousand Tons/Plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key plants</td>
<td>36</td>
<td>65</td>
</tr>
<tr>
<td>Local plants</td>
<td>130</td>
<td>2200</td>
</tr>
<tr>
<td>Rural plants</td>
<td>43</td>
<td>2500</td>
</tr>
</tbody>
</table>

Source: SBMCI

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 30 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% of the cement output (SBMCI, 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 (SBMCI, 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 kgc/ton-clinker and for key wet-process plants, about 205 kgc/ton-clinker (SBB, 1992). The fuel intensity of vertical kilns spans a wide range, from 110 to more than 220 kgc/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 kgc/ton-clinker. The industry-wide weighted fuel intensity was about 180 kgc/ton-clinker (estimate, Table 3-6). In U.S. plants in 1985, average kiln fuel use per ton of clinker was about 137 kgc/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 kgc/ton-clinker in the late 1980s (Nakajima, 1990).

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

Energy efficiency of brick making is considered very poor. While the large brick enterprises (using tunnel kilns) can manufacture bricks at a fuel intensity of about 110 kgc/1000-piece, smaller local or rural enterprises usually have a fuel intensity of about 150 kgc/1000-piece. Primitive kilns can have fuel intensities as high as 200-400 kgc/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 kgc/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 this potential 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 SO₂ source after the thermal power industry, accounting for 10% of the total emissions. N₂O emissions are also high because cement, lime, brick, and tile production all require high-temperature pyroprocessing. 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 CO₂ emissions reductions. Cement and lime production also generate additional CO₂ emissions because calcining 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

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

In order to acquire advanced flat glass manufacturing technologies, in the 1980s China participated in two 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 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 6.5 Mtoe/year in energy-saving capacity, 60 MW electricity capacity (co-generation through waste-heat boilers), and 8.7 Mtoe/year of newly increased cement production capacity [SBBMI, 1991]. Investments from local governments and enterprises are considered to

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 continue increasing. 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 Mtoe per year at present production.¹⁸ The cost of such efforts is expected to be moderate since all technical expertise is domestically available.

¹⁸ About 90% 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 = 455 billion pieces x 95% x 40 kgce/1000-piece = 17.8 Mtoe.
Serious destruction of farmland 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 kiln 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 200-600 kgce/1000-piece [Tao, 1983].

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 25-36% 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 not yet widespread in China. The reason is that quality standards and technical difficulties for hollow 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. A lack 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 [Qu, 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:

- Kilns 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 burn at least three times as much as that of central government lands.

Based on experiences in the 1980s, the SBBMI has formulated 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 million/year, save 430,000 tons of 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, where free-wheeling local and private economies expand. Economic incentives for energy conservation may also be weakened when strict demand pushes up product prices and allows marginal plants to survive. It is our concern that the Chinese building materials industry may take an
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.\textsuperscript{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 Mte in 1990,\textsuperscript{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 450, 43, and 5 million pieces per year respectively. The rural enterprises contribute about 64% 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.

\textsuperscript{16} Drying bricks in a separate dryer is found to be more efficient than in the baking kiln.

\textsuperscript{17} The brick plants also manufacture a small amount of roofing tiles. This energy-use figure may include both brick and tile production.
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 kJ/kg/case, according to the output and energy data in 1989, while the equivalent U.S. figure was about 30 kJ/kg/case in 1985. This efficiency gap indicates a conservation potential of about 1 MTCal/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 kJ/kg/case in 1980 to 36 kJ/kg/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 kJ/kg/case because of the relative decline in average furnace size in this category. The lowest fuel intensity achieved is about 25 kJ/kg/case, a figure still higher than the mid-1980s average of 53% level of 22 kJ/kg/case and the average Japanese level of 18 kJ/kg/case. These domestic or international efficiency gaps indicate significant conservation potential.

Furnace size is the most important factor influencing fuel intensity. Larger furnaces not only lose less unit radiant 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 tons/day. Among the 21 float-process lines built in the 1980s, seven have furnaces with a melting capacity of 400-700 tons/day; others are in the range of 200-300 tons/day. The most inefficient small factories, which use furnaces below 100 tons/day (average fuel intensity at about 90 kJ/kg/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 tons/day and is far below the common sizes (more than 500 tons/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 loss) but also shortens the life of furnaces. 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 interior 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 interior 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 lining. 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 temperatures, using fuel economizer boost techniques (such as the installation of hoppers in the bottom of melter 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 flat-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 the production of energy-efficient goods. To diversify the industry, new product technologies, such as low-E windows, that improve the end user's energy efficiency as well, should be introduced.

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 1980 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 (SBR, 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 (BEC, 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 material markets. Long-distance transportation of cement is considered inappropiate, but shipping by water can be economically efficient. A classic example of a product with low value/weight ratio. Cement exports from China have increased rapidly in recent years, rising from 40 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 precleaner 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 63% in 1989 from 6% in 1980. The importance of small cement plants is expected to decline in the long run, but the recent revival of the industry 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 5341 units in 1990. The number of more expensive rotary kilns increased from 305 units to 671 units in the same period (Energy Efficiency Handbook of China, 1991). By importing equipment and technologies, the cement industry put 16 precleaner production lines (a flow of cement domestically manufactured) into operation in the 1980s. But these modern units only produce about 5% of the total output. Figure 3-1 depicts the Chinese cement production structure in 1990 by the type of kiln employed.
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, 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 66% of the energy used, while raw materials preparation, glass formation, and finishing each account for 18%, 12%, and 2% respectively [Habcock, et al., 1988]. The Chinese factories use significantly higher shares of energy for melting and refining—40% 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) [SBMBM, 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 go 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 Mtoe, a very small figure compared with the amounts used for cement, brick, or lime manufacturing [SBMBM, 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 980 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 improved, but the variety of products is still limited. The bulk of the output (about 60%) is used for 3.1.2 ENERGY CONSUMPTION TRENDS

Cement manufacturing consumed about 41 Mtoe 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 [SBMBM, 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 scarce for the most important part of the industry: the small kiln sector.
<table>
<thead>
<tr>
<th>Year</th>
<th>Cement Output (Mt)</th>
<th>Technology Mix (a)</th>
<th>Fuel Intensity (b)</th>
<th>Fuel Demand (c)</th>
<th>Capital Cost (d) (£Mil 1990)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>370</td>
<td>71% VK 01, 23% PK</td>
<td>180</td>
<td>2.2</td>
<td>32</td>
</tr>
<tr>
<td>1995</td>
<td>450</td>
<td>51% VK 01, 49% PK</td>
<td>160</td>
<td>2.6</td>
<td>60</td>
</tr>
<tr>
<td>Scenario I</td>
<td>450</td>
<td>77% VK, 15% PK</td>
<td>126</td>
<td>3.7</td>
<td>82</td>
</tr>
<tr>
<td>Scenario II</td>
<td>450</td>
<td>52% VK, 24% PK</td>
<td>124</td>
<td>4.6</td>
<td>106</td>
</tr>
</tbody>
</table>

(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/kilns=1.2).
(d) Investment requirements for achieving the production goal with different mixes of technologies.
(e) But 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% unused vertical kilns. In Scenarios I and II, all vertical kilns are the advanced type.

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. 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 [Venkateswarao and Lott, 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 other hand, rotates slowly to achieve an involuntary flow of materials and the required temperature.

2Formerly, 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.
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 preceramic kilns gaining 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, 1982]. 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 gross 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 150 kgce/ton-clinker, instead of the figures given in the two scenarios. Compared with the business-as-usual case, the reduced fuel-saving capacity is estimated at 12 billion Mtoe/year in Scenario I and Scenario II respectively. Saved one-time front capital investment in coal supply would thus be $1.1 billion in Scenario I and $1.2 billion in Scenario II. 3 Table 3-6 summarizes the general results of our scenarios.

3 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- and dry-process kilns to modern precancer 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 1.62 Mtoe 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 Venketaswaran and Lovitt [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 [Venketaswaran and Lovitt, 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.

3 Capital cost of bringing one ton coal into market in 1990 is estimated to be $700 per ton-coal. The saved capital investment in coal supply is equal to saved coal capacity times unit cost of coal supply.

### 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 must be higher due to losses. For example, the key elements 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>
<thead>
<tr>
<th>Requirement</th>
<th>MJ/ton-clinker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating raw materials from 20 to 450°C</td>
<td>639.2</td>
</tr>
<tr>
<td>Dehydration of clay materials at 450°C</td>
<td>150.6</td>
</tr>
<tr>
<td>Heating materials from 450 to 900°C</td>
<td>1786.0</td>
</tr>
<tr>
<td>Dissociation of CaO at 900°C</td>
<td>735.2</td>
</tr>
<tr>
<td>Heating calcined feed from 900 to 1400°C</td>
<td>470.0</td>
</tr>
<tr>
<td>Netz heat of heat</td>
<td>94.9</td>
</tr>
<tr>
<td>Sintered</td>
<td>3022.8</td>
</tr>
<tr>
<td>Clinker clinker</td>
<td>3176.8</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>1990 Base Year</th>
<th>Renovation</th>
<th>2000 Scenario I New Plants</th>
<th>Baseline†</th>
<th>Renovation</th>
<th>2000 Scenario I New Plants</th>
<th>Baseline†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement Output (Mt)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manual vertical kilns</td>
<td>21 (250)†</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mechanical vertical kilns</td>
<td>126 (185)</td>
<td>61 (46)</td>
<td>143</td>
<td>300 (125)</td>
<td>61</td>
<td>48</td>
<td>230 (125)</td>
</tr>
<tr>
<td>Wet-process kilns</td>
<td>22 (109)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lepid kilns</td>
<td>5 (160)</td>
<td>1</td>
<td>0</td>
<td>6 (330)</td>
<td>1</td>
<td>0</td>
<td>6 (330)</td>
</tr>
<tr>
<td>Shaft-preheater kilns</td>
<td>4 (180)</td>
<td>2</td>
<td>0</td>
<td>6 (145)</td>
<td>2</td>
<td>0</td>
<td>6 (145)</td>
</tr>
<tr>
<td>Cylindro-preheater kilns</td>
<td>5 (130)</td>
<td>49 (b)</td>
<td>45 (135)</td>
<td>45 (135)</td>
<td>40</td>
<td>45 (135)</td>
<td></td>
</tr>
<tr>
<td>Other dry-process kilns</td>
<td>15 (220)</td>
<td>0</td>
<td>0</td>
<td>5 (185)</td>
<td>0</td>
<td>5 (185)</td>
<td></td>
</tr>
<tr>
<td>Preheater kilns</td>
<td>10 (130)</td>
<td>0</td>
<td>48</td>
<td>50 (115)</td>
<td>0</td>
<td>143</td>
<td>155 (115)</td>
</tr>
<tr>
<td>Subtotal</td>
<td></td>
<td>146</td>
<td>46</td>
<td>300 (115)</td>
<td>0</td>
<td>143</td>
<td>155 (115)</td>
</tr>
<tr>
<td>Gross Cost (Rmb)</td>
<td>450</td>
<td>450</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manual vertical kilns</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mechanical vertical kilns</td>
<td>24 (60)</td>
<td>16</td>
<td>50</td>
<td>14</td>
<td>12</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Wet-process kilns</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lepid kilns</td>
<td></td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Shaft-preheater kilns</td>
<td></td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Cylindro-preheater kilns</td>
<td>6 (90)</td>
<td>60</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Other dry-process kilns</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Preheater kilns</td>
<td></td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>72</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td></td>
<td>82</td>
<td>106</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Incremental production cost for renovation; Non-plan new plants, unless noted.

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 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. Much of the equipment needed to make the cement industry more efficient and less polluting is 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 projects. 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 government 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 factor. 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.
manage than a rotating shaft. The predetermined mix of fuel and raw materials in the vertical kilns 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 tons/criner are already considered to be productive. The most productive vertical kilns in China have an annual capacity of about 100,000 tons/criner, which is one tenth the capacity of a typical precalcer kiln.

Compared with the most efficient mechanized kilns (with a fuel intensity of 110 kgce/ton-cliner), 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-criner)

<table>
<thead>
<tr>
<th>Kiln Process</th>
<th>Group A (7 units)</th>
<th>Group B (19 units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drying heat consumption</td>
<td>627.5</td>
<td>615.5</td>
</tr>
<tr>
<td>Heat loss via tail gases</td>
<td>417.9</td>
<td>230.3</td>
</tr>
<tr>
<td>Heat loss due to chemically incomplete combustion</td>
<td>1210.5</td>
<td>784.4</td>
</tr>
<tr>
<td>Heat loss due to physically incomplete combustion</td>
<td>224.6</td>
<td>19.6</td>
</tr>
<tr>
<td>Waste heat in clinker</td>
<td>171.7</td>
<td>163.3</td>
</tr>
<tr>
<td>Radiation heat loss</td>
<td>26.1</td>
<td>16.7</td>
</tr>
<tr>
<td>Clinker formation heat loss</td>
<td>1711.1</td>
<td>1729.2</td>
</tr>
<tr>
<td>Other heat loss</td>
<td>86.5</td>
<td>142.4</td>
</tr>
<tr>
<td>Total heat balance</td>
<td>4559.9</td>
<td>3971.4</td>
</tr>
</tbody>
</table>

Source: SBMBI, 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 burner capacity and linkage 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 CO2 and generates CO.

Incomplete combustion relates to uncombusted residual fuel in the pyroprocess. Poor pellet quality and operation practice. 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 pyroprocesses, 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 shell that rotates around an axis inclined about 2° from the vertical center. The feed materials move slowly downward inside the rotating kiln to meet with countercurrent flames fired by a gas 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 evaporator compartments to facilitate heat transfer.

3.4 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 1990s, it was concluded that the existing facilities will have the following results (data obtained from SBMBI, for special cases, see discussions in Section 3.3.3):

- Comprehensive measures for mechanized VK capacity must achieve 30% over the pre-renovation level; fuel intensity decreases from 165 to 125 kgce/ton-cliner; 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-cliner). 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 cyclones preheater case). Capacity increases 80% over the pre-renovation level; fuel intensity decreases from 140 to 125 kgce/ton-cliner; gross capital investment is $85 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-cliner; gross capital investment is $100 per ton of newly increased cement capacity, or $652 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 140 to 125 kgce/ton-cliner; gross capital investment is $170 per ton of pre-renovation cement capacity, or $130 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 SBMBI estimates, new PK plants require an investment of about $600/ton-cliner in 1990 prices, or about $500/ton-cement at present cement market rates. 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 VK plants will achieve a fuel intensity of 115 kgce/ton-cliner and new VK plants will achieve a fuel intensity of 125 kgce/ton-cliner. Table 3-5 gives a full description of these scenarios.
Rejuvenation 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 grinding machines used in the process but the more efficient roller mills could save about 20-30% electricity. Introducing high-efficiency classifiers can also reduce electricity consumption. For example, the O-SEPFA 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 Xiniujing 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 kW consumption 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 raw materials and clinker 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 varied with 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 the cement processes used in China. Compared to vertical kilns, roller kilns are much more efficient in terms of producing incomplete combustion because of the direct burning of powdered coal.

Table 3-3: Heat Balance of Typical Wet Processes

<table>
<thead>
<tr>
<th>Kiln Type</th>
<th>Exposition heat consumption</th>
<th>Heat loss via tail gases</th>
<th>Radiation heat loss</th>
<th>Heat loss due to inreception</th>
<th>Combustion heat consumption</th>
<th>Waste heat in kiln</th>
<th>Subtotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry-clinker</td>
<td>1897 - 2370</td>
<td>921 - 1230</td>
<td>586 - 921</td>
<td>144 - 251</td>
<td>1630 - 1842</td>
<td>377 - 416</td>
<td>5412 - 6866</td>
</tr>
<tr>
<td>Wet-clinker</td>
<td>190 - 234</td>
<td>190 - 234</td>
<td>190 - 234</td>
<td>190 - 234</td>
<td>190 - 234</td>
<td>190 - 234</td>
<td>190 - 234</td>
</tr>
</tbody>
</table>

Source: Lin and Li, 1999

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 15 m and produces 580 ton-clinker/day. By converting it into a 3.5 x 8 m cyclone preheating dry-process kiln, production capacity could be increased to 1500 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 losses 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 producing incomplete combustion because of the direct burning of powdered coal.

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. Production of about 205 kgs of cement per kiln in 1990, compared to about 200 kgs of clinker of U.S. wet-process plants in the mid-1980s (SSB, 1991; Venkataprasan 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 basic 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, and fuel savings may not be substantial if waste heat is not recovered. Tar 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 kilns 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 [Venkataprasan 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 (cyclones).

The grate-type preheater is related to the Lepid process, which uses pelletized raw materials. Pellets are preheated on a traveling grate before entering the kiln. In China, the Lepid 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 Lepid-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 multiple cyclones and dryer 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 kgcement/ton-clinker in 1990, comparable to the fuel intensity of U.S. preheater plants of the mid-1980s (Chen, 1992; Venkateswaran and Lovitt, 1988). Kaiser Cement, one of the most advanced cement plants in North America, has achieved a fuel intensity of 104 kgcement/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 (655,000 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 Jiangsu 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 kgcement/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**

<table>
<thead>
<tr>
<th>Kiln Size</th>
<th>Plant A</th>
<th>Plant B</th>
</tr>
</thead>
<tbody>
<tr>
<td>(China)</td>
<td>(Japan)</td>
<td>(Japan)</td>
</tr>
<tr>
<td>Kiln size (ton-clinker/day)</td>
<td>4,160</td>
<td>4,760</td>
</tr>
<tr>
<td>Kiln capacity (ton-clinker/day)</td>
<td>2092</td>
<td>2250</td>
</tr>
<tr>
<td>Clinker formation heat consumption (MWh)</td>
<td>1737</td>
<td>1722</td>
</tr>
<tr>
<td>Heat loss in preheater gasses (MWh)</td>
<td>1023</td>
<td>692</td>
</tr>
<tr>
<td>Heat loss in exhaust gasses (MWh)</td>
<td>490</td>
<td>533</td>
</tr>
<tr>
<td>Radiation heat loss (MWh)</td>
<td>468</td>
<td>324</td>
</tr>
<tr>
<td>Waste heat to clinker (MWh)</td>
<td>87</td>
<td>123</td>
</tr>
<tr>
<td>Total heat consumption (MWh)</td>
<td>3783 (129 kgcement)</td>
<td>3496 (116 kgcement)</td>
</tr>
</tbody>
</table>

Sources: Fu, 1990.

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 kgcement/ton-clinker in 1985 (Venkateswaran and Lovitt, 1988). Kaiser Cement, one of the most advanced cement plants in North America, has achieved a fuel intensity of 104 kgcement/ton-clinker for a kiln that produces about 4500 ton-clinker/day (data from Mark McKenna, Kaiser Cement, Cupertino, CA).

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 kgcement/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.

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 (somewhere 800°C), fuel intensities of these kilns are often as high as 260 kgcement/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 kgcement/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 16 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 kgcement/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 precalencer, 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

<table>
<thead>
<tr>
<th>Pre-removal</th>
<th>kiln capacity</th>
<th>fuel intensity</th>
<th>electricity intensity</th>
<th>capital cost</th>
<th>total investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-removal</td>
<td>kiln capacity</td>
<td>fuel intensity</td>
<td>electricity intensity</td>
<td>capital cost</td>
<td>total investment</td>
</tr>
</tbody>
</table>

Example 4

<table>
<thead>
<tr>
<th>Pre-removal</th>
<th>kiln capacity</th>
<th>fuel intensity</th>
<th>electricity intensity</th>
<th>capital cost</th>
<th>total investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-removal</td>
<td>kiln capacity</td>
<td>fuel intensity</td>
<td>electricity intensity</td>
<td>capital cost</td>
<td>total investment</td>
</tr>
</tbody>
</table>

Table 3-4 shows the heat balance of selected precalciner kilns in China and Japan. The data are presented for comparison.

**Source:** Fu, 1990.
Example 2

<table>
<thead>
<tr>
<th>Process</th>
<th>Kiln Capacity</th>
<th>Fuel Intensity</th>
<th>Electricity Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-reduction</td>
<td>180,000 t/annum</td>
<td>214 kg/ton-clinker</td>
<td>104 kWh/ton-clinker</td>
</tr>
</tbody>
</table>

Example 3

<table>
<thead>
<tr>
<th>Process</th>
<th>Kiln Capacity</th>
<th>Fuel Intensity</th>
<th>Electricity Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-reduction</td>
<td>174,000 t/annum</td>
<td>299 kg/ton-clinker</td>
<td>100 kW/ton-clinker</td>
</tr>
</tbody>
</table>

At original capacity:

- Total Investment: $30 million (1990 prices)
- At original capacity:
  - Coal savings: 180,000 t/annum
  - Increased electricity use: 180,000 t/annum
  - Increased clinker production: 75,000 t/annum

SPT = $30 million / 75,000 t/annum = 0.40 t/annum

(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 redeveloping the building of a plant, the cost is the highest among the three measures. Example 3 is a summary of such a project [Cheng, 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 increase. Converting the 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 studies are needed for a better evaluation of such projects. The reason that the Chinese cement industry choose such conversion projects is very practical, such as a capital commitment for new plants is often not available and increasing capacity through conversions can save money. Retrofitting 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.

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 over-supply 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 factor for their lower radiation heat loss.

There are 17 dry-process kiln plants in China, with an average fuel intensity of 164 kg/ton-clinker in 1990. For the good efficiency of the Jingdong 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 kg/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.

Renovation of Lepol Kilns

The 16 Lepol kilns in the industry are among the largest 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-aideing mineral additives, preheater retrofits (reducing bunker breakdown), increasing the heat-transfer efficiency, firing gun retrofit, air leakage plugging, cooling system retrofit and waste heat recovery, and computer control of pyroprocessing. The demonstration project in Shaan Duan Cement Plant was able to reduce the fuel intensity from 160 kg/ton-clinker to 130 kg/ton-clinker and increase clinker production capacity by 16% with a capital investment of about $125/ton-clinker at original capacity (1990 prices) [SSBMMI data, 1992]. The impact on electricity intensity is not known. Example 4 is an imagined project based on the above observations, indicating possible results of such renovations.

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 kg/ton-clinker, with an average fuel intensity of 165 kg/ton-clinker indicating 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 hot losses arise from chemically incomplete combustion and high-temperature gas tails. Evaporating (drying) feed materials also consumes a significant amount of heat. Removal of the mechanized vertical-kiln plants is considered an overall retrofit that will not only increase energy efficiency and cement quality but also improve air-pollution controls.

Electricity use in finish grinding usually comprises about 10% of the total energy use in cement production. On a worldwide basis, about 40 kW are used to grind each ton of clinker [Venkataraman 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 kW 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 plants 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.
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 of such renovation projects. Adopted measures include numbers 1, 3, 4, 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 tons clinker/year
- Fuel intensity: 152 kgce/ton-clinker
- Electricity intensity: 87 kWh/ton-cement

Post-renovation condition:
- Kiln capacity: 103,000 tons clinker/year
- Fuel intensity: 116 kgce/ton-clinker
- Electricity intensity: 75 kWh/ton-cement

Total investment: 17 million (9000 points)

Cost of new capacity (mechanized vertical kiln):
- Investment: $300,000/ton-clinker (1990 price)

A-related raw plant investment:
- $1,000,000/ton-clinker (88,000 tons/yr) + 300 + 72 x 10^6 + 2.5 million

Energy savings at original capacity:
Coal = 42 x 84, 000 x 72 x 0.0001 / 3600 x 0.8 x 0.80
Electricity

Considering profits from additional sales of cement ($42,000/ton) and cost savings from energy conservation ($1,500/ton), the simple payback time (SPT) of this project is

SPT = $271 x 10^6 / ($1,500 x 0.8 + $40,000 x 0.80 x 0.80

Renovating vertical kilns is usually justified in a straight economic sense because of the short payback period and its high economic returns. This project is an example of how the cost has been reduced.

This is perhaps one of the best performances in cement industries. On the average, retrofit projects like this yield a positive net return on investment. Since economic benefits from increased cement production usually make up a 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 investments involved in such projects in order to utilize limited energy-conservation funds more 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 automated 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 tons cement/year and convert others to high-efficiency mechanized kilns, i.e., with fuel intensities of 125 kgce/ton-clinker. This kind of project is simple in nature and the removal of mechanized kilns and also helps its capital recovery on newly increased production capacity. Electricity intensity tends to increase after the conversion because of the decreased cement production and the strong demand for cement in the last ten years have, to some extent, hindered this process. Strictly regulated 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 with fuel intensities of around 210 kgce/ton-clinker. Renovations of wet-process plants in the 1980s usually fall into three categories: comprehensive retrofit projects (keeping the wet process), semi-dry-process conversions, and dry-process conversions.

(1) Comprehensive Retrofits: Measures include the installation of heat-resistant steel lining (enhancing evaporation efficiency) and high-quality refractory lining; improving insulation and plugging leaks; retrofitting fuel injectors 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% reduction in fuel consumption with capital investment of about 30% per ton-clinker at original capacity. It is not known whether electricity intensity is affected. Increased production capacity from such measures is small, usually about 5%–8% (Cheng, 1992). The following is an example showing the possible results of such a comprehensive retrofit (information about any real case is not available):

Example 1

Pre-renovation:
- Kiln capacity: 200,000 tons clinker/year
- Fuel intensity: 210 kgce/ton-clinker
- Electricity intensity: 105 kWh/ton-cement

Post-renovation:
- Kiln capacity: 200,000 tons clinker/year
- Fuel intensity: 170 kgce/ton-clinker
- Electricity intensity: to be changed

Total investment: 17 million (9000 points/ton-clinker at original capacity)

Energy savings in original capacity:
- Coal 40 x 100,000 x 0.80 = 6400 tons/year
- Electricity

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 is the conversion 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 hump raw materials are then put into a drying and crushing process and are eventually fed into the dry-process plant. The demonstration project of this kind in Bao Ma Shan Cement Plant has the following conditions and results (Chao, 1992):

This is the current practice in the cement industry.
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 of such renovation projects. Adopted measures include numbers 3, 4, 5, and 7 (listed above) and the addition of an automated gridding-control system for raw materials (Cheng, 1992).

<table>
<thead>
<tr>
<th>Pre-renovation condition</th>
<th>Post-renovation condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kiln capacity</td>
<td>88,000 tons clay/year</td>
</tr>
<tr>
<td>Fuel intensity</td>
<td>152 kg/ton-clinker</td>
</tr>
<tr>
<td>Electricity intensity</td>
<td>67.4 kWh/ton-clinker</td>
</tr>
<tr>
<td>Post-renovation condition</td>
<td></td>
</tr>
<tr>
<td>Kiln capacity</td>
<td>103,000 tons clay/year</td>
</tr>
<tr>
<td>Fuel intensity</td>
<td>116 kg/ton-clinker</td>
</tr>
<tr>
<td>Electricity intensity</td>
<td>75 kWh/ton-clinker</td>
</tr>
</tbody>
</table>

Total investment: $7 million (9000 points)

Cost of new capacity (mechanized kiln): $35 million (non-clinker)

Rewilded raw plant investment: $105,000 (98,000), 90,000, 70,000, 60,000, 50,000, 40,000, 30,000, 20,000, 10,000, 0

Energy savings at original capacity: Coal = 428.8 + 425.8 + 425.8 + 425.8 + 425.8 + 425.8 + 425.8 + 425.8 + 425.8 + 425.8

Electricity = 425.8 + 425.8 + 425.8 + 425.8 + 425.8 + 425.8 + 425.8 + 425.8 + 425.8 + 425.8

Considering profits from additional sales of cement ($450/ton) and cost savings from energy conservation ($120/ton for coal, $205/ton for electricity), the simple payback time (SPT) of this project is SPT = S/0.15 + 3/0.15 + 2/0.15 + 1/0 = 2 years.

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 tons cement/year and convert others to high-efficiency mechanized kilns, i.e., with fuel intensity approaching 125 kg/ton-clinker. This kind of project is simple 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 the decentralized automation 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 fuel intensities of around 210 kg/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 tubes, improvement of 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 ¥50/ton-clinker at original capacity ($190/ton). It is not known whether electricity intensity is affected. Increased production capacity from such measures is small, usually around 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**

<table>
<thead>
<tr>
<th>Pre-renovation</th>
<th>Post-renovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kiln capacity</td>
<td>200,000 tons/year</td>
</tr>
<tr>
<td>Fuel intensity</td>
<td>210 kg/ton-clinker</td>
</tr>
<tr>
<td>Electricity intensity</td>
<td>195 kWh/ton-clinker</td>
</tr>
<tr>
<td>Post-renovation</td>
<td></td>
</tr>
<tr>
<td>Kiln capacity</td>
<td>205,000 tons/year</td>
</tr>
<tr>
<td>Fuel intensity</td>
<td>170 kg/ton-clinker</td>
</tr>
<tr>
<td>Electricity intensity</td>
<td>see above</td>
</tr>
<tr>
<td>Total investment</td>
<td>¥35 million (non-clinker and 9000 points)</td>
</tr>
<tr>
<td>Energy saving at original capacity: Coal = 428.8 + 428.8 + 428.8 + 428.8 + 428.8 + 428.8 + 428.8 + 428.8 + 428.8 + 428.8</td>
<td></td>
</tr>
<tr>
<td>Electricity = 428.8 + 428.8 + 428.8 + 428.8 + 428.8 + 428.8 + 428.8 + 428.8 + 428.8 + 428.8</td>
<td></td>
</tr>
</tbody>
</table>

*This 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 routine of raw material preparation in the wet process but adds a water-extraction device that reduces the water content of the slurry-state to around 18%. The humpy raw materials are then put into a drying and crushing process and are eventually fed into the dry-process plant. This demonstration project of this kind in Badi Shanzhen Cement Plant has the following conditions and results (Chao, 1992):

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.
Example 2

Pre-revaporation
kiln capacity: 180,000 ton clinker/year
fuel intensity: 214 kgs/ton-clinker
electricity intensity: 101 kWh/ton-clinker
Post-revaporation
kiln capacity: 255,000 ton clinker/year
fuel intensity: 143 kgs/ton-clinker
electricity intensity: 123 kWh/ton-clinker
Total Investment: $50 million (1990 prices)

At original capacity:
Coal savings: $180,000 + $8/100,000 = $800,000/year
Increased electricity use: $180,000 + $8/100,000 = $800,000/year
SFT = (30/10) x ($180,000 + $5/100,000) = 0.225 + 0.005 = 0.235

(3) Conversion to Dry Process: This measure is actually an overhaul of the original wet-process plant. The preparatory 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 renewed 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 a substantial investment in a plant, the cost is the highest among the three measures. Example 3 is a summary of such a project [Chen, 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 the 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 studies 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. Rolling out 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-revaporation
kiln capacity: 174,000 ton clinker/year
fuel intensity: 299 kgs/ton-clinker
electricity intensity: 100 kWh/ton-clinker
Post-revaporation
kiln capacity: 315,000 ton clinker/year
fuel intensity: 118 kgs/ton-clinker
electricity intensity: 126 kWh/ton-clinker
Total Investment: $65 million (1990 prices)

At original capacity:
Coal savings: $174,000 + $8/100,000 = $1,267,000/year
Increased electricity use: $174,000 + $8/100,000 = $1,267,000/year
SFT = (30/10) x ($174,000 + $5/100,000) = 0.225 + 0.005 = 0.235

Renaissance 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 are included: pellet quality control, the use of calcination aids and metal additives, preheater retrofit (replacing bronw breakers) for increasing heat-transfer efficiency, firing of retrofit kilns, air leakage plugging, cooling system retrofit and waste heat recovery, and computer control of prepyroprocessing. The demonstration project of Shao Tao 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) [SBMBI data, 1992]. The impact on electricity intensity is not known. Example 4 is an imagined project based on above information.

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 [Chen, 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 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 clinker than the rotary kilns, many of them are inefficient. The fuel intensities of mechanized kilns range from 110 to 125 kgce/ton-clinker, yet 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 gas tails. Evaporating (drying) feed materials also consumes a significant amount of heat. Renovation of the mechanized vertical-kiln plant is considered an overall retrofit that will not only improve energy efficiency and cement quality but also improve air-pollution controls. Such a
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 at the mid-1980s (Chen, 1992; 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).

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 around 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

<table>
<thead>
<tr>
<th>Kiln Size (Kiln Capacity)</th>
<th>Plant A</th>
<th>Plant B</th>
</tr>
</thead>
<tbody>
<tr>
<td>(China)</td>
<td>(Japan)</td>
<td>(Japan)</td>
</tr>
<tr>
<td>Kiln size (kiloton)</td>
<td>4.0</td>
<td>2.4</td>
</tr>
<tr>
<td>Kiln input (kiloton/day)</td>
<td>4.0</td>
<td>2.4</td>
</tr>
<tr>
<td>Kiln capacity (ton/day)</td>
<td>2750</td>
<td>1600</td>
</tr>
<tr>
<td>Klinker formation heat consumption (MJ/ton)</td>
<td>1771</td>
<td>1722</td>
</tr>
<tr>
<td>Heat loss in kiln (MJ/ton)</td>
<td>1023</td>
<td>492</td>
</tr>
<tr>
<td>Heat loss in kiln (MJ/ton)</td>
<td>490</td>
<td>339</td>
</tr>
<tr>
<td>Radiation heat loss (MJ/ton)</td>
<td>62</td>
<td>234</td>
</tr>
<tr>
<td>Waste heat to clinker (%)</td>
<td>86</td>
<td>44</td>
</tr>
<tr>
<td>Total heat consumption (MJ/ton)</td>
<td>3785 (129 kgce/ton)</td>
<td>3460 (116 kgce/ton)</td>
</tr>
</tbody>
</table>

Source: Fu, 1990.

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 cost 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 16 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):
3.1 CEMENT PRODUCTION CAPACITY BY 2000

From 1980 to 1988, increases in cement production and real gross output were linked to 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 the cement 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

<table>
<thead>
<tr>
<th>Process</th>
<th>MJ/Mt-clinker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exergetic heat consumption</td>
<td>1987–2325</td>
</tr>
<tr>
<td>Heat loss via tail gases</td>
<td>921–1130</td>
</tr>
<tr>
<td>Radiative heat loss</td>
<td>586–921</td>
</tr>
<tr>
<td>Heat loss due to incineration</td>
<td>146–251</td>
</tr>
<tr>
<td>Combustion heat consumption</td>
<td>1650–1842</td>
</tr>
<tr>
<td>Waste heat in dryer</td>
<td>377–416</td>
</tr>
<tr>
<td>Subtotal</td>
<td>5612–6866</td>
</tr>
</tbody>
</table>

Source: Li and Li, 1999

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 1650 ton-clinker/day (Chao, 1990).

In the wet process, heat is consumed in the evaporation stage. Radiation heat loss is significant due to the large surface area of the kiln. Heat losses via tail gases is also great compared to that of the vertical-kiln pyroprocess. Table 3-3 reveals that 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.

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 kilns in the U.S. was about 175 kce/t-clinker, while similar processes in China in 1990 had fuel intensities over 200 kce/t-clinker (Venkateswaran and Lowitt, 1985; SSB, 1991). There is clear advantage of the long-dry process over the wet process in the Chinese cement 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 calculating part of the feed materials before the enter the kiln. There are two types of preheater systems: grate-type 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 25% of cement production. The fuel intensity of this process is typically about 160 kce/t-clinker.

The suspension preheater is a system of spray-drying cyclones and dryer 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 calculation of 40-50% of feed and increases production capacity.
manage than a rotating shaft. The predetermed 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 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 tons-clinker are already considered to be productive. The most productive vertical kilns in China have an annual capacity of about 100,000 tons-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)

<table>
<thead>
<tr>
<th>Kiln Process</th>
<th>Group A (7 units)</th>
<th>Group B (19 units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drying heat consumption</td>
<td>627.5</td>
<td>615.5</td>
</tr>
<tr>
<td>Heat loss via tail gas</td>
<td>417.9</td>
<td>230.3</td>
</tr>
<tr>
<td>Heat loss due to chemically incomplete combustion</td>
<td>1210.5</td>
<td>724.4</td>
</tr>
<tr>
<td>Heat loss due to physically incomplete combustion</td>
<td>249.6</td>
<td>39.6</td>
</tr>
<tr>
<td>Waste heat in clinker</td>
<td>171.7</td>
<td>163.3</td>
</tr>
<tr>
<td>Radiation heat loss</td>
<td>28.1</td>
<td>16.7</td>
</tr>
<tr>
<td>Clinker formation heat loss</td>
<td>1711.4</td>
<td>1729.2</td>
</tr>
<tr>
<td>Other heat loss</td>
<td>86.5</td>
<td>144.3</td>
</tr>
<tr>
<td>Total heat balance</td>
<td>4519.9</td>
<td>3971.4</td>
</tr>
</tbody>
</table>

Source: SBMM, 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 inefficient 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 CO2 and generates CO.

Incomplete combustion relates to uncombusted residual fuel in the pyroprocess. Poor pellet quality and operation silence 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 pyroprocesses, 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. The feed materials move slowly downward inside the rotating kiln to meet with countercurrent flames fired by a gas 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 evaporator part of the kiln to facilitate heat transfer.

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 VC capacity will be at the present manual VC 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 55% over the pre-renovation level; fuel intensity decreases from 180 to 145 kgce/ton-clinker, gross capital investment is $70 per ton of pre-renovation cement capacity, or $310 per ton of newly increased cement capacity (in 1990 yuan).

Renoation of shaft-preheater kilns: Capacity increases 35% over the pre-renovation level; fuel intensity decrease from 210 to 145 kgce/ton-clinker, gross capital investment is $70 per ton of pre-renovation cement capacity, or $310 per ton of newly increased cement capacity (in 1990 yuan).

Renoation of other dry-process kilns is usually very expensive and considered not practical. We assume that about 40 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 SBMM estimates, new PK plants require investment of about $600/ton-clinker in 1990 prices, or about $900/ton-clinker at present prices. We assume that new advanced VK plants require half that amount as gross investment, i.e., $250/ton-clinker at 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 3-2 gives a full description of these scenarios.
Table 3-5. Cement Production Structure in 2000 and Estimated Gross Incremental Costs (over 1990 Output)

<table>
<thead>
<tr>
<th>Year</th>
<th>1990 Base Year</th>
<th>Renovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement Output (Mt)</td>
<td>23 (25)††</td>
<td>0</td>
</tr>
<tr>
<td>2000 Scenario I</td>
<td>New Plants</td>
<td>Sideout</td>
</tr>
<tr>
<td>2000 Scenario II</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Kiln Type</th>
<th>New Plants</th>
<th>Sideout</th>
<th>Renovation</th>
<th>New Plants</th>
<th>Sideout</th>
<th>Renovation</th>
<th>New Plants</th>
<th>Sideout</th>
<th>Renovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual vertical kilns</td>
<td>126 (165)</td>
<td>41 (4)</td>
<td>143</td>
<td>530 (625)</td>
<td>61</td>
<td>48</td>
<td>230 (255)</td>
<td>60</td>
<td>48</td>
</tr>
<tr>
<td>Mechanized vertical kilns</td>
<td>22 (30)</td>
<td>0</td>
<td>0</td>
<td>70 (75)</td>
<td>0</td>
<td>0</td>
<td>70 (75)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wet-process kilns</td>
<td>5 (56)</td>
<td>1</td>
<td>0</td>
<td>6 (70)</td>
<td>1</td>
<td>0</td>
<td>6 (70)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Lepel kilns</td>
<td>4 (180)</td>
<td>2</td>
<td>0</td>
<td>6 (145)</td>
<td>2</td>
<td>0</td>
<td>6 (145)</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Shaft-preheater kilns</td>
<td>5 (156)</td>
<td>40 (50)</td>
<td>6 (130)</td>
<td>6 (145)</td>
<td>2</td>
<td>0</td>
<td>6 (145)</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Cyclone-preheater kilns</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5 (180)</td>
<td>0</td>
<td>0</td>
<td>5 (180)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Preheater kilns</td>
<td>10 (130)</td>
<td>6</td>
<td>48</td>
<td>38 (135)</td>
<td>0</td>
<td>143</td>
<td>155 (155)</td>
<td>0</td>
<td>143</td>
</tr>
<tr>
<td>Subtotal</td>
<td>450</td>
<td>450</td>
<td>106</td>
<td>450</td>
<td>450</td>
<td>106</td>
<td>450</td>
<td>450</td>
<td>106</td>
</tr>
</tbody>
</table>

†† Figures in parentheses are the average fuel intensity (kgce/tonne-clinker) for each type of kiln in the corresponding year.
(a) Increased production from renovation, including 23 Mt converted from manural kilns.
(b) Increased production realized from converting wet-process kilns (original plus increased output).
(c) Assume that 10 Mt capacity has been retired. Cost of intensity reduction for the remainder is assumed to be negligible.
(d) Capital investment for renovating mechanized VKs and converting manural 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 option, appears to be more favorable. However, the expensive scenario will provide more high-quality cement, which is critical for the long-term benefits society. Large modern plants have more effective pollution control than small plants. Many of the technologies and equipment needed to make 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, 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 problem. 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.
3.2 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 losses. For example, the key plants produce clinker at an average heat consumption of 5420 MJ/Mton-clinker. The best mechanized vertical kilns in China can achieve 3220 MJ/Mton-clinker. Table 3-1 lists the theoretical heat required to produce one ton of cement clinker.

| Table 3-1. Theoretical Heat Requirements to Produce Cement Clinker |
|-----------------------------|----------------|
| Heat Absorbed               | MJ/Mton-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 CaO at 900 °C | 733.2 |
| Heating calcium fuel from 900 to 1400 °C | 470.0 |
| Net heat of burning | 94.0 |
| Selvedge | 3023.8 |
| Heat Evolved               | MJ/Mton-clinker |
| Crystallization of dehydrated clay | 37.6 |
| Heat of formation of cement compounds | 376.0 |
| Cooling clinker from 1400 to 30 °C | 1353.6 |
| Cooling CaO at 900 to 20 °C | 451.2 |
| Cooling raw materials from 450 to 20 °C | 100.2 |
| Selvedge | 2239.6 |
| Net theoretical heat required | 3073.8 - 2239.0 = 1534.3 MJ/Mton-clinker |


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 a profound change in the 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 for 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 88 billion in Scenario I and about 91 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 kgeq/ton-clinker to 126 kgeq/ton-clinker in Scenario I and 124 kgeq/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 150 kgeq/ton-clinker, instead of the figures given in the two scenarios. Compared with the business-as-usual case, the realized fuel-saving capacity is estimated at 17 and 15 Mtoe/year in Scenario I and Scenario II respectively. Saved one-time front capital investment in coal supply would thus be 91 billion in Scenario I and 92 billion in Scenario II.13 Table 3-4 summarizes the general results of our scenarios.

3.5 CONCLUSIONS

With an average fuel intensity of 124 kgeq/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 kgeq/ton-clinker and advanced precalciner kilns produce clinker at 104 kgeq/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 Mtoe energy per ton of clinker, or 55 kgeq/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 Loviti (1988), advanced pyroprocessing technology under development in the mid-1980s can bring clinker fuel intensity below 100 kgeq/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 Loviti, 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.
cement plants. Published statistics show that fuel intensity of the key plants, consisting of both dry and wet processes, decreased from 207 kgce/t-clinker in 1981 to 185 kgce/t-clinker in 1990, a 11% reduction in 10 years. However, electricity intensity of key plants rose from 99 kWh/t-clinker in 1981 to 110 kWh/t-clinker, 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/t-clinker, a figure significantly lower than the average 185 kgce/t-clinker of the key plants. The best mechanized vertical kilns achieve 110 kgce/t-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/t-clinker, 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.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Capital Cost (billion 1990)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>360</td>
</tr>
<tr>
<td>1991</td>
<td>450</td>
</tr>
<tr>
<td>1992</td>
<td>520</td>
</tr>
</tbody>
</table>

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. 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 [Venkatachalam and Lottici, 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 other hand, is rotating and uses mechanical means to transport raw materials to the discharge end.
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 flat-glass factories and 95% for sheet-glass 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 go 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 Mtoe, 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 2800 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 improved, but the variety of products is still limited. The bulk of the output (about 60%) is used for cement manufacturing, indicating its energy-intensive nature [SBBMI, 1991 Statistics].

3.1.2 ENERGY CONSUMPTION TRENDS

Cement manufacturing consumed about 41 Mtoe 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 using rotary kilns have quite different energy aspects compared to plants that use vertical kilns. In addition, data and information are scarce for the most important part of the industry: the small

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14In the float process, molten glass flows horizontally from the furnace under a water and over a lip (or spout) into the float chamber, which is a shallow tin bath approximately 50 to 60 meters long and 6 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.

15In 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 vertically and passes between iron or steel rollers. The glass ribbon formed is then carried on conveyor rollers to the annealing jet. The plate process consumes more energy than the sheet process because of the grinding and polishing processes involved.
window glass 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/ton in 1988, according to the output and energy data in 1989, while the equivalent U.S. figure was about 30 kgce/ton in 1985. This efficiency gap indicates a conservation potential of about 1 Mtoe/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 flat-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-1980s 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 conservation 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 tons/day. Among the 21 flat-process lines built in the 1980s, seven have furnaces with a melting capacity of 400-700 tons/glass/day; others are in the range of 200-300 tons/glass/day. The most inefficient small factories, which use furnaces below 100 tons/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 tons/day, which is far below the common sizes (more than 500 tons/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 tons/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 lining. 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, using turbo-dusting techniques (such as the installation of hoppers in the bottom of nozzles 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 more energy-efficient goods. To diversify the industry, new product technologies, such as low-E windows, that improve the end user's energy efficiency as well, should be introduced.

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 1980 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 [SSR, 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 [BRO, 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. 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 40 thousand tons in 1985 to about 11 million tons in 1991. This latter figure is approximately the output from existing precutainers. 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 mechnicalized vertical kilns. The industry now boasts some 5700 factories and about one million employees. Small plants, thriving on 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 65% in 1989 from 58% in 1980. The importance of small cement plants is expected to decline in the long run, but the recent revival of state-owned enterprises 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. Cement production (14 million tons of China, 1991). By importing equipment and technologies, the cement industry put 16 precalciner production lines (a flow of cement domestically manufactured) into operation in the 1980s. But these modern units only produce about 5% of the total cement. Figure 3-1 depicts the Chinese cement production structure in 1990 by the type of kiln employed.
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. 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 m³ is equivalent to about 700 pieces of bricks). According to SBBMI statistics, energy use in brick manufacturing was about 55 Mte in 1990, 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 450, 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.

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 farmlands 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窑 enterprises can produce bricks at about 110 kceg/1000-piece fuel consumption, smaller local or rural enterprises usually have fuel intensity of about 150 kceg/1000-piece. Primitive vertical kilns have fuel intensity as high as 200-600 kceg/1000-piece [Tao, 1985].

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 the 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 as one of the necessary conditions 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 kceg/1000-piece [Qu, 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:

- Kilns 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 consumption at least three times as much as that of central government lands.

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 precalceration 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 3.6 Mt/year, save 430,000 tons of 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.
  - Apply imported technologies of the 500 toul/day float-process furnaces to retrofit existing 200-300 toul/day float-process furnaces.
  - Retrofit existing sheet-process furnaces.
  - Line 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. Strict 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 energy 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 strict demand pushes up product prices and allows marginal plants to survive. It is our concern that the Chinese building materials industry may take an
According to a survey of 800 lime kilns in China, the average fuel intensity of lime production was 182 kgeach in 1989. Advanced domestic technology uses only 120 kgeach 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 SOX source after the thermal power industry, accounting for 10% of the total emissions. NOX emissions are also considered high because cement, lime, brick, and tile production all require high-temperature processes. 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 CO2 emissions reductions. Cement and lime production also generate additional CO2 emissions because calcining 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

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

In order to acquire advanced flat glass manufacturing technologies, in the 1980s China participated in two flat-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 flat-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 8.5 Mte/year of newly increased cement production capacity [SBBMI, 1991]. Investments from local governments and enterprises are considered to 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.

18 About 99% of present brick output is produced at 150 kgs/1000-piece, 40 kgs 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 kgs/1000-piece = 17.8 Mtce.
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 30 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% of the cement output (SBMBMI, 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 (SBMBMI, 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 [SBMB, 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 [Venkatwaran 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 kiln 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).
Table 2-1. Physical Output of Major Building Materials in China, 1980-1990

<table>
<thead>
<tr>
<th>Year</th>
<th>Cement (Mt/M)</th>
<th>Bricks (Billions)</th>
<th>Flat Glass (Million Cases)</th>
<th>Lime (Mt/M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>79.9</td>
<td>154</td>
<td>27.7</td>
<td>28.5</td>
</tr>
<tr>
<td>1981</td>
<td>82.3</td>
<td>164</td>
<td>30.6</td>
<td>28.2</td>
</tr>
<tr>
<td>1982</td>
<td>95.2</td>
<td>196</td>
<td>35.5</td>
<td>30.2</td>
</tr>
<tr>
<td>1983</td>
<td>108.3</td>
<td>206</td>
<td>41.7</td>
<td>37.2</td>
</tr>
<tr>
<td>1984</td>
<td>123.0</td>
<td>250</td>
<td>41.9</td>
<td>40.1</td>
</tr>
<tr>
<td>1985</td>
<td>146.0</td>
<td>294</td>
<td>48.4</td>
<td>46.0</td>
</tr>
<tr>
<td>1986</td>
<td>166.1</td>
<td>375</td>
<td>52.0</td>
<td>53.0</td>
</tr>
<tr>
<td>1987</td>
<td>185.3</td>
<td>399</td>
<td>58.0</td>
<td>66.6</td>
</tr>
<tr>
<td>1988</td>
<td>210.1</td>
<td>460</td>
<td>72.9</td>
<td>113.9</td>
</tr>
<tr>
<td>1989</td>
<td>210.3</td>
<td>472</td>
<td>84.4</td>
<td>118.2</td>
</tr>
<tr>
<td>1990</td>
<td>229.7</td>
<td>449</td>
<td>90.7</td>
<td>93.8</td>
</tr>
</tbody>
</table>

1 One case is equal to 50kg.
2 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 these 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 1990 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. 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 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, with 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.

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 reenforcement. Total energy consumption in lime manufacturing was 12 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 80 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 kgcce/ton-lime and the lowest fuel intensity achieved is 138 kgcce/ton-lime. On the other hand, mechanized kilns average 134 kgcce/ton-lime and can reach a fuel intensity as low as 100 kgcce/ton-lime. The average fuel intensity of the industry is estimated at 182 kgcce/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, optimizing the coal/limestone ratio for better firing efficiency, increasing air flow, improving fuel-feeding techniques, stabilizing 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.

18This operational procedure requires careful feeding in order to distribute the larger size limestone in the middle of the kiln and the smaller size limestone around the side. Such practice enhances heat convection and increases lime yield.
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. For Chinese industry as a whole, respective energy-use shares are 58%, 8%, 5%, and 27% [SSB, 1992].

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 C-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 economics 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.

\[ A \text{ total energy use of 97 Mtce in the official statistics might underestimate actual energy use in the building materials industry because energy used in thousands of rural plants might not be fully counted. The SBBMI estimated the about 130 Mtce energy was consumed in the building materials industry in 1990.} \]

[2] In this report, electricity is converted into its fossil fuel replacement value, which was about 11.7 MIOE/kWh in 1990.
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, assaulter 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, skilful 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 Incentives. 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
The 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.

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. 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 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
# REFERENCES


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An Overview

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