ENERGY EFFICIENCY OF BRICKMAKING IN CHINA

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THE BRICK INDUSTRY IN CHINA

Brickmaking is a traditional but important industry in most developing countries, as bricks are the basic building material in these countries. In addition, establishing and operating brickworks have low requirements for capital investments, raw materials, and labor skills.

In China, bricks are the most widely used building material. At present, China is the single largest brick producer in the world. In 1994, brick production in China stood at close to 800 billion (tiles are included). China has more than 84,000 small brickworks in rural areas throughout the country and about 1,200 large and medium-sized ones in the vicinity of cities and towns. The small brickworks are operated by the so-called "township and village enterprises" (TVEs), whereas the large and medium-sized brickworks are almost exclusively state-owned enterprises (SOEs). TVE plants account for about 90 percent of the total brick production in China and employ more than five million people. Because of the small-scale production and backward technologies, the productivity of brickmaking in China, despite steady improvement in recent years, still lags far behind the level of developed countries. Table 1 below compares China's brick industry with that of the United States and the United Kingdom. (For the sake of comparison, 1990 data are used unless otherwise specified.)

Table 1. Comparison of the Brick Industry in China, the U.S., and the U.K. (1990)

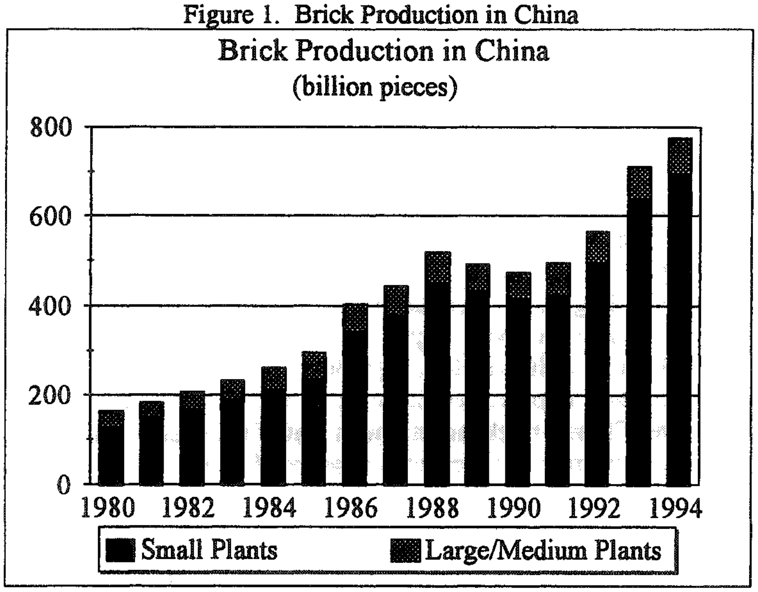
	China	United States	United Kingdom
Production (billion)	417.4 (small plants) 70.2 (large/medium-sized plants, 1991)	8 (approximately)	4 (approximately)
Number of plants	100,510 (small) 1,182 (large/medium, 1991)	265	157
Employment	4,794,000 (small) n.a. (large/medium)	15,500	9,000
Production per plant (million)	4.2 (small) 50-60 (large/medium) 4.6 (overall - approximately)	30.2	35 (typical)
Production per employee (thousand)	87 (small) n.a. (large/medium)	516	500
Employees per plant	48 (small) n.a. (large/medium)	58	70

Note: n.a. = not available.
Source: Refs. 1 and 2 on China, Refs. 3 and 4 on the U.S., and Ref. 5 on the U.K.

Because of their popularity as an inexpensive but versatile building material, demand for bricks in China has experienced a steady growth in the past few decades. The growth in demand for bricks has been compounded by the boom of the economy in general and that of the construction sector in particular in recent years, as well as by population growth. Bricks are produced in every province of the country. Although new building materials are being introduced in China, bricks continue to be the predominant building material in China, especially in rural areas, where more than three quarters of the population lives.

Since the initiation of the economic reform programs in the late 1970s, China's brick industry, mainly the TVE brick sector, has expanded quite rapidly. In 1980, total brick output was about 150 billion pieces; by 1994, the output reached close to 800 billion -- a more than five-fold increase in 14 years (see Figure 1). While brick output has increased steadily, the number of brickworks and persons employed have actually decreased slightly, indicating an increase in the scale of production and labor productivity. As shown in Table 2, both the scale of production and labor productivity doubled between 1986 and 1993, while the average number of employees per enterprise stayed virtually unchanged.

Figure 1. Brick Production in China



Source: Refs. 1 & 2 and author's estimate.

Table 2. Productivity of Brickmaking by TVE Plants		
	1986	1993
Production (billion)	345	641
No. of enterprises (thousand)	100	90
No. of employees (million)	5.01	4.58
Production per enterprise (million)	3.45	7.16
Production per employee (thousand)	69	140
Employees per enterprise	50	51
Source: Ref. 1.		

MAJOR TECHNOLOGIES OF BRICKMAKING

There is a wide of spectrum of technologies used for brickmaking -- from basic manual production to sophisticated automated operation. Although mechanization of the brick industry has progressed quite rapidly during the past four decades in industrial countries, brickmaking in China by and large remains one of the most labor-intensive industries. The tunnel kiln, which represents the state of the art of brickmaking technologies and has reached 70-90 percent of the market in many industrial countries,[6,7] occupies only a minuscule share of the Chinese market. Of the nearly 800 billion bricks produced in China, less than five percent are manufactured in tunnel kilns.

In terms of production process, brickmaking can be divided into four basic stages (clay winning and hauling is not considered here): clay preparation, molding, drying, and firing. Energy use for brickmaking occurs mainly at the last two stages of brick drying and firing.

Clay Preparation

The basic raw material for manufacturing common bricks is clay, which is usually extracted from the local land resources. (This is particularly true of the TVE brick plants in China.) Preparation of the clay is done according to the properties of the clay and the requirements of the finished product. To ensure consistency of the raw material, the clay must be treated and screened properly. The preparation process typically involves crushing the raw material, mixing it with water, blending, and screening. Many TVE brickmakers in China are equipped with only an agitator and a roll and have to use high-quality clay to make solid bricks. Extruders and high-speed breaking rolls, which are indispensable in modern brick plants, are still uncommon among TVE brick plants.

Waste fuels or other carbonaceous materials can be added to the clay to enable bricks to burn internally during the firing process. According to a Chinese study, about 20 percent of brickworks with annular kilns in China mix some kind of carbonaceous wastes in the clay as a body fuel to help with the brick firing process thereby reducing coal use.[8] Such practice not only saves energy for brick firing, but it is also environmentally sound in that it provides a solution to the problem of industrial solid waste disposal while conserving land resources by substituting waste materials for clay. The waste materials that have been used in China include fly ash, gangue, coal dust, and coal slurry. It was reported that more than 10 million tons of industrial wastes were utilized by brickmaking in China in 1990.

Brick Molding

Several processes of brick molding (pressing and shaping) are available, including extrusion, soft-mud molding, semi-dry or dry pressing, and vibration-compaction. In China, the most widely used method for making common bricks is extrusion.

In this process, the clay is first blended in the pug mill and then fed into the extruding machine, which consists of a helix (called an auger) rotating within a cylindrical barrel. After the clay is forwarded to an auger extractor, it is forced through a die to form a column of clay. The extruded column of clay is then cut into bricks by a wire-cutter.

In some areas of China where bricks are produced by farmers for their own use, the pressing and shaping of clay into bricks is still done manually by throwing a lump of clay into a collapsible wooden box, slicing away the surplus clay from the top, and then removing the wooden box.[9] In general, however, mechanical brick forming has replaced manual forming.

Brick Drying

Green bricks can be dried naturally (i.e., in open air) or artificially (i.e., by some kind of dryer). Brick drying requires a large amount of energy, since the drying process must evaporate the water contained in the green bricks, raise the temperature of the clay body, and heat the air which effects the drying. There is also heat loss during the process. It has been estimated that drying 1,000 freshly extruded bricks (with a 240x115x71 mm dimension, which contains 700 g of water) requires 2,900-8,200 MJ of energy. This is equivalent to burning 70-196 liters of No. 5 heavy oil.[10]

Natural drying uses solar energy to dry bricks set on racks. Since natural drying process is vulnerable to rains, brickmaking using natural drying becomes a seasonal operation, and production capacity is therefore underutilized. In northern parts of China, the temperature in winter is too low to dry bricks in open air, while in southern parts of China, there is a relatively long rainy season, and brickworks using natural drying can operate for only half of a year.

Artificial drying can be done on hot floors or using a chamber or tunnel dryer. Hot-floor drying uses a heated floor with a roof on top to give protection from the weather but allows the evaporated water to escape. This method of drying, which was once common in Europe, is now more or less obsolete.

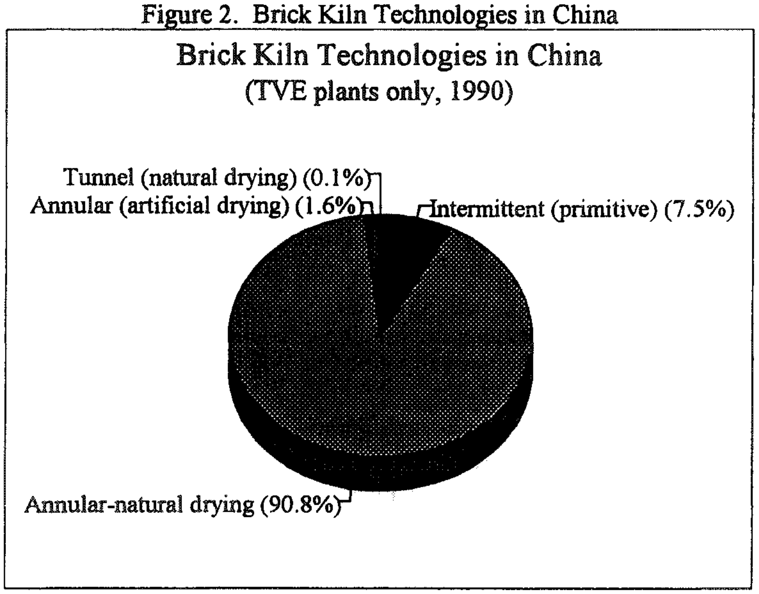
Chamber drying is a batch process. Bricks are loaded and unloaded by a finger car into the chamber, where bricks are dried by waste heat recovered from the kiln which may be supplemented by steam from external sources. Modern chamber dryers have sophisticated control systems to ensure product quality and heat efficiency.

Tunnel drying is a continuous process. The cars carry bricks through the tunnel dryer where drying temperature increases from the entrance to the exit. The tunnel dryer also uses the heated air recovered from the kiln supplemented with external steam. Heat can also be supplied from external fuel-burners. Both chamber and tunnel dryers are significantly more efficient than floor drying (14-25 percent efficiency for hot floor drying vs. 20-54 percent for chamber and tunnel drying) and have high capital but low labor requirement.[11]

Brick Firing and Types of Kiln

There are three basic types of brick kiln currently used in China: the intermittent "horse-foot" kiln, the annular (Hoffman) kiln, and the tunnel kiln. Figure 2 provides a breakdown of brick production by TVE plants in 1990 by types of kiln. The state-owned brick plants use large-scale annular kilns and tunnel kilns, but since their output accounts for only 10 percent of total brick output in China, the overall share of tunnel kilns may reach around five percent.

Figure 2. Brick Kiln Technologies in China



Source: Ref. 8.

The traditional design of the Chinese brick kiln is one that is sunk into the ground. Green bricks are loaded from the sides at the ground level and from the top. The shape of the is like a horse foot, thus the name of "horse-foot" kiln. The production process of the traditional kiln is intermittent; loading and unloading is done manually.

In terms of technological sophistication, the "horse-foot" kiln has been labeled the "primitive" type in China. The intermittent kiln has long been rendered obsolete in developed countries because of its inherent inefficiencies,[12] except for firing bricks for specialized uses. In China, much progress has been made, especially during the 1980s, to phase out the traditional kilns. By 1990, these kilns made up about seven percent of total brick production among TVE plants (see Figure 2).

Apart from the traditional kilns, the most basic type of kiln used in China is the annular design. The annular kiln (also known as the Hoffman kiln), unlike the intermittent kiln, loads and unloads bricks in the chambers inside the kiln under high temperatures without interruption. In the annular kiln, the firing moves continually around the kiln while the bricks stay stationary during the firing. More than 90 percent of bricks manufactured in China are fired in annular kilns.

The most advanced kiln technology in brickmaking is the tunnel kiln. In the tunnel kiln, like the annular kiln, the firing of bricks is a continuous process, but, unlike the annular kiln, the firing zone remains stationary while the bricks move through the kiln. Bricks are loaded and unloaded on cars outside the kiln at normal temperature.

In China, tunnel kilns have been adopted mostly by the state-owned large and medium-sized plants. Only a negligible percentage (0.1 percent in 1990) of TVE plants have adopted tunnel kilns (Figure 2). The high requirement for capital investment and sophistication in operation renders the technology inappropriate for wide application among TVE brickmakers.[13]

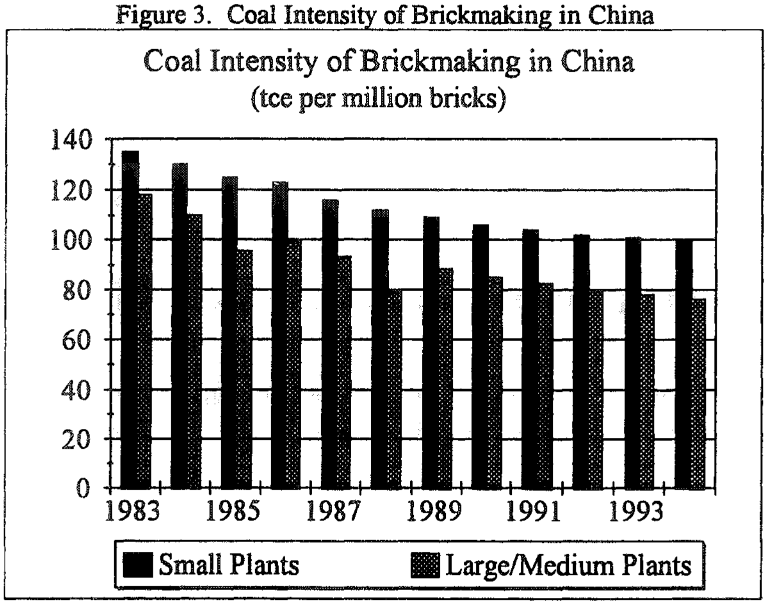
ENERGY EFFICIENCY OF BRICKMAKING

Brickmaking, like the manufacture of other building materials, is an energy-intensive operation. The two production processes where extensive energy is required is brick drying and firing. Since the predominant technique of brick drying in China is open-air drying (about 95 percent of total brick production), energy is used primarily at the stage of brick firing.

Fuel use for brickmaking in China is mainly coal. This is in contrast to the practice in most other countries. The dominant fuel used by the U.K. brick industry, for instance, is gas, which accounts for 80 percent of the total energy consumption for brickmaking, while electricity (10 percent), coal (seven percent), and oil (three percent) make up the rest.[14] The choice of fuel for brick firing largely depends on the local availability of resources and relative fuel prices. In many developing countries, wood chips and paddy husks are also used as fuel for firing bricks.

Due to the backward kiln technologies and the mammoth size of the brick industry, energy use for brickmaking in China is enormous. Although no published statistics on energy consumption by China's brick industry is available, the following estimate can be made. According to a Chinese study, the average coal consumption for brickmaking in China in 1990 was about 105-110 tons of coal equivalent (tce) per million bricks.[15] Based on the reported decreasing trend of unit energy use for brickmaking in China (as shown in Figure 3), the author estimates that in 1994 coal consumption per million bricks was approximately 100 tce for TVE brickmakers and 75 tce for large and medium-sized plants (an optimistic estimate indeed). China produced close to 800 billion bricks in that year (about 90 percent by small plants) and thus consumed more than 75 million tce of coal. This is about 100 million tons of raw coal or about eight percent of total coal production in China -- the largest coal producer in the world!

Figure 3. Coal Intensity of Brickmaking in China

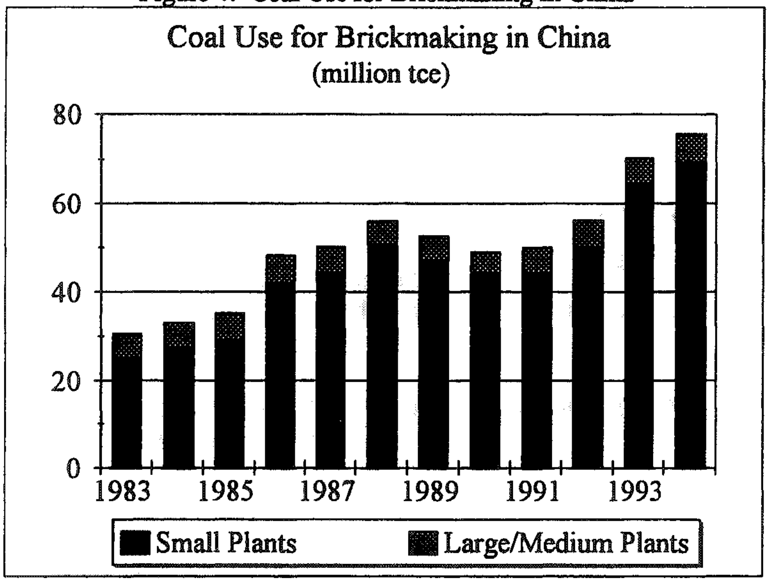


Source: Refs. 2 & 8 and author's estimate.

Figure 3 above provides estimates for the coal use per unit of brick produced in China between 1983 and 1994 by small TVE and large and medium-sized SOE plants, respectively. Although figures for some of the years come directly from Chinese studies and others are the author's estimate, they should be taken as indicative because of inconsistencies found among different sources of information.

Figure 4 below illustrates the total amount of coal used for brick production in China between 1983 and 1994. It is based on the estimated coal intensity shown in Figure 3 and the annual coal production shown in Figure 1.

Figure 4. Coal Use for Brickmaking in China



Source: Author's estimate based on Refs. 2 & 8.

In terms of energy use by types of kiln, the intermittent kiln has the highest level of fuel consumption. To produce one million bricks, as much as 200-250 tce of coal is used by the intermittent kiln in China. (No electricity is used.) Although the share of these kilns is presently relatively small and has been declining, the absolute quantity of bricks and the amount of energy consumed by these kilns are still quite staggering: about eight million tce of coal was used to produce an estimated 40 billion bricks (a rough estimate for 1994).

Fuel consumption by the annular kiln ranges from 80 tce to some 110 tce per million solid bricks depending on the scale of the plant, with small plants on the higher end and large and medium-sized plants on the lower end. In addition, 30,000-40,000 kWh of electricity is used (for small plants). However, if combustible body fuel is mixed with the clay, substantial reduction in net energy use can be achieved (as low as 20-30 tce/million bricks).[16]

The state-of-the-art kiln technology represented by the tunnel kiln has made its way to the Chinese market, but is limited mainly to the sate-owned large and medium-sized plants. Because of its high level of mechanization, the tunnel kiln tends to require more energy to operate than the annular kiln. In most countries, modern tunnel kilns are typically fired by oil or gas. Fuel consumption ranges from around 150 tce per million bricks for top-fired kilns (using impulse burners and heavy fuel oil) to around 200 tce per million bricks for side-fired kilns (using atomizing oil burners). The top-fired kiln, however, produces enough hot air to dry bricks from higher moisture content (20 percent) than the side-fired kiln (10 percent moisture content).[17]

In China, bricks made in tunnel kilns are also fired by coal. Coal consumption is reported to be about 130 (100 to 150) tce per million solid bricks plus 35,000-45,000 kWh of electricity with an overall energy consumption of about 140 tce. To produce hollow bricks using the tunnel kiln, coal use is considerably lower (80 tce/million bricks), but electricity use goes up (45,000-55,000 kWh/million bricks), with the overall energy use about 85 tce per million bricks.[18]

Comparison of energy efficiency between China and other countries is not easy to make in general terms, because not only the types of kiln and its level of automation but also the brick specification determines the level of energy use. The overwhelming majority of bricks made in China are low-quality bricks for general structural purposes. Their structural and mechanical strength in general is not up to the standards of developed countries. As such, the overall unit energy consumption of brickmaking in China appears lower than that in the U.S. or the U.K. (see discussion that follows).

According to the account of a U.S. brickmaker, fuel consumption by his tunnel kiln was around 400 tons of soft coal (which is about 280 to 400 tce, depending on the heat value) per million bricks produced.[19] In the U.K., net energy consumption of (gas-fired) tunnel kilns averages 240 tce (producing non-fletton bricks),[20] which is lower than the level in the U.S. (but higher than the level in China). But, again, without knowing the detailed specifications of the bricks they make, it is not meaningful to draw a comparison.

It is interesting to note, however, that energy consumption of brickmaking in the U.K. varies considerably, from 210 to 550 tce per million non-fletton bricks (averaging 270 tce). Many of these bricks are used as facing and engineering bricks; some are produced in small batches by intermittent kilns for special color effects or quality. For fletton and common bricks, which are used for general structural purposes, net energy consumption is only 50 tce per million bricks. These bricks use high carbon content clay and are fired by annular kilns.[21]

A fair and more meaningful comparison would be between energy use of brickmaking in China and fletton brickmaking in the U.K., since the products are somewhat similar. Figures from the above discussion would indicate that energy efficiency of China's brick industry is only half the level of the U.K. (100 tce vs. 50 tce per million common bricks). Apart from backward technologies and lack of economies of scale, the production of almost exclusively solid bricks deems the Chinese brick industry high in energy use. The share of hollow bricks in other countries tends to be 50-80 percent of the total production. The Chinese study has also indicated that making hollow bricks would reduce the unit energy use by as much as over 40 percent.

ENVIRONMENTAL POLLUTION FROM BRICKMAKING

As coal is virtually the only type of fuel used in China for firing bricks, a major environmental problem of brickmaking is emissions from coal burning. Since no pollution abatement devices are installed in brickworks, the amount of emissions is basically a function of coal use. Table 3 below provides the emission factors of SO_2 and CO_2 by types of kiln for 1990.

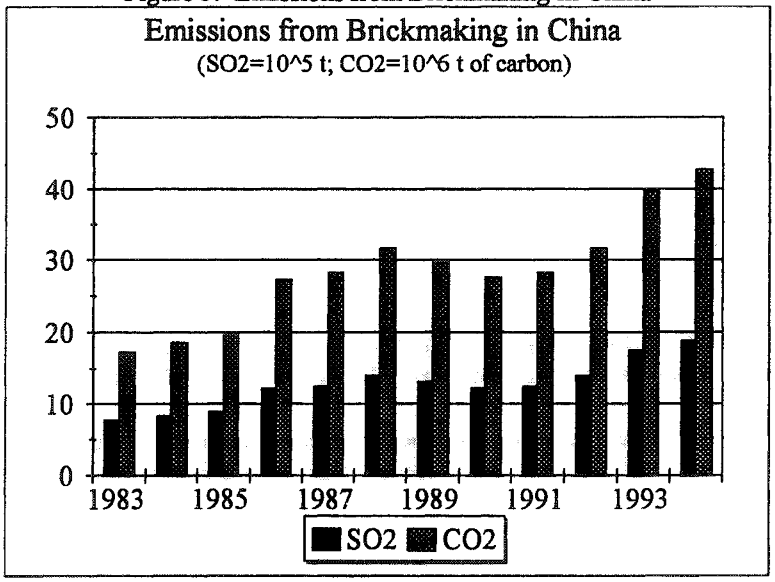
Table 3. Emission Factors of Brickmaking in China

	SO_2 Emissions (t per million bricks)	CO_2 Emissions (t of carbon per million bricks)
Primitive kiln	5.0	113
Annular kiln		
Natural drying-solid bricks	2.7	62
Artificial drying-solid bricks	2.7	63
Artificial drying-hollow bricks	1.6	37
Tunnel kiln		
Artificial drying-solid bricks	3.5	80
Artificial drying-hollow bricks	2.0	48

Source: Ref. 8.

Based on the emission factors given in Table 3, the amount of SO_2 and CO_2 emissions from China's brick industry is estimated for the period of 1983-1994. Adjustments are made for the emission factors over the years according to the change of coal consumption per unit of output. The result of the emissions estimate is shown in Figure 5. In 1994, China's brick industry is estimated to have released 1.9 million tons of SO_2 and about 43 million tons of CO_2 (carbon). Because of the built-in assumption of technical change (i.e., energy efficiency improvements), the emissions in 1994 were about 2.5 times the 1983 level and is only half the growth of brick production in China during this period (brick production grew more than five-fold).

Figure 5. Emissions from Brickmaking in China



Source: Author's estimate based on Refs. 2 & 8.

Pollution control for brickworks is almost non-existent in China. In addition to SO_2 and CO_2 emissions (which are regional and global pollutants, respectively), smoke dust emissions pose a direct threat to the health of the workers and the local community. Some brick plants in China have not even installed tall stacks to effectively "dilute" their emissions. Smoke dust emissions from these plants have been reported to far exceed the national air quality standards.

Another type of emission from brickmaking is fluorine, which is contained in the clay as fluorides and released during firing. Emission factors of fluorine from brickmaking are given in Table 4. According to the survey of environmental pollution of TVE industry conducted in 1990, a total of 136,000 tons of fluorine was emitted from TVE brick and ceramics industries, and accounted for 87 percent of total TVE fluorine emissions.[22]

Table 4. Emission Factors of Fluorine from Brickmaking

	Average (kg/million bricks)	Range (kg/million bricks)
Rate of release (%)	51.0	39.9 - 65.3
Total fluorine	538	371 - 705
Gaseous fluorine	286	196 - 376

Note: (1) Rate of release refers to the fluoride (in terms of fluorine) released during brick firing as a percentage of total fluorides (in terms of fluorine) contained in the clay.
(2) 60 percent of the fluorine released from the clay is emitted into the atmosphere with other gases; the rest of it goes into the coal cinder. Gaseous fluorine is more detrimental (especially hydrogen fluorine) than the fluoride carried in coal cinder.
Source: Ref. 23.

Fluorine, being toxic and chemically reactive, can cause serious pollution on vegetation. Fluorine-contaminated leaves are detrimental and even fatal to silkworms. In Jiangsu and Zhejiang Provinces where sericulture prospers, cases of fluorine contamination from brick plants have been reported almost every year.[23]

Fluorine emissions from brickmaking have been regulated by the government in some countries such as the U.S.[24] Several U.S. brick companies have installed scrubbers using limestone as the scrubbing agent to reduce fluorine emissions. Of course, these systems do not come cheap: the scrubber itself costs up to $200,000 and the whole system, including the exhaust stack, controls, and ductwork, costs twice that amount.

Apparently, for a country which has not yet installed scrubbers for its coal-fired electric power plants, scrubbing fluorine from brick plants would not be considered a priority. However, there appear to have been some initiatives in developing indigenous devices to reduce fluorine emissions.[25] But generally speaking, very little effort has been made to control fluorine emissions from the brick industry in China, and there is no enforcement of environmental regulations with respect to fluorine emissions from brickmaking.

Land use by brick plants has probably caused more concern in China than air pollution. In some areas, the winning of the raw material (clay) for brickmaking comes from already scarce agricultural land. Moreover, since most of the green bricks are air-dried, brickworks have occupied large areas of land. For a brick plant with an annual production of 10-15 million bricks, as much as two hectares of land is needed. To produce 700 billion bricks, a total of 140,000-210,000 hectares of land would be required for brick drying and stacking. Although in general, fertile arable land is not used for this purpose, brick drying and stacking, as well as clay winning, does pose a potential threat to land conservation in some rural areas in China.

POLICIES AND OPPORTUNITIES FOR REDUCING ENERGY USE FROM BRICKMAKING IN CHINA

Government policies on brickmaking in China have always stressed energy and land conservation and technology improvements. These policies can be found in several documents issued during the 1980s by the State Council, the State Planning Commission, and the Ministry of Agriculture, and other concerned agencies. In 1988, four government agencies (the National Building Materials Industry Administration, the Ministry of Agriculture, the National Land Management Administration, and the former Ministry of Urban and Rural Construction and Environmental Protection) jointly issued guidelines to restrict the use of agricultural land for brickmaking. The basic principle called upon was to "suit measures to local conditions, protect agricultural land, conserve energy, utilize wastes, and improve product quality."[26]

Because the large population and relatively small area of arable land in China, it has been a long-standing policy to preserve agricultural land. As discussed earlier, brickmaking in China occupies at least 100,000 hectares of land, and it is not in the country's best interest to have brickmaking compete with agriculture for land use. In stead of winning clay from agricultural land, other local resources, such as barren hillocks, riverbed sludge, and shale, should be encouraged to be used as raw materials for brickmaking,

The use of industrial wastes and other carbonaceous materials also should be promoted. Not only can this reduce clay requirement, adding these materials to the clay is also an important measure to reduce energy use for external firing. To promote the comprehensive utilization of industrial wastes, China's State Planning Commission stipulates that energy use for brickmaking includes only raw coal, electricity, and fuel oil. (Gas is not used for brickmaking in China.) The heat value of coal dust, gangue, coal-washing residues, coal slurry, and other low-grade fuels are not included as part of the enterprise's energy use.[27]

Another important option that has been promoted to save both land and energy is making hollow bricks. Compared with solid bricks, making hollow bricks reduces both clay and energy use by 20-50 percent. Moreover, drying and firing period can be shortened by 10-15 percent. Because hollow bricks are lighter and have better thermal properties, transportation costs and heating costs also can be saved by 20 and 30 percent, respectively.[28] All these characteristics make hollow bricks a more desirable product than solid bricks. However, hollow bricks have stringent requirements for clay preparation, pressing and shaping, as well as brick drying and firing.

Artificial drying has not been actively promoted in China because it tends to use more energy than open-air drying and incurs more capital investment. However, there are significant savings of land and increase in capacity utilization. For overall economic efficiency, artificial drying should be considered in future technical renovation programs. Brick plants with artificial dryers can operate all year round and therefore can increase output by as much as 50 percent. The additional cost of the dryer may well be warranted.

With respect to kiln technologies, annular kilns are likely to remain as the dominant type of kiln in China in the foreseeable future. Efforts should be made to seek opportunities to improve the design and thermal efficiency of the existing annular kilns. Measures may include lining chambers with low thermal mass and higher insulating refractory products and in the improved control and design of air flow and damper arrangements.[29]

Promotion of tunnel kilns should be done where technical and financial requirements can be met. At present, labor costs are still very low in rural China, so substituting capital for labor to install tunnel kilns simply does not make economic sense. Only until the overall technological levels are sufficiently improved (including labor skills) and the demand for high-quality bricks sufficiently increases, will it be likely for tunnel kilns to find wide application in China.

SUMMARY AND CONCLUSION

China's brick industry is characterized by its enormous size in output, predominantly small-scale production with backward technologies, and low labor productivity. The kiln technologies used in China is primarily the Hoffman-type annular kiln, and most of the products are solid common bricks. Because of the economic growth and construction boom, demand for bricks is quite strong, and brick production has been growing rapidly during the last 15 years.

Energy consumption by China's brick industry is dominated by coal. Although there have been reported improvements in fuel use over the years, brickmaking in China still has low fuel efficiency and generally produces low-quality products. Although it is difficult to compare energy efficiency of brickmaking in China with that in other countries because of variations in product type and quality, there are large potentials to increase the energy efficiency as well as overall economic efficiency of brickmaking in China through investments in new and improved technologies, such as production of hollow bricks, artificial drying, and upscaling and renovating existing annular kilns.

The introduction of the tunnel kiln technology has been slow in China. In Europe, it took 30-40 years for the tunnel kiln to reach 70-90 percent of the brickmaking market.[30] This trend of technology diffusion is probably not going to occur in China. The most optimistic projections of brickmaking technologies in China placed the share of tunnel kilns between 20 and 40 percent by 2010. This is not likely to happen, however, because the capital requirement for installing tunnel kilns of that magnitude to replace the existing capacity would amount to billions of dollars.

Environmental concerns about the brick industry in China include air pollution (SO_2, CO_2, and fluorine emissions) and farmland use by brick plants for brick drying and clay winning. Environmental regulations for the brick industry are not strict, and enforcement of any regulation among the 840,000 small plants is practically impossible. Since coal burning for brick firing is the main source of air pollution (SO_2 and CO_2), the best way to reduce pollution is through fuel efficiency improvements of brickmaking by improving the existing kilns and by producing hollow bricks. Adding carbonaceous industrial wastes has also been proved to be an effective and environmentally sound way of reducing fuel use for brickmaking.

Several government directives were issued during the 1980s to restrict the use of agricultural land for brick operations and to encourage the use of industrial wastes and other low-grade fuels in brickmaking in order to reduce energy consumption and industrial solid wastes. But so far, little is known about the effects of these policies. Some local governments have also initiated policies to improve energy efficiency and increase the scale of brick plants. Statistics has shown that the scale of production and labor productivity in China have increased over the years, but overall they still lag far behind those of industrial countries.

The future development of China's brick industry will also be determined by the market demand for bricks and other building materials. The swift growth of brick production in China is not likely to continue for another 15 or 30 years, although in the near future the demand for common solid bricks will still be quite high. With continued economic growth and improvements of people's living standards, the demand for high-quality structural and facing bricks as well as better materials substituting bricks will likely pick up. Although energy efficiency is not a goal for brickmakers, they will opt for energy efficiency measures that can improve their profitability. Programs designed to increase energy efficiency in brickmaking must be placed in the context of improving the industry's technological levels and increasing the overall efficiency and profitability of the brick plant.

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11. West, H.W.H., The Establishment of the Brick and Tile Industry in Developing Countries, New York: United Nations, 1969.
12. However, it is reported that nine percent of the kilns in the U.K. are still of the intermittent type (see Ref. 5). But these intermittent kilns found in the U.K. are not what they used to be. In modern intermittent kilns, loading and unloading has been automated, and some have installed gas-fired systems that cost as much as £200,000.
13. According to the Chinese estimate (Ref. 8), capital investment for the tunnel kiln is about 200 *yuan* (1990 price) per 1,000 bricks while that for the annular kiln ranges from 40 to 60 *yuan* (1990 price) per 1,000 bricks depending on the drying process (natural or artificial) and the product type (solid or hollow bricks). These investment figures seem considerably lower than those found for other countries.
14. See Ref. 5.
15. See Ref. 8.
16. See Ref. 2.
17. See Ref. 13.
18. See Ref. 8.
19. See Ref. 4.
20. See Ref. 5.
21. ibid.
22. National Environmental Protection Agency, Ministry of Agriculture, and State Statistical Bureau, China, An Investigation and Evaluation of Pollution Sources of Township and Village Enterprises in China, 1993. (in Chinese)
23. ibid.
24. Sheppard, Laurel M., Making Brick and Meeting Regulations, American Ceramic Society Bulletin, Vol. 72, No. 1 (January 1993), pp. 31-39.
25. Yearbook of Township and Village Enterprises in China (1978-1987), Beijing: Agriculture Press, 1989. (in Chinese)
26. Yearbook of Township and Village Enterprises in China (1989), Beijing: Agriculture Press, 1990. (in Chinese)
27. While such stipulation may have some impact on the state enterprises since energy use is often factored into the assessment of enterprise performance, it will not affect TVE brick plants because they are not owned or controlled by the state.
28. See Ref. 8.
29. See Ref. 5.
30. See Refs. 6 and 7.