Energy Efficiency Opportunities in China

Industrial Equipment and Small Cogeneration

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ENERGY EFFICIENCY OPPORTUNITIES IN CHINA: INDUSTRIAL EQUIPMENT AND SMALL COGENERATION

Beijing Energy Efficiency Center (BECon)

February 1995

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Pacific Northwest Laboratory Richland, Washington 99352

SUMMARY

A quick glance at comparative statistics on energy consumption per unit of industrial output reveals that China is one of the least energy efficient countries in the world. Energy waste not only impedes economic growth, but also creates pollution that threatens human health, regional ecosystems, and the global climate. China's decision to pursue economic reform and encourage technology transfer from developed countries has created a window of opportunity for significant advances in energy efficiency. Policy changes, technical training, public education, and financing can help China realize its energy conservation potential.

Studies conducted by the Energy Conservation Division of China's Energy Research Institute conclude that China has the technical potential to save 40-50 percent of the total volume of current energy consumption by raising its industrial energy efficiency to advanced levels. If China were to maximize energy efficiency and minimize the energy intensity of its economy, it could double GNP by the year 2000 without increasing energy use. A survey of the energy conservation potential of three major types of equipment--boilers, furnaces, and fans--illustrates the point.

- China's industrial boilers consume 9.1 exajoules of coal annually, about one third of the national total. If boiler efficiency were raised from the current 65 percent average to the 80 percent average attained by developed countries, then 1.7 exajoules of coal could be saved every year.

- Industrial furnaces use about one quarter of China's total energy. Chinese industrial processes such as steel and glass production and copper smelting consume 25-110 percent more energy per unit produced due mainly to the efficiency gap between furnaces in China and advanced ones. If China's furnaces were raised to advanced levels, then China would could save around 40 percent of the energy used by furnaces, or 2.9 exajoules every year.

- China's 3.9 million fans consume one tenth of total electric power. Fan efficiency improvements could save hundred of millions of kilowatt hours every year.

In addition to improving the efficiency of equipment, China can also save energy through cogeneration, that is, using waste heat or pressure from industrial processes to generate electric power. Seventy percent of residual heat resources, or 0.84 exajoules, could be tapped. As for residual pressure resources, experts estimate that almost half of the boilers with capacities of at least 10 tons of steam per hour are suitable for small cogeneration. Less than 10 percent of this resource has been exploited, meaning 9000 megawatts are still available.

The technical potential clearly exists, but China needs to make several policy and institutional changes in order to achieve it. China's transition from a planned to a market economy is changing the government's role in promoting energy efficiency. The state will have to relinquish direct control over energy conservation administration, but it can create a new mission for itself, that of creating the market for energy efficiency. Its agenda can include

- Creating market-based incentives to raise efficiency, such as rebates, fees, and taxes

- Financing and project preparation

- Encouraging local planning methods that allow fair competition between supply side and demand side energy investments.

The government can also support technical training, public education, and the creation of an energy efficiency loan fund.

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This report is not an official policy statement, but rather represents the opinions of the group of senior energy researchers listed below. Zhou Fengqi, Director of the Energy Research Institute and Founder of BECon, provided advice and support. Much of the data came from various studies conducted by the Energy Conservation Division of the Energy Research Institute.

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CONTENTS

CONVERSIONS

Energy

1 gigajoule = 1 x 10^9 Joules
1 exajoule = 1 x 10^{18} Joules

1 exajoule = 0.95 quadrillion British thermal units (Btu)
= 34.1 million tons of standard coal equivalent (Mtce)
= 47.8 million tons of Chinese average raw coal
= 23.9 million tons of Chinese average crude oil
= 26.5 billion cubic meters of standard natural gas
= 25.6 billion cubic meters of Chinese average natural gas
= 84.4 billion Kwh of electricity
= 59-71 million tons of air-dried firewood
= 62-83 million tons of air-dried crop residues

1 kilowatt (Kw) = 1 x 10^3 Watts
1 megawatt (MW) = 1 x 10^6 Watts
1 gigawatt (GW) = 1 x 10^9 Watts

(Sinton 1992)

Currency

Prices given in 1990 yuan were multiplied by the following conversion and inflation factors:

As of January 1, 1994

$1.00 = Y 8.72
Y 1.00 = $0.11

Inflation factor from 1990 to 1993 is 1.62.

(Bank of China)

I. TECHNICAL OPPORTUNITIES TO IMPROVE ENERGY EFFICIENCY

China has long been a largely agricultural nation, depending on biomass, such as wood and crop residues, for much of its energy needs. Internal strife and foreign invasion kept China from industrializing until the Chinese Communist Party took power in 1949. Commercial fuel use totaled 0.94 exajoules, only 15 percent of total energy consumption in that year and roughly three percent of current consumption. Industrialization in partnership with the Soviet Union began in earnest in the 1950s, and China's use of fossil fuels, especially coal, began to grow. Commercial energy now supplies three quarters of China's total energy, and coal dominates the energy landscape (see Figure 1). China's energy consumption growth rate usually equaled and at times surpassed that of economic growth during the centrally planned period, 1949 to 1978.

This period in Chinese history led to three structural features that continue to contribute to a low level of energy service in China today. First, much of China's current production capacity is based on Soviet technology of 1930s and 1940s vintage. China imported equipment from the Soviet Union in the 1950s, then lost contact with the industrialized world during the Sino-Soviet split in the early 1960s and the Cultural Revolution that followed (1966-1976). Many Chinese enterprises continued to rely on 1930s Soviet designs well into the 1980s. Second, China followed the Soviet model of channeling most of its fuel to the energy-intensive industrial sector, leaving only a small share for agricultural, residential, and commercial use. Third, China did not, until recently, emphasize electric power development. Electricity therefore comprises a relatively small share of total energy end use, and power supply falls far short of demand. These features have begun to change under China's current policy of market reform and opening to the outside world.

China initiated the policy of reform and opening up in the late 1970s, but held energy sector reform in check until the early 1990s to maintain social and economic stability. In the absence of market incentives to conserve energy in the 1980s, China achieved significant energy savings through a state-administered conservation drive. State funds were used to import advanced technologies from abroad and improve domestic technologies. Efforts focused on the industrial sector because it consumes two thirds of China's total commercial energy (see Figure 2). The gross national product (GNP) grew by 140 percent while energy consumption grew by only 60 percent, a great achievement for a developing country.

TECHNICAL POTENTIAL

China was able to achieve such large efficiency gains in the 1980s in part because it started at a very low level. Studies conducted by the Energy Conservation Division of China's Energy Research Institute conclude that China still has the technical potential to save 40-50 percent of the total volume of current energy consumption. This potential is defined as the savings that would be achieved by immediately replacing exisiting obsolete equipment and industrial processes with the world's most advanced equipment and processes. If China were to maximize energy efficiency and minimize the energy intensity of its economy, it could double GNP between 1990 and 2000 without increasing energy use. However, capital shortages in China make this technical potential more of a theoretical reference point than an actual target.

While a 50 percent reduction in energy intensity may be unrealistic, a 30 percent reduction could actually be achieved by renovating existing production capacity using the best technology currently available in China and minimizing the energy intensity of the economic structure. If this were to occur, China could double GNP between 1990 and 2000 with only a 25 percent increase in energy consumption.

By choosing the most cost-effective measures to save energy, China could achieve a 30 percent reduction in energy use per unit output and pay only 55 percent of the cost of constructing an equivalent amount of new supply resources. That is, the effect achieved by investing $100 in capital construction can be achieved by investing only $55 on average in energy efficiency. When external costs, such as environmental damage, are included, the cost of energy efficiency is only 35 percent of that of the energy production.

TYPES OF TECHNICAL OPPORTUNITIES

China's production capacity is still extremely energy intensive due to the use of outdated equipment, outmoded industrial processes, and inappropriate or low quality materials. Chinese enterprises have many opportunities to improve industrial energy efficiency by taking the following measures: changing industrial processes; switching feedstocks; increasing scale; modernizing equipment; using energy conservation technologies; and raising the efficiency of widely used equipment, such as boilers, furnaces, and fans.

Adopting better industrial processes can greatly reduce energy waste. For example, in chloroalkali production, liquid alkali produced using a membrane process uses 30 percent less energy than that produced using a metal polar process. In 1990, Japan used the membrane process for 80 percent of its liquid alkali production, but China used it for only 4 percent.

The choice of materials used in chemical and manufacturing industries also influences energy efficiency. For example, using coke to manufacture synthetic ammonia in fertilizer production consumes 70 percent more energy than using natural gas. China produces 66 percent of its synthetic ammonia using coke, while the United States produces 98 percent of its ammonia using natural gas. A process using light diesel oil accounts for 62 percent of ethylene production in China, whereas Japan primarily uses naphtha in a process that consumes 20 percent less energy per unit of ethylene produced.

Taking advantage of economies of scale is a third way to improve energy efficiency, since larger operations often use energy more efficiently. For example, the average scale of China's paper-making enterprises is only 2,500 tons per year, and enterprises with an annual production over 10,000 tons account for only 37 percent of the total. A survey of paper pulp plants in the world's major paper-making countries revealed that their average annual production is 180,000 tons, and that of paper and cardboard plants is 61,000 tons. The world average scale of enterprises is about 50,000 tons per year. China is thus well below the world average and even farther below the world's major paper-making countries in the scale of enterprises. The small scale of enterprises is not only inherently inefficient, but also precludes adopting advanced technologies for environmental protection and energy conservation, such as alkali recycling and cogeneration. Like China's paper plants, most of the small and medium-sized synthetic ammonia enterprises, which account for 75 percent of the country's total synthetic ammonia production capacity, are also too small to be highly efficient and environmentally friendly.

Modernization of equipment can improve not only energy efficiency but also product quality. The textile industry, for example, could benefit from improvements in the performance, speed, and automation of its equipment. At present, much of China's cotton textile equipment is outdated--one third of the equipment produced in 1940s and 1950s is still in operation. The problem of obsolete equipment is very serious in the wool, linen, and silk industries. Electromechanical integration of textile equipment has spread quickly in the industrialized countries, but China is just beginning to adopt it. New, efficient technologies, such as open-end spinning, shuttleless looms, and round-netted printing machines are not as widespread in China as they are in the rest of the world. Globally, the penetration rates of these three technologies are 13 percent, 15 percent, and 50 percent, respectively, while in China, the penetration rates are only 3 percent, 3 percent, and 10 percent.

Technologies aimed at energy conservation, such as residual heat recycling, ladder utilization of energy, and comprehensive and optimized utilization, also offer significant savings potential. For example, the penetration rate of dry quench coking in Japan's iron and steel industry is 72 percent, blast furnace cogeneration is 92 percent, basic oxygen furnace gas recovery is 90 percent, and continuous casting is 94 percent. The corresponding penetration rates of the these technologies in China are 4 percent, 16 percent, 40 percent, and 22 percent.

Improving the design, manufacture, and operational efficiency of widely used equipment, such as industrial boilers, fans, pumps, and compressors, is the last, but certainly not least, way of improving energy efficiency. China could reap tremendous energy savings by ending the production and use of low efficiency equipment and replacing it with high efficiency equipment. For example, a recent survey of several textile plants in Shanghai revealed that many of the fans are old and inefficient. If 1000 of the old fans were replaced by domestic high efficiency ones, and if the entire air flow system were designed to maximize efficiency, the factories could save a total of 27 gigawatt hours (GWh) of electricity per year and recoup their investment in two years. Opportunities to improve the energy efficiency of China's boilers, furnaces, and fans are discussed in the following three sections.

II. INDUSTRIAL BOILERS

China had 430,000 industrial boilers in 1991, more than any other country in the world. China's industrial boilers consume 9.1 exajoules of coal annually, about one third of total national coal consumption. The term "industrial boiler" refers to all devices, except household coal stoves and power plant boilers, that burn fuel to produce heat, hot water, or steam for industrial, commercial or residential use. The main uses of industrial boilers are making steam for industrial processes, heating water, heating homes, and cogenerating heat and power.

The minority of China's boilers use oil, consuming 0.16 exajoules of oil annually. China's industrial boilers have a total installed capacity of about one million tons of steam per hour; 280,000 are steam boilers with capacity of 700,000 tons of steam per hour, and 150,000 are hot water boilers with capacity of 280,000 tons of steam per hour.

If the thermal efficiency of China's industrial boilers were raised from the current 65 percent average to the 80 percent average attained by developed countries, then 1.7 exajoules of coal could be saved every year. According to a forecast of future boiler demand by the Energy Research Institute, the operational volume of boilers by the year 2010 will be about 1.5 million tons of steam. If this is correct, 2.6 exajoules of coal could be saved annually by raising the efficiency of China's industrial boilers from current levels to 80 percent.

FACTORS AFFECTING ENERGY EFFICIENCY

Why are China's boilers so inefficient? The major contributing factors are fuel quality, design and manufacture of combustion equipment, quality of auxiliary machinery, scale and load factor, degree of mechanization and automation, and waste heat losses.

The low quality of coal burned in China greatly decreases boiler efficiency. Of the total amount of coal consumed by industrial boilers, 76 percent is bituminous, 9.7 percent is anthracite, 9.1 percent is coking coal, and 5.6 percent is lignite. Most of it is unwashed, has high ash content (averaging 20-40 percent), and is often pulverized (45-65 percent are particles smaller than 3 millimeters). The underdeveloped market gives customers little choice in quality of coal. In developed countries, most industrial boilers use oil and gas. When coal is used, consumers select high-grade, washed coal of reliable quality with low ash content (averaging 5-10 percent) and even grain size (15-25 millimeter grain coal, with pulverized coal accounting for only 10-20 percent).

Obsolete design and poor manufacturing of combustion equipment also contribute to low boiler efficiency. Chinese boilers tend to use chain stokers, reciprocating stokers, and fixed stokers. Most equipment is at the level of the 1960s and 1970s. Advanced, efficient technologies currently used in other countries, such as spreader burning, vibrating stokers, and tipping stokers, have not yet been introduced in China. The main auxiliary machinery of boilers are fans, pumps, valves, instruments, and control equipment. The manufacturing quality and corresponding performance of such supporting parts affect the overall performance of boilers. The low quality of auxiliary machinery and accessories adversely affects boiler efficiency in China.

The country's 430,000 boilers are scattered in 220,000 boiler houses. They tend to be small and therefore inefficient. The average capacity of individual boilers is less than 2.5 tons per hour, whereas that of the United Kingdom is 6 tons per hour and that of the United States is 14 tons per hour. In addition, the designed power output capacity often does not match the load, leading to the widespread phenomenon of "big horses pulling small carts." The lack of coordination causes loads to fluctuate by 60 percent on average. Boiler houses in other countries are highly mechanized and automated, whereas most of the boiler houses in China are operated manually by workers with little or no training.

The low performance of China's industrial boilers is reflected in the high levels of excess air and high exhaust temperature (averaging at 140°C). The failure to recycle residual heat means energy is lost as waste heat.

POLLUTANT EMISSIONS

Particulate and sulfur dioxide emissions from boilers cause serious environmental problems in China. Even with filters, the particulate concentrations of exhaust from Chinese boilers range from 300-400 milligrams per cubic meter, much higher than the exhaust particulate standard of less than 100 milligrams per cubic meter in developed countries. China's emissions tend to be much higher than those of developed countries due to the use of unwashed and/or low quality coal. China began to install equipment to filter particulate matter in the early 1980s. The design efficiency of cyclone filters, those used in most small and medium-size boilers, is usually 90 percent, and the actual efficiency is 75-85 percent.

Sulfur dioxide emissions result in serious acid rain problems, especially south of the Yangtze River. Since about 90 percent of airborne sulfur dioxide comes from coal burning, measures to control sulfur dioxide emissions from boilers are urgently needed, but have not yet been adopted.

CHINA'S INDUSTRIAL BOILER MARKET

From 1986 to 1990, China produced 160,000 industrial boilers with capacity of 400,000 vapor tons, a 20 percent increase over the previous five-year period (1981-1985), with an annual growth rate of 3.5 percent. Altogether, over 300 specifications of industrial boilers are currently produced in China. The characteristics of the boiler market are as follows:

- **Boiler type.** The main types of boilers in China are water tube and water-and-fire tube fast-loading boilers. Only a small number are internal combustion and vertical boilers.

- **Combustion Equipment.** The most common type is laminated combustion equipment, most commonly chain stokers. They account for 53 percent of total industrial boilers output and 59 percent of total capacity.

- **Capacity.** Most boilers are low-pressure boilers with low capacity. The industrial boilers with capacities of less than 2 tons per hour account for 25 percent of the total, those with capacities of 4-6 tons per hour industrial boilers make up 45 percent, and those larger than 10 tons per hour account for 30 percent.

- **Water Heating.** Production of hot water boilers has grown rapidly to keep up with the demand created by new construction. Current output of hot water boilers accounts for 30 percent of total boiler output.

- **Consumer Profile.** The leading consumers of industrial boilers in China are light industry and textiles, according to statistics from the Ministry of Machinery and Electronics. (See Table 3-1.)

Table 3-1. Consumer Profile

Type of Industry	Percentage
Light industry and textiles	19
Coal, power, oil	15
Commerce	10
Farming, forestry, animal husbandry, sideline occupations, and fishery	7.3
Building materials	6.7
Chemicals	6.5
Education and scientific research organizations	6.2
Metallurgy	5.4
Communication and postal services	4.7
Export	0.5
Other	18

Source: Ministry of Machinery and Electronics.

The output of China's industrial boilers during the 1980s was 2.4 times that of the 1970s, if calculated in vapor tons. The annual growth rate was 9 percent. The Ministry of Machinery and Electronics forecasts future output as follows:

1995	85,000-100,000 tons of steam
2000	100,000-125,000 tons of steam
2010	130,000-160,000 tons of steam

The boiler market shows increasing demand in the following areas: advanced high-efficiency equipment, oil-burning boilers, environmentally friendly auxiliary equipment, large-scale boilers for central heating and cogeneration, and boilers of small capacity suitable for town and village enterprises and the service industry.

OPPORTUNITIES TO IMPROVE ENERGY EFFICIENCY

Under ideal testing conditions, the energy efficiency and particulate emission control of China's latest models of industrial boilers are fairly good: thermal efficiency coal-burning boilers with capacity of 4 tons of steam per hour is over 80 percent and particulate concentrations in flue gases are less than 200 milligrams per cubic meter. The gap between domestic products and foreign advanced products has thus been narrowed. Actual operating conditions, however, are less than ideal. Aggregate data show that the actual performance of China's industrial boilers is over 20 years behind that of developed countries. We recommend that China strive to close this gap by improving R&D, importing advanced technologies, and improving information and technical services.

Improving R&D. The research institutes of the Chinese Academy of Sciences, universities, and enterprises can be pulled together into a powerful R&D force to improve industrial boilers. R&D efforts can encompass not only design improvements for boilers, auxiliary machines, and environmental protection equipment, but also raising load factors and developing automated control systems. Engineers should optimize the design of the two most basic boiler types (water-and-fire tube boilers and fast-loading water tube boilers) using the most advanced domestic technologies. The government should ensure that new boilers are well designed by controlling production licenses, and systematically renovate existing boilers.

The focus of development in the days to come will be on central heating, cogeneration, and circulating fluidized bed boilers. The need for centralized heat supply and cogeneration can be met by developing boilers of large and medium capacity, improving adaptability to different types of coal, applying secondary wind and fly ash re-burning technologies, improving operational efficiency, and reducing the particulate concentration of exhaust gas. Circulating fluidized bed boilers have many advantages, such as a high burn-up rate (almost 98-99 percent) and the ability to use low quality coal. Currently, there are 21 boiler plants in China developing and experimenting with different versions of this kind of boiler. However, many problems still exist, and further research and technology importation is needed.

Importing Advanced Technologies. China needs to develop and/or import advanced models of the following equipment:

- Auxiliary machinery for industrial boilers;
- Boiler house equipment, including high-efficiency, low-noise blowers, induction draft fans, and secondary fans;
- Filter baghouses;
- In-boiler desulfurization and denitrification technologies;
- Pre-combustion coal treatment technologies;
- Waste water treatment and control technologies; and
- Automated equipment.

Improving Information and Technical Services. Better information services, system design guidance, and product maintenance services for design departments and customers are also needed.

III. INDUSTRIAL FURNACES

Industrial furnaces use about one quarter of China's total energy. The Energy Research Institute of the State Planning Commission of China estimates that 40 percent of the energy used by furnaces, or 2.9 exajoules, could be saved every year by raising furnace efficiency.

Furnaces are used in a wide range of industrial processes, from enamel firing to steel smelting. Most of the energy consumed by furnaces is used to make chemicals (22 percent), bricks and tiles (18 percent), iron (14 percent), and cement (12 percent). China has hundreds of different types of furnaces with varying levels of energy efficiency; describing and analyzing the energy efficiency of each kind is beyond the scope of this paper. Instead, this section will present a general picture and provide a detailed case study of one type of furnace, cement kilns, which account for 3 percent of the China's total energy consumption.

ENERGY EFFICIENCY OF INDUSTRIAL FURNACES

The average energy consumption per unit produced by China's furnaces is 40-100 percent higher than that of developed countries. While China has succeeded in developing and importing some advanced furnaces and supporting equipment that are at the level of the early 1980s, the majority of industrial furnaces now in operation, particularly those in small and medium-sized enterprises, and in enterprises at county level or below, are still at the level of the 1940s to 1960s.

Table 4-1
Comparison of Unit Energy Consumption of Industrial Processes Using Furnaces

Production Process	Energy Consumption per Unit Produced (gigajoules per ton)		Ratio of China to International Level
	China	International Level[a]	
Steel	29	18	1.6:1
Coarse Copper Smelting	50	41	1.2:1
Cement Clinker Material	5.6	2.9	1.9:1
Liquid Glass	88	41	2.1:1

Why does the efficiency of China's industrial furnaces lag so far behind those of the advanced countries? The main reason is that China's uses mostly small, old, coal-burning furnaces that lack mechanization and automation. Inadequate management and technical expertise, underutilization of residual heat resources, and insufficient market information service are also contributing factors.

The small scale of China's furnaces is a serious constraint to efficiency. For example, the average capacity of China's iron smelting blast furnaces is 230 cubic meters per set, whereas that of most existing blast furnaces in

[a] All statistics refer to Japan except for liquid glass, which refers to the United Kingdom.

CEMENT KILN CASE STUDY

A survey of cement kilns in the 1980s found them to be in dire need of technological renovation. Vertical shaft kilns accounted for 70 percent of cement production capacity and rotary kilns made up the remaining 30 percent. Half of the rotary kilns were low efficiency wet-method kilns, and the other half were dry-method ones that had undergone preliminary retrofits. Advanced dry-method rotary kilns equipped with devices to extract heat from the flue gas and preheat the kiln feed accounted for only 4.5 percent of production capacity.

The State Building Materials Management Bureau introduced a program aimed at raising the efficiency of these kilns. The program included technology development, optimization and comprehensive retrofit of the whole system, demonstration projects, and technical and economic assessments. Demonstration projects showed that technological renovation, i.e., renovating the existing facilities without fundamentally changing them, is a very quick and cost-effective way to improve efficiency.

The Energy Conservation Division of the Energy Research Institute conducted technical and economic assessments of energy conservation potential based on the results of the demonstration projects. (Energy Research Institute 1992) Their report concludes that if technological renovation is implemented throughout the cement industry in China, the total annual coal conservation potential is 0.33 exajoules, the annual power conservation potential is 38 million kWh, and the sum of the two amounts to 32 percent of the total energy consumption of China's cement industry in 1992. Raising cement kiln efficiency will require a $4.6 billion investment, far less than China will pay for additional coal and power if the technology remains at its current level. Raising cement kiln efficiency costs only $.29 per gigajoule of coal (less than one quarter the average price of coal in 1990) and only $.010 per kWh or electricity (less than one quarter the average price of electricity in 1990). Thus, these measures are not only practical in terms of overall economic efficiency, but are also financially feasible from the point of view of enterprises. (See Appendix A for more cost data.)

Japan is more than 3,000 cubic meters per set. Most of China's cement (70 percent) is made in shaft kilns with the average unit production capacity being 38,000 tons of clinker per set per year, while the corresponding figures for Japan, the former West Germany, and the United States are 70,000, 380,000, and 320,000 tons of clinker per set per year respectively. The output of China's large, advanced, dry-method rotary kilns only accounts for 4.5 percent of the total, whereas almost all cement is currently produced by this kind of kiln in Japan and the United States. China's large furnaces tend to be highly mechanized and automated, but the majority, which are small and medium-sized, have low levels of mechanization and automation. As a result, furnaces in China generally consume less electricity but more fuel than advanced foreign ones.

Reliance on coal, losses of waste heat, and inadequate selection of advanced refractory materials and auxiliary equipment also hamper efficiency. Most industrial furnaces in China use coal. The rest of China's furnaces use oil (13 percent), power (8 percent), gas (6 percent), or other sources (1 percent). Developed countries, on the other hand, tend to use primarily oil and gas. Blast furnaces and copulas in China use coke, produced in either industrial coke ovens or primitive earthen ovens. Cement kilns use pulverized coal. Brick, tile, and lime kilns and some heating ovens in small and medium-sized enterprises burn raw coal directly.

Large amounts of residual heat are wasted, as the residual heat recycling rate of furnaces is only 27 percent in the top four sectors producing residual heat in China (metallurgical, building materials, machinery, and light industries). Recently, China has produced more high temperature fireproof bricks, and pouring and injecting materials, but the selection is inadequate. The application of refractory fiber to insulate furnaces is expanding, but the product quality (particularly that of high grade refractory fiber for over 1,100°C) is unreliable. Its low quality not only affects its insulating qualities, but also affects the furnaces' life span, and therefore has a large impact on the energy efficiency of the furnace. China needs more furnace manufacturers that not only design and produce standard furnaces, but also design and produce supporting products, i.e., high efficiency burners, automatic control systems, and components for furnaces and walls.

OPPORTUNITIES TO IMPROVE ENERGY EFFICIENCY

Table 4-1 shows that, compared with Japan and the United Kingdom, Chinese production processes consume 20-110 percent more energy per unit of output produced. The difference is due mainly to the efficiency gap between furnaces in China and those in industrialized countries. In other words, if China's furnaces were raised to advanced levels, then these processes would use 17 to 52 percent less energy.

Unfortunately, China cannot renovate and replace all existing furnaces within the next 20 years. Even furnaces currently produced in China fail to attain advanced levels because of capital constraints and inadequate domestic supplies of highly efficient equipment. Capturing as much as possible of the large energy conservation potential of China's industrial furnaces will require eliminating low efficiency furnaces, importing and developing advanced furnace technologies, and renovating existing furnaces.

Eliminating Low Efficiency Furnaces. The Chinese government has issued orders to limit new construction and eliminate existing glass smelting kilns with low energy efficiency and less than 200 tons per day of glass output. The government has already closed down over 1,000 small cement plants. This work can be expanded in the future, and taxes and revoking production licenses can be used to speed up the elimination of low efficiency furnaces.

Importing Advanced Furnace Technologies. Only a small proportion of China's furnace production is standardized. Most furnace users commission professional design institutes to design their furnaces, and users often construct and/or install the furnaces themselves. As a result, new furnaces often fail to incorporate advanced technologies.

China has begun to rectify the situation by importing some relatively advanced industrial furnace technology from abroad:

- Wuhan Iron and Steel Company imported heat exchangers from the former West Germany.
- The Third Iron and Steel Plant of Shanghai imported hot air iron smelting furnaces from the former West Germany.
- Baoshan Iron and Steel Company imported dry coking extinguishing equipment and heat utilization equipment for sintering machines from Japan.
- Taiyuan Iron and Steel Plant imported burning method converter gas recycling equipment from Austria.
- Advanced floating glass production assembly has been imported from the United Kingdom and the United States.
- Production assembly lines of dry method rotary kilns with precalciners have been imported from Japan.

International cooperation in improving China's furnace technology can be strengthened in the future.

Renovating Existing Furnaces. The large numbers of existing furnaces will continue to operate for the next 10-20 years. Therefore, the Chinese government can continue to sponsor technological renovation of existing furnaces.

IV. FANS

China has approximately 3.9 million fans, according to incomplete statistics for 1990. The overwhelming majority of fans is driven by electric motors. Overall, fans consumed one tenth of total electric power in 1990. In some industrial sectors, such as food processing and the production of cement, fertilizer, light bulbs, and iron and steel, fans consume more than a fifth of the sector's total power (see Table 5-1.).

Table 5-1
Power Used by Fans as a Percentage of Each Industry's Total Power Use

Type of Industry	Percentage of Power Used by Fans
Cement	30
Fertilizer	25
Light Bulb	24
Food Processing	22
Iron and Steel	20
Glass	18
Textile	15
Beer	13
Coal	10
Oil-refining	10
Paper-making	10
Thermal Power Plants	0.6-4.0

Fan efficiency improvements can save hundreds of millions of kilowatt hours and millions of dollars every year, as the following examples illustrate:

- The 8,000 iron-smelting furnace fans designed and manufactured by Hubei Ventilator Factory are currently saving 140 GWh of power each year. If all of the 25,000 cupola furnaces in the country were equipped with that type of fan, then 450 GWh could be saved annually, cutting yearly electric power costs by $128 million.

- The Shenyang Ventilator Plant and The Northeast Industrial Institute jointly developed an axial flow fan used to ventilate mines. By increasing static efficiency by 14 percent over the old model, each fan saves 85 GWh of power annually, reducing electricity bills by $2.4 million per year, if yearly demand is calculated at 8,760 hours per year per set for 150 sets.

- The Shenyang Ventilator Factory designed and manufactured the DH centrifugal compressor, a double-axis, four-level centrifugal compressor, using imported technology. The compressor is used mainly in aerodynamic stations and air separation devices in large scale enterprises and has great energy conservation potential. For example, the compressor with a 10,000 cubic meter air separation device uses 1.8 GWh less power per year than a similar device made in Germany. It uses 5.6 GWh less than the products of another foreign company, and 15 GWh less than the old DA350-61 centrifugal compressors made in China. If all 200 of the obsolete DA350-61 compressors currently operating in the country were replaced with DH type compressors, then 3,000 GWh of power could be conserved each year, saving $84 million per year.

- The full-pressure internal efficiency of Y5-47 series boiler centrifugal induction draft fans, produced by Anshan Ventilator Factory, is 85.6 percent. The 5,500 sets of Y5-47 series products manufactured by the factory since 1989 have a total capacity of 94 megawatts (MW). If they were to replace old Y4-70 and Y9-35 series fans, they could save 12 GWh of power annually (calculated at 3,000 operational hours per fan per year), cutting annual power bills by $330,000.

- The 1,200 9-19 and 9-26 series fans manufactured by Beijing Ventilator Factory in 1991 have 34,000 kilowatts (kW) of capacity. They operate for 5300 hours per year. If they were to replace the old 8-18 and 9-27 series fans currently in place, 180 GWh of power could be conserved and $5 million could be saved annually.

STATE EFFORTS TO IMPROVE FAN EFFICIENCY

In the 1950s, China imported fans from the Soviet Union or produced fans according to Soviet designs. In the 1960s, Chinese engineers started to imitate the design of Soviet products. In the 1970s, they independently developed and manufactured fan products, gradually improving their design capabilities. They assimilated, absorbed, and experimented with patented fan production technologies imported from abroad, and, as a result, the performance of China's fans improved considerably. Since the 1980s, China has successfully introduced advanced fan technology from abroad, and China's turbo-compressors and large scale ventilators are among the world's most advanced fan technologies.

Most fans produced in 1970s had low efficiency. During that decade, for instance, China produced many 8-18 series and 9-27 series high pressure centrifugal ventilators using technologies developed in the 1950s. Their total pressure efficiency is only about 65 percent, 15 percentage points lower than that of similar products in other countries. The 50,000 centrifugal ventilators in China consume 1,000 GWh more power than high efficiency ventilators of the same type in other countries. To take another example, the efficiency of the 2BY series and 70B2 series, the main ventilators used in coal mines, is only 70 percent. If calculated at average power capacity of 500 kW of each unit, the 4,500 ventilators used by state-run coal mines consume 600 GWh more power each year than similar ventilators in other countries with 83-88 percent efficiency. Low efficiency ventilators such as these are still widely used in China.

Faced with the problems of obsolete equipment and limited technical expertise, domestic fan manufacturers joined forces in the early 1980s to improve the design of several widely used fans. With the help of universities and research institutes, Chinese fan manufacturers improved product and system design, and raised the efficiency of five different types of fans by 6 to 16 percentage points over previous models.

Importing technology from abroad has also helped improve efficiency. The Shenyang Ventilator Factory imported DH-type double axis fourth-level compressor technology from the Hitachi Company of Japan. The main features of these high performance, economical, reliable products are the adoption of ternary moving blades and operation of all the blades of each level at the optimum speed (equivalent to isothermal compression), making efficiency of the whole unit as high as 75 percent.

The fan industry has developed 28 types of high efficiency fans since 1982, according to state statistics on energy efficient products.

MAJOR FACTORS AFFECTING ENERGY EFFICIENCY

Fan efficiency is determined by the efficiency of fan design and by the efficiency of the system within which it operates. Efforts to conserve energy used by fans should place equal emphasis on improvement of design efficiency and operational efficiency.

Design Efficiency

After a decade of technology importation and domestic R&D, the design and manufacture of China's fans show considerable improvement. However, the efficiency of Chinese fans is generally 2-3 percent lower than advanced levels.

China lags behind the developed countries in the use of advanced theories and technologies, such as the ternary moving theory and the use of magnetic bearings. China needs to further develop computer assisted design and manufacturing, electronic speed controls, diagnostic systems to predict potential problems, and equipment to test thermodynamic properties and analyze stability. The world's leading manufacturers of turbo-compressor have achieved single level pressure ratios of 2.5-6.0, whereas China's is only 2.2. In other countries, the linear velocity of turbo-compressor blade wheels has reached 380 meters per second (450 meters per second for the half-open type), while China's is only 340 meters per second. The moving speed of bearings in other countries is as high as 100 meters per second, while China's is only 80 meters per second.

Other countries have developed several varieties of turbo-compressors for large-scale equipment. In China, however, the following fans are not available domestically: compressors for 0.3-0.5 million tons per year synthetic ammonia equipment; compressors for 0.3-0.45 million ton per year of ethylene equipment; and compressors for 30,000 meters per hour of air separation equipment. Plate pretreatment equipment, numerical control, and photoelectrical and plasma cutting are widely used in manufacturing in other countries, with the numerical control cutting rate reaching 100 percent in some countries. Plate pretreatment equipment and photoelectrical cutting have not been adopted at all in China, and numerical control cutting only accounts for 40 percent of fan production.

China's machine processing equipment lags behind that of the foreign plants in programming, automation, and the degree of adoption of numerical control machines. Processing systems that are centrally controlled by large computers are more developed in foreign countries than in China. Other countries use advanced equipment to mold ventilation under pressure, while China still uses inefficient model pressing, which requires many dies and a large area for stock.

System Efficiency

Even high efficiency fans will waste energy if the system in which they operate is inefficient. Operational efficiency can be improved by choosing the right size of fan, installing and using speed controls, and improving fan maintenance.

Incorrect calculation of air volume and pressure requirements leads to selecting fans of the wrong size. Selection of a fan that is too big may lead to the increase of actual air volume, power capacity, energy consumption, primary investment, size and weight, and other adverse consequences. Selection of fan that is too small, on the other hand, may lead to insufficient air volume and failure to meet production needs, as well as low efficiency of electric motors that are constantly operating at low load. Improper fan selection is due to both flawed design specifications and technical problems. In some cases, non-professionals fail to carry out adequate investigations, calculations, and analysis in selecting fans, relying on the existing models at hand alone. In other cases, designers place excessive emphasis on safety and ignore economic considerations. As a result, they overestimate the air volume and pressure requirements in their calculations. Technical problems leading the selection and use of the wrong size of fan include inferior quality of design and installation of pipe systems, poor maintenance and management practices, and the appearance of unexpected problems which design personnel are unable to solve.

About 90 percent of fans in China have no controls, which means they often operate at less than full load, resulting in inefficient operation of fans and the electric motors driving them. Since the power required to drive a fan is proportional to the cube of its speed, reducing speed at part load can result in enormous energy savings. For example, an investigation of a certain iron and steel company revealed that only the draft fans of sintering plants and the furnace blast and induction draft fans of power plants had controls. The rest had no controls or had only entry (or exit) throttling controls. It is not unusual for controls not to be used even when they are attached to fans. The absence of accurate specifications for air pressure and volume, coupled with the lack of necessary controls, means that operational efficiency will be low even if high efficiency fans are selected. An investigation conducted by the Northeast and Inner Mongolian Coal Industrial Cooperative shows that less than 10 percent of fans tested meet the 70 percent operational efficiency requirement set by the State Council, and that more than 60 percent of fans have operational efficiencies of less than 55 percent. The fact that only 15 percent of the fans have a load rate above 76 percent, whereas more than 65 percent fans have a load rate below 60 percent, reveals the huge potential for energy conservation.

Many enterprises have no on-site managers responsible for maintaining fans. Some maintenance personnel are concerned only with reliable operation and do not understand the importance of energy efficiency. As a result, many firms use fans that have been banned by the state and leave fans on even when they are not needed. For example, an investigation of a large scale iron and steel company discovered that the factory persisted in using obsolete fans, self-made ones, and fans designated by state regulations as being in need of immediate removal owing to their extremely low efficiency. This kind of situation directly violates the "three prohibitions" stipulated by the State Economic Commission and Ministry of Machinery and Electronics, i.e., prohibition of the manufacture, use, and purchase of inefficient fans. Another investigation of 12 plants of an iron and steel company showed that among the company's 660 total existing fans, as many as 460, or 69 percent, were prohibited. In some plants, all the fans were prohibited, and fans were often left on even when they were not needed.

OPPORTUNITIES TO IMPROVE EFFICIENCY

Taking the following measures will encourage the improvement of fan efficiency in China:

- **Promoting manufacture of efficient models of widely used fans and introducing a production licensing system in order to reduce the existence of substandard and inefficient fans.**

- **Introducing advanced fan technologies from abroad and providing a greater variety of fans so as to give customers a wider selection.**

- **Studying and introducing advanced design theories and methodologies for developing high-efficiency products to replace existing obsolete methods, and testing new products.**

- **Developing and introducing new speed control equipment and capacity control equipment so as to improve fan system efficiency.**

- **Developing and introducing better processing techniques so as to raise product quality, lower manufacturing costs, and reduce labor intensity.**

V. SMALL COGENERATION

In addition to improving the efficiency of equipment, China can also save energy through cogeneration, that is, using waste heat or pressure from industrial processes to generate electric power. Small cogeneration refers to units of less than 6 MW. China built 1.8 gigawatts (GW) of small cogeneration capacity during the 1980s with annual generation of about 8 billion kWh. Installing this cogeneration capacity helped alleviate power shortages and reduced environmental pollution.

OVERVIEW

When China began to focus on energy conservation in the late 1970s and early 1980s, the government designated small cogeneration as a key energy saving measure in the technological renovation of existing enterprises. Development of cogeneration projects in all sectors and localities has been encouraged and supported by the adoption of policies such as the establishment of a special fund for technological renovation, subsidies for energy conservation loans, and pre-tax loan payment terms.[a]

Small cogeneration is divided into two major categories: power generation from residual heat and power generation from residual pressure.

Power Generation from Residual Heat

Residual heat boilers and turbo-generator units use combustible gas emissions or heat from chemical reactions to generate power. Currently, these small cogeneration units have a total capacity of 700-800 MW. They do not require any additional energy beyond the waste heat produced by other industrial processes. Small cogeneration has been developed in various industries, including iron and steel, chemicals, building materials, non-ferrous metals, and petrochemicals.

Blast furnace coal gas from iron and steel production has low combustible content, with CO accounting for 30 percent. Except for a small quantity of hydrocarbons, the rest is non-combustible. In the past, this low heat value coal gas (800-900 kilocalories per cubic meter from small blast furnaces, and 600-700 kilocalories per cubic meter from large blast furnaces) was emitted, leading to environmental pollution and energy waste. In the mid-1980s, some boiler plants in Hangzhou and Wuxi developed 10 tons per hour, 35 tons per hour, and 75 tons per hour boilers that burn only low heat value coal gas. These boilers have proven successful and can drive 1.5 MW, 3 MW, 4 MW or even 12 MW turbo-generators. Some independent iron plants in Sichuan, Jiangsu, and Henan have set up scores of blast furnace coal gas power generator units.

There has been a trend toward building large high-pressure blast furnaces, then recycling the power from the coal gas pressure and attaching turbines for generation. This type of equipment is called a top recovery turbine (TRT). TRT development began rather late in China--so far only 7 units have been set up (including two imported ones), with a capacity of 78 MW. Annual power generation is expected to reach 320 GWh. TRT units do not consume energy and they have low generation costs. There are four plants in China that can manufacture TRT equipment, including the Shanxi Ventilator Plant and the Shanghai Turbine Plant. Currently, wet-method filters are generally used for blast furnace coal gas dust elimination. If dry-method filters (electrostatic precipitators) are adopted for furnace top coal gas dust elimination, then for the blast furnaces installed with TRT units of the same capacity, dry-method ones will generate 40 percent more power than wet-method ones.

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[a] The Chinese government allows firms to deduct payments on certain types of loans, including energy conservation loans, from their taxable income.

Sulfuric acid plants use residual heat from sulfuric incinerators to supply residual heat boilers. The production of each ton of sulfuric acid can then produce 1 ton of medium-pressure steam as a byproduct, from which 200 kW power can be generated. Of this total, 100 kW of power is used by the plant itself, and the other 100 kW of power is supplied to other users. Rough statistics show that as of 1988, 68 MW of sulfuric acid residual heat power production units had been built, with annual power generation of 260 million kWh.

Carbon black plants consume large quantities of energy and emit large amounts of pollution. Carbon black production consumes 2.5-3 tons of crude oil per ton of output, including oil used as both feedstock and fuel. In the energy balance, chemical heat accounts for 34 percent in its tail gas, which is emitted as waste gas. The former Soviet Union started to design tail gas boilers in the 1970s, but as of 1975, only one carbon black plant used tail gas boilers. China also started its research of tail gas in the 1970s, and in 1978, the first boiler burning carbon black tail gas was built in the Shaoyang Carbon Black Factory, Hunan Province. It was used for power generation. In 1980, the Hangzhou Sunrise Boiler Plant designed and tested low heat value tail gas boilers of two sizes (10 tons per hour and 20 tons per hour) and four specifications.

Hollow rotary kilns are primitive dry-method kilns used for cement production. China has 200 of these kilns, and the temperature of their exhaust gas is 850-950°C. In hollow dry-method rotary kilns without residual heat devices installed, heat losses from exhaust account for 40-50 percent of total heat consumption. For instance, a hollow dry-method kiln with an annual production of 10,000 tons of cement has an annual heat losses from exhaust of more than 290,000 gigajoules. For this reason, over the past decade, the dry-method hollow kilns in large and medium-sized cement plants have all been renovated into residual heat generating kilns. Currently, there are 50 kilns of this kind, with 100 MW of installed capacity and 500 GWh of annual power generation.

Power Generation from Residual Boiler Pressure

The other main type of small cogeneration is power generation using residual pressure from boilers. Most of China's 430,000 boilers are small, and their scattered operation leads to irrational energy use. For the purpose of energy conservation, the Chinese government drew up a policy which stipulated that "all industrial boilers with unit capacity of more than 10 tons per hour or collective capacity of more than 20 tons per hour and more than 4,000 hours of annual operation should adopt small cogeneration." Over the past decade, Chinese enterprises have installed many residual pressure small cogeneration units, with total installed capacity of 1,000 MW. Back pressure turbo-generating units are generally used, and energy consumption is 250 grams of coal equivalent per kWh. This type of small cogeneration device is applicable to places with year-round or even round-the-clock negative balance, stable heat load, and heat/power load. Great potential for its development exists in the textile, paper-making, and sugar refining industries.

The textile printing and dyeing industries have a stable heat load and balanced heat/power load, thus creating favorable conditions for development of small cogeneration. During the 1980s, China invested 330 million yuan in the textile industry cogeneration. As a result, 90 small cogeneration devices have been put in place with installed capacity of 270 MW. These devices generate power using residual steam pressure and substitute temperature and pressure reducing devices with back pressure units. The advantages of textile industry cogeneration are the use of simple equipment, small investments, low cost, fast construction, and stable and reliable operation. Generally speaking, the design, implementation, equipment installation, and commencement of operation can be achieved in approximately one year. As for places in which heat load changes greatly, back pressure turbo-generating units can be used to adjust the load.

Current installed cogeneration capacity of the sugar refining and paper industries stands at 500 MW. Most of China's sugar refining and paper production enterprises are too small to use small cogeneration. However, the development of small cogeneration in large-scale paper making and sugar refining enterprises has saved them energy and money.

OPPORTUNITIES FOR DEVELOPMENT

China has great potential for further developing small cogeneration from both industrial residual heat resources and boiler residual pressure resources. Incomplete 1990 statistics on the iron and steel, non-ferrous metallurgy, petrochemicals, building materials, chemicals, light textile, and machinery industries show that residual heat resources suitable for use totaled 1.2 exajoules, of which only 30 percent are currently being used. For example, over two thirds of the total residual heat resources of the iron and steel industry is high-temperature residual heat. If calculated in terms of exergy, the energy of high-temperature residual heat accounts for over 90 percent. In addition, large quantities of medium and low temperature (200-400°C) residual heat resources remain unutilized in China. R&D is needed in this area.

As for boiler residual pressure resources, experts estimate that the capacity of industrial boilers of over 10 tons per hour totals 250 thousand tons of steam. Almost half of the boilers of this size are suitable for small cogeneration development with possible installed capacity reaching over 10 GW. Less than 10 percent of this total is currently being used.

China can promote further development of small cogeneration by taking the following measures:

- **Formulating policies to promote development of small cogeneration.** Incentives can include loans, credits, tax breaks, and electricity price discounts. Also, if they are connected to the grid, small cogeneration units should not be used in peak modulation because back pressure machines and extracting back pressure machines require very stable heat loads in order to maintain high efficiency.

- **Pooling efforts to research new types of residual heat boilers, and producing them according to standards.**

- **Strengthening guidance for enterprises.** Local economic management departments can instruct enterprises in conducting feasibility analyses and selecting appropriate cogeneration equipment.

VI. THE TRANSITION FROM PLANNING TO MARKETS: POLICY OPPORTUNITIES

China clearly has great potential to improve energy efficiency, but capturing that potential will require major policy and institutional changes. The government will have to transform itself from an administrator of energy efficiency programs to a catalyst for energy efficiency business in the private sector. Enterprises that have become accustomed to applying to the state for energy efficiency grants will now have to apply for loans from commercial banks. The government's view is that now that enterprises are allowed to retain their profits, they can reap the financial benefits of energy conservation, and they ought to shoulder the burden of the investment as well. As a result, state investment in technological renovation has declined every year for the past decade. (China State Statistical Bureau 1992) Energy conservation's share of total investment in technological renovation fell from 4.2 percent in the early 1980s to 3.2 percent in 1992. Average annual state appropriations and preferential loans directly devoted to energy conservation projects dropped from $120 million in the early 1980s to $73 million in the early 1990s.

Unfortunately, enterprises do not appears to be picking up the slack left by decreases in state investment. The majority of new factories built in the 1980s, which constitute a significant proportion of the nation's total, use obsolete processes and lack economies of scale, and are therefore very inefficient. If the problem goes unchecked, China will miss the opportunity to raise its efficiency and will suffer the consequences for a long time to come. Why is China failing to invest in energy efficiency? Experts often cite the scarcity of capital, yet billions of dollars in overseas capital are pouring into China's power sector.

THE INVESTMENT GAP

China's success in financing electric power development provides an interesting contrast to its failure to finance energy efficiency. As in the case of conservation, the state has steadily reduced its share of investment in power production, but new power plant construction, unlike conservation, has attracted funds from both local governments and foreign investors. In China, as in the rest of the world, investment tends to gravitate toward building new power plants even when demand side measures such as energy conservation are more cost-effective within the same time frame. Discussions with officials, utility managers, and entrepreneurs all over China reveal the extent of the investment gap. For example, one of the energy conservation offices of a large southern city has abandoned its conservation responsibilities in favor of building a power plant. The head of the power division of a major enterprise in North China said he would rather buy fuel and power as long as he had the money--it was so much simpler than conserving energy. An entrepreneur in East China said he would rather make an investment in a paper mill with five-year payback than in an energy conservation project with two-year payback. The problem is that the two types of investments, supply side and demand side, do not compete on a level playing field because of the legacies of central planning, market failures, and lack of awareness of the importance of energy efficiency. These three sets of barriers to efficiency and ways to overcome them will be discussed in detail below.

Legacies of Central Planning

Many of the reasons why enterprises fail to invest in energy efficiency are legacies of central planning. The overwhelming majority of enterprises were state-owned during the centrally planned period and managers (or party secretaries) were appointed and supervised by government officials. Production targets were dictated from the top, and most of the profits were turned over to the state, leaving little autonomy for enterprises. Enterprise autonomy has grown during the reform period, but managers of most firms are still appointed by government officials, and through the managers, the government still has the right to control some of the firms' financial transactions and approve or revoke business licenses. The government can even exert some control over privately-owned enterprise and town-and-village enterprises. Thus, enterprises are still greatly influenced by government intervention, particularly in the energy sector, where reform has been relatively slow. Energy production and supply are still mainly controlled by the state planning process. The role of the market is increasing, but still affects less than half of all transactions. The expansion drive, energy price subsidies, short-term behavior of managers, and the other obstacles to energy conservation described below can be best understood in this context.

The expansion drive is one of the worst legacies of central planning. China's current "expansion fever" is as rampant as it was during the centrally planned period, when government agencies at all levels set high production targets. Government officials and managers still tend to stress expanding production by increasing inputs while neglecting to raise internal efficiency. Those managers who are willing to invest in energy efficiency are often unable to obtain loans because the government pressures banks to direct their limited financial resources to capital construction projects, leaving very little for energy conservation.

Energy price subsidies are an equally serious barrier to efficiency. The government subsidized low prices for energy and raw materials until the late 1980s. This not only inflated the demand for energy, but also failed to provide enterprises with incentives to invest in energy efficiency because of low rates of return. Despite many energy price hikes, the situation has not improved because energy price reform has been outpaced by price reform in other sectors. From 1980 to 1991, the average annual growth rate of the selling price of raw coal produced by China's key enterprises was 10 percent, but coal production costs rose by 10 percent as well. Not until the early 1990s did China rapidly adjust the relative prices of energy. However, the distortion of energy prices is yet to be completely rectified, and thus energy efficiency is still unable to compete on an equal footing with other investments.

Unclear ownership rights also affect efficiency. Managers still do not own their enterprises and are often transferred between different enterprises. Therefore, they have no stake in the firm's long-term success or failure. In order to get a good performance review and be promoted to manager of a bigger plant, the manager must produce more output value, more profits, and more benefits for workers. This emphasis on short-term results discourages investment in energy efficiency. When an engineer proposes an energy conservation project (e.g., replacing an inefficient piece of equipment with a highly efficient one) to the manager, and suggests that the loans be paid back in three years, the first thought that occurs to the manager is that his/her term is just three years, and that s/he may not even be around to receive praise when the investment begins to pay off. Thus, the manager has no incentive to take the risk associated with a long-term investment.

"Forced substitution" refers to the involuntary use of inappropriate inputs due to shortages, a common phenomenon in planned economies. This particular type of shortage is not an absolute but relative; it is the result of irrational allocation of goods in the absence of market mechanisms. (Kornai 1980) Forced substitution results in the use of inappropriate types and qualities of fuel and equipment. For example, due to scarcity, most Chinese enterprises use coal rather than oil or gas, and they often use low quality coal that is not suitable for their equipment, both of which lead to lower efficiency. Limited selection of equipment poses a similar problem.

Corruption is another contributing factor. Managers of state enterprises are classified as "officials" in China. Government agencies at all levels often appoint officials as managers, or transfer managers to official posts. Exchanges of power and money within this unified system sometimes interfere with raising energy efficiency. For example, low efficiency, substandard products from ailing state enterprises can easily be sold on "commission" or through "connections," while highly efficient products in the private sector are unable to compete.

Even energy conservation officials can be part of the problem if they remain rooted in a central planning mentality. Some officials, accustomed to drawing power from their control over state energy conservation resources, complain that their financial resources are drying up and threaten to quit. They fail to realize that the shift to a market economy means transferring most of the burden of energy efficiency investment from the state to the nonstate sector. They delay reform by debating the scale of state investment instead of focusing on developing new market incentives and regulations to encourage energy efficiency.

Market Failures

Not all barriers to efficiency can be attributed to the remnants of central planning. Obstacles to energy conservation exist even in market economies due to market imperfections, incompleteness, and other factors. China's underdeveloped market mechanisms exacerbate problems common in the west, including risk, insufficient information, high implicit consumer discount rates, and externalities.

Consumers usually lack the time and energy to collect the information needed to compare all available options before making a purchase, and they may have trouble comparing the lifetime costs (initial cost plus energy consumption cost) of various types of equipment. Consumers also lack the resources to verify manufacturers' claims of product quality and reliability. Given these challenges, many consumers tend to hastily select a relatively cheap product that may be inefficient, inappropriate for the system, and in the end, uneconomical. The risk involved in choosing an unknown product also discourages managers from replacing old obsolete equipment.

Another barrier to the purchase of highly efficient equipment is the high implicit consumer discount rate. Consumers may be unwilling to pay the higher upfront cost of insulated housing or high efficiency motors even though they will pay less in the long run when savings on their utility bills are added into the equation.

When enterprises waste energy, the additional emissions released incur various environmental and health costs, ranging from forest damage due to acid rain to lung disease from inhaling coal dust. Because companies do not have to pay for the damage they cause, environmental and health effects of inefficient energy use are "externalities." If these costs were incorporated into the price of fuel or inefficient equipment, i.e., if the externalities were internalized, enterprises would have greater financial incentives to save energy than they do now.

Attitude Problems

A couple of the obstacles to efficiency are related to attitudes and are not specific to either type of economic system. One key problem is that some policymakers do not understand the importance of energy conservation. They think that because individual energy conservation projects are small they can never add up to significant savings. People unfamiliar wimanagement fail to see how a combination of electricity efficiency improvements can actually take the place of a new power plant. Another problem is that many customers purchasing vehicles and household appliances are more concerned with the appearance and features of the products than with their energy efficiency.

POLICY RECOMMENDATIONS

Overcoming the constraints to efficiency described above will require speeding up economic reform and formulating a range of new polices, from command-and-control standards to market-based incentives and penalties. The state will have to devise ways to shift the burden of energy efficiency investment from itself to the nonstate sector, leveraging its limited funds through interest rate subsidies and tax breaks, and supporting the creation of nonstate energy efficiency organizations. Government agencies at all levels can promote better understanding of energy efficiency by supporting public education and social research in this area.

Accelerate Economic Reform

Because many obstacles to energy efficiency in China today are legacies of central planning, the key to overcoming them is to pick up the pace of economic reform and promote market development. This means freeing energy prices, clarifying ownership rights, and separating the government from enterprises. Progress toward a market economy will lead to more efficient allocation of goods and services, and provide energy producers and consumers with more incentives to raise efficiency.

Establish New Regulations to Address Market Failures

Economic reform alone will not ensure adequate levels of energy efficiency. Establishing energy efficiency standards and engineering design review can help overcome the problems of risk, inadequate information, and high implicit consumer discount rates associated with market economies. An efficiency standards program can include the following elements:

- **Establishing a system for setting and periodically revising efficiency standards for various types of equipment.** Efficiency standards overcome the high implicit consumer discount rate problem. The Chinese government has developed some energy efficiency standards for equipment, but the agencies that designed them have neither the legal nor political authority to enforce them. These agencies also need to do more research to determine what level of efficiency is feasible and decide how to enforce standards.

- **Issuing production licenses only to enterprises that produce equipment that meets the standard.** China needs to regulate engineering design in order to prevent the construction of new inefficient enterprises. Many engineering design departments are still designing inefficient equipment and do not design systems to optimize efficiency. The problem can be addressed by requiring engineering design review and issuing production licenses only to efficient enterprises. Shanghai and Beijing have led the way in this area. In 1993, they both introduced an energy efficiency review process as part of the design review and business licensing procedure for enterprises in energy intensive industries.

- **Testing equipment to guarantee product quality, reliability, and efficiency and reduce consumer risk.**

- **Labeling equipment with energy efficiency and lifetime cost information.**

Use Carrots and Sticks

China can also benefit from a revised system of incentives to save energy and penalties for wasting it. For example, the government can replace the energy rationing system of the 1980s with a regulatory structure similar to China's pollution emission fee system. The old energy rationing system succeeded in controlling energy use, but failed to encourage energy efficiency. Although enterprises that achieved energy savings were rewarded financially, they also ran the risk of having their energy ration reduced. In many cases, the enterprises felt that the money from the government was inadequate compensation for the losses resulting from a reduced energy ration. A more effective regulatory system would be similar to the state's emission fee system for pollutant releases, which is based on the "polluter pays" principle. The more emissions the polluter releases, the higher the fee. Conversely, reducing emissions through energy efficiency would result in lower fees. The emission fee system would be coordinated with other financial incentives, allowing enterprises that save energy to save money as well.

The government can also use taxation to encourage energy efficiency. For example, the government can give tax breaks to manufacturers and end users of highly efficient equipment, and an energy tax can be levied on those enterprises that have rapidly expanded production without raising energy efficiency. This type of irrational expansion is very common in China now because fast economic growth has led to shortages of construction materials such as steel and cement, and the high demand has led to price hikes, allowing high profit rates for steel and cement producers, regardless of their efficiency. However, such an energy tax might be difficult to collect. If the inefficient enterprise refused to pay an energy tax, the government could raise the firm's income tax or sales tax.

Shift Responsibility to the Nonstate Sector

The state played a dominant role in implementing energy efficiency improvements in the 1980s. The State Economic and Trade Commission allocated an annual average of $120 million in grants and preferential loans to technological renovation energy efficiency projects in the 1980s and an annual average of $73 million in the early 1990s. In addition, the State Planning Commission's Energy Conservation Investment Company invests about $18-27 million in state-owned enterprises for capital construction energy efficiency projects (e.g., small cogeneration, cement kiln renovation, and fluidized-bed combustion boilers) every year.[a]

State energy efficiency funds were important in the past and will continue to play a role in the future, but the bulk of future investment will have to come from enterprises, which will have to borrow money from commercial banks. Future state investment in energy efficiency may be limited to providing subsidies for interest on loans, supporting major demonstration projects, and developing new technologies. The state will have to rely on the regulations and incentives described above to encourage nonstate investment in energy efficiency.

The changes in the state's role will eliminate many of the state sector jobs involving administrating energy efficiency funds and managing projects, but will create opportunities for designing and implementing new policies, raising public awareness, and creating new institutions in the nonstate sector to provide technical and financial services in energy efficiency. The new institutions may include energy efficiency service centers, energy research societies, energy efficiency design review and supervisory agencies, and highly efficient equipment leasing companies. One example of a new institution is BECon, the Beijing Energy Efficiency Center. BECon is an independent, not-for-profit organization, established in 1993 to develop energy efficiency policy, promote international energy efficiency business development, provide information on energy efficiency technology, and coordinate technical training and demonstration projects.

Expand Public Education Efforts

Insufficient information is one of the major obstacles to energy efficiency. The Chinese government has promoted public awareness of the importance of energy efficiency by

- Designating the first week of October as energy efficiency education week
- Setting up energy efficiency technical service centers in each province and city
- Disseminating energy efficiency publications
- Supporting the establishment of energy efficiency academic societies
- Sponsoring workshops, technical exchanges, conferences, and exhibitions.

Current efforts are useful but scattered, and could benefit from better coordination. Government agencies and enterprises engaged in promoting energy efficiency could be more effective if they established an energy efficiency information/service network. The network could provide general information and specific recommendations to enterprises, customers, and design departments both before and after the installation of energy efficiency products.

Conduct Policy Research

Developing effective energy policy requires an approach that encompasses both economics and engineering, and integrates both supply side and demand side perspectives. Recognition of the need for an interdisciplinary

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[a] Energy conservation is divided into two categories in China. The term "technological renovation" refers to technological improvements of existing enterprises; this is supervised by the State Economic and Trade Commission. The term "capital construction" refers to establishing new facilities with energy efficient technologies; this is supervised by the State Planning Commission.

approach to energy policy led to the creation of several energy research institutes in China over the past decade. Organizations such as the Energy Research Institute of the State Planning Commission, the China Energy Research Society, the Beijing Energy Institute, and the Shanghai Energy Research Institute have become important resources for energy policy makers at the state and local level. The Energy Research Institute, for example, has developed the following capabilities:

- Energy forecasting and energy development planning
- Assessing new energy efficiency and renewable energy technologies and products
- Performing energy-related environmental assessments
- Assessing energy technology imports
- Developing energy standards and other policies.

Energy policy research, however, is underfunded and remains a weak link in China. Ongoing research is needed to help China develop energy policies to suit its evolving economic system.

CONCLUSION

Inefficient energy use is creating a multitude of economic and environmental problems in China, not to mention its contribution to the threat of global climate change. The Chinese government recognizes the serious implications of the country's growing greenhouse gas emissions, but refuses to sacrifice economic growth in order to control them. Therefore, China welcomes foreign assistance in reducing emissions through measures such as improving energy efficiency that benefit both China and the rest of the world. However, in a country as big as China, foreign aid can only play a small role. The important changes--continuing to rationalize energy prices, enforcing energy efficiency standards, and creating market-based incentives to save energy--must come from within.

WORKS CITED

1. *China Energy Statistical Yearbook.* (In Chinese.) Beijing: China State Statistical Bureau, 1991.

2. *China Machinery and Electronics Industry Yearbook.* (In Chinese.) Beijing: Ministry of Machinery and Electronics, 1991.

3. *China, Reform and the Role of the Plan in the 1990s.* Washington, DC: The World Bank, 1992.

4. *China Statistical Yearbook.* (In Chinese.) Beijing: China State Statistical Bureau, 1992.

5. *Energy Conservation Potential of Four Major Energy Consuming Sectors in Jiangsu Province: Analysis and Counter-Measures Study.* (In Chinese.) Beijing: Energy Conservation Division, Energy Research Institute, 1992.

6. Dai Yande. *Energy Problems in Rapid Economic Growth.* (In Chinese.) Beijing: Energy Research Institute, 1992.

7. Janos Kornai. *Economics of Shortage.* Amsterdam: North-Holland, 1980.

8. Jonathan Sinton, ed. *China Energy Data Book.* Berkeley, CA: Lawrence Berkeley Laboratory and the Energy Research Institute of the State Planning Commission of China, revised November 1992.

9. Wang Qingyi, *et al. Investigation of Unit Energy Consumption of Major Industrial Products Abroad.* (In Chinese.) Beijing: China Energy Research Society, 1993.

10. Wang Shumao and Zhou Fengqi. "Economic Growth and Several Macro-Targets of Energy Conservation." (In Chinese.) *Energy in China*, 1992, Issue 4.

11. Zhou Dadi. *Energy Price Reform Study.* (In Chinese.) Beijing: Energy Research Institute, 1991.

Appendix A

Coal Use by Type of Equipment, 1990

Type of Equipment	Annual Coal Consumption (exajoules)	Percentage of Total Coal Consumption
Industrial Boilers	7.3	33
Power Plant Boilers	5.7	26
Coke Ovens and Smelting Furnaces	2.2	10
Household Stoves	1.9	8.5
Brick, Tile, and Limestone Kilns	1.8	8.1
Cement Kilns	1.1	5.12
Coal Gasification	0.94	4.3
Porcelain and Glass Kilns	0.44	2
Mechanical Heating Furnaces	0.32	1.4
Steam Locomotives	0.29	1.3
TOTAL	22	100

Source: Energy Research Institute, State Planning Commission of China.

Appendix B

Oil Use by Type of Equipment, 1990

Type of Equipment	Annual Oil Consumption (exajoules)	Percentage of Total Oil Consumption[a]
Kilns	1.1	23
Road Vehicles	1.1	22
Power Plant Boilers	0.56	12
Boats and Ships	0.43	9.1
Tractors	0.17	3.7
Industrial Boilers	0.16	3.5
Other Diesel Motors	0.14	3.0
Diesel Locomotives	0.12	2.5
Other Gasoline Motors	0.04	0.9
Airplanes	0.02	0.4
Gas Generating Furnaces	0.02	0.4
For Other Purposes	.94	20
TOTAL	4.7	100

Source: Energy Research Institute, State Planning Commission of China.

[a] Percentages of total oil refers to the total amount of oil directly consumed by equipment in either crude or refined form. Oil field losses (4.7 percent) are not included in this total.

Appendix C

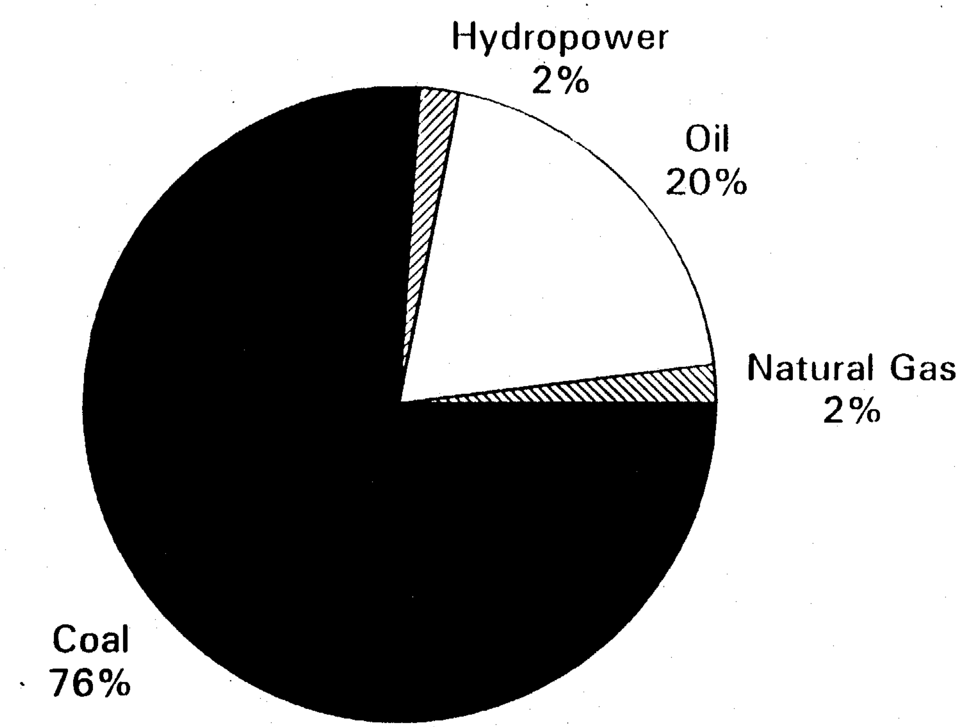
Power Use by Type of Equipment, 1990

Type of Equipment	Annual Power Consumption (TWh)	Percentage of Total Power Consumption
Pumps	1300	21
Fans	650	10
Compressors	585	9
Lighting and Household Appliances	480	8
Air Conditioners	343	5
Small and Medium-Sized Motors	325	5
Industrial Furnaces	325	5
Cement Grinders	229	4
Gas Separating Machines	187	3
Non-Ferrous Metal Electrolyzers	156	2
Farm Machinery for Irrigation and Drainage	143	2
Caustic Soda Production Electrolyzers	93.5	2
Electric Trains	38	1
Welding Machines	32.5	1
Other	909	15
Transmission and Distribution Losses	435	7
TOTAL	6,200	100

Source: Energy Research Institute, State Planning Commission of China.

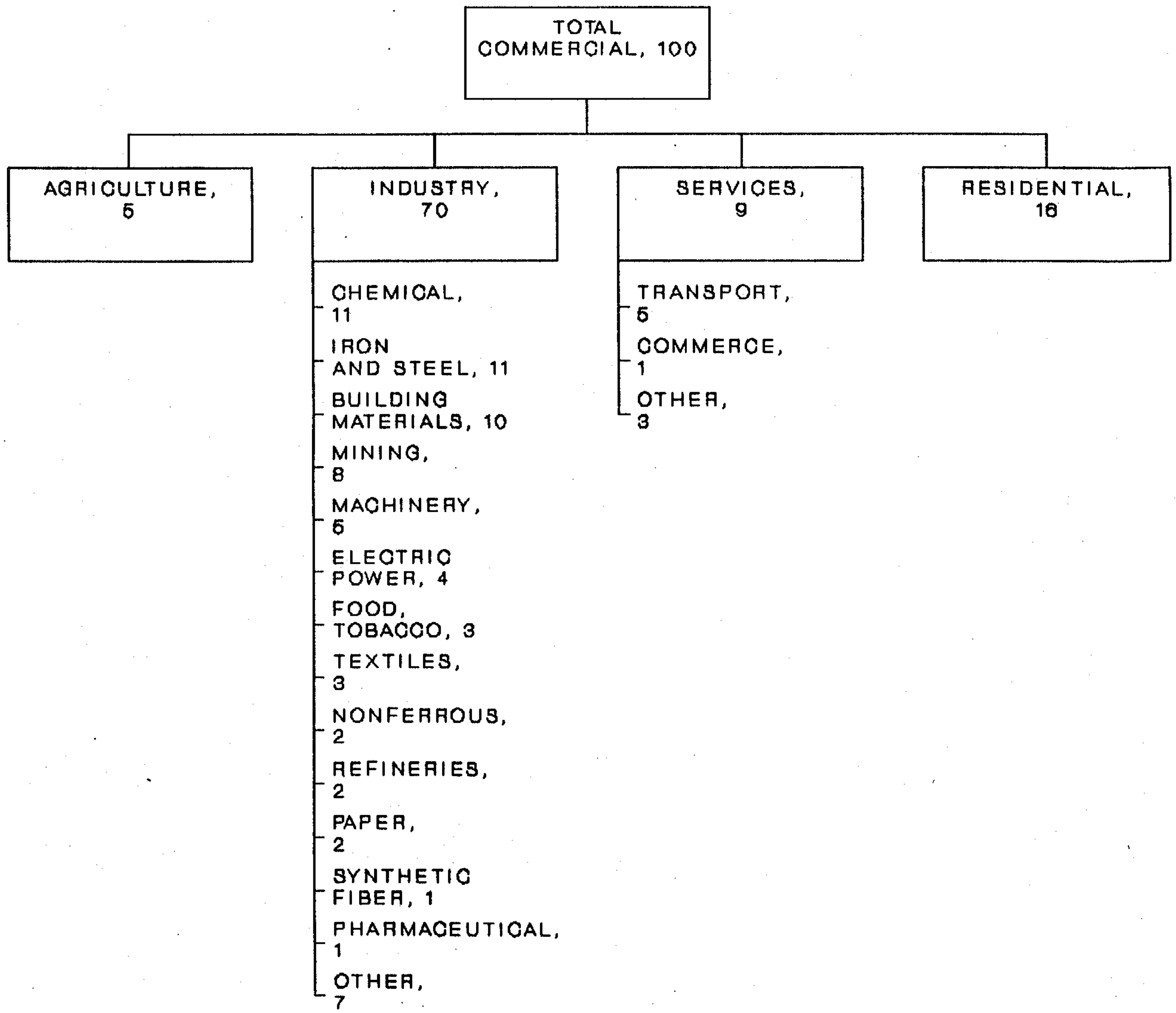
Fig. 1 Primary Energy Use, 1993

Total: 31 Exajoules



State Statistical Yearbook, 1994.

Fig. 2 Energy Use by Sector, 1990 (%)
Total: 28 Exajoules



Energy Research Institute, China State Planning Commission.