DOE/FE/63313--T3-P4.8

China's Clean Coal Technology Program

(Translation Abstract)

China Energy Research Society

**Sponsored by the State Science and Technology Commission
and the State Economic and Trade Commission**

June 1994

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Executive Summary Prepared by the East-West Center

- **China is Heavily Dependent on Coal:** Coal accounted for 75 percent of China's total primary energy consumption. Coal reserves account for 90 percent of China's total proven energy reserves. In the next 30-50 years, coal will continue to dominate China's energy consumption.
- **Coal Combustion is the Major Source of China's Air Pollution:** It is estimated that coal accounted for 90 percent of China's SO₂ emissions and 70 percent of particulate emissions. Coal related environmental problems have become a barrier affecting China's economic and social development.
- **China Has an Ambitious Environmental Target:** According to the target set by the government, by 2000 total SO₂ emissions should be limited to less than 20 Mt (16.85 Mt in 1992), and particulate emissions less than 18 Mt (14.14 Mt in 1992); SO₂ emissions in power plants should remain at the 1990 level. By 2010, the Chinese government wants to popularize the utilization of CCTs, and to restrain SO₂ emissions from all coal combustion facilities at the 2000 level.
- **The Average Sulfur Content of China's Thermal Coal:** The average sulfur content of China's commodity thermal coal was 1.09 percent in 1992, and the average sulfur content of China's thermal coal reserves is 1.15 percent.
- **Increasing Thermal Efficiency is Most Important:** China's coal demand is increasing rapidly, coal utilization efficiency is very low, and there is not sufficient capital to spend on environmental protection; therefore, the overall target should be increase thermal efficiency first and also give consideration to environmental protection.
- **China's CCT Priorities (from highest to lowest):** Briquetting, coal preparation, advanced combustion facilities, coal water slurry, coal gasification, FBC, IGCC, FGD, coal liquefaction, and fuel cells (see Figure 1). The evaluation of CCTs is based on their environmental effects, energy conservation rates, maturity, and economics. The four sets of indexes are given a weight of 0.25 each.
- **China's CCT Project Budget:** During the 1994-2000 period, China will conduct 40 CCT R&D and demonstration projects. The total budget of these projects is 2.7 billion yuan (\$320 million). During 2001-2005, China is expected to spend 7.5 billion yuan (\$890 million) in CCT projects, of which 80 percent will be used in the commercial demonstration of IGCC, coal liquefaction, and the second generation of PFBC technologies.

Figure 1. Overall Evaluation of CCT Priorities in China

<<China's CCT Program>> General Report

I. Clean Coal is the Future of China's Energy

China is the largest coal producer and consumer in the world. It is also one of the few countries in the world that use coal as the major energy source. In 1992, China's coal production reached 1,116.4 million metric tons (Mt), coal consumption reached 1142.7 Mt, accounting for 24.4 percent of the world's total coal consumption. Coal accounted for 74.9 percent of China's total primary energy consumption in 1992.

Coal is China's most abundant energy source. If we convert China's exploitable hydropower resources to coal equivalent based on the fuel consumption of thermal power plants (350 grams of coal equivalent per Kwh) and assume that the life-span of reservoirs is 100 years, then proven coal reserves in 1992 accounted for 90 percent of China's total proven energy reserves.

Coal played an important role in China's economic and social development. In 1992, coal provided 76 percent of electricity generation, 75 percent of industrial fuel and power, 80 percent of residential commercial energy consumption, and 60 percent of chemical raw materials. Coal production, transportation, processing, and utilization provided millions of employment opportunities. Coal is also an important export commodity -- coal exports in 1992 were 23.8 Mt.

According to China's energy resource availability, its technological and economic development levels, and the world energy

situation, in the next 30-50 years, coal will continue to dominate China's energy consumption, and the role of coal in China's future energy system will be even more important.

Coal production and utilization are the most important factors contributing to regional environmental problems, such as air pollution and acid rain, as well as global climate change.

In 1992, China's total SO₂ emissions reached 16.85 Mt and particulate emissions reached 14.14 Mt. It is estimated that coal accounted for 90 percent SO₂ emissions and 70 percent of particulate emissions. The annual daily average total suspending particulate (TSP) were 0.403 mg/m³ in northern cities and 0.243 mg/m³ in southern cities; while the daily average SO₂ concentrations were 0.097 and 0.09 mg/m³ respectively. Widespread acid rain has occurred in Southwest and South China, and the acid rain area is expanding.

China's coal related environmental problem is mainly urban air pollution caused by coal burning. If coal consumption increases to 1400 Mt by 2000, and consumption structure and emission levels remain unchanged, SO₂ emissions will reach 21.6 Mt, and particulate emissions will reach 23.9 Mt. According to the target set by the National Plan of Environmental Protection for 2000, by 2000 total SO₂ emissions should be limited to less than 20 Mt, and particulate emissions less than 18 Mt; SO₂ emissions in power plants should remain at the 1990 level.

Coal related environmental problems have become a barrier affecting China's economic and social development, especially in

major cities and areas consuming high sulfur coals. Environmental factors have become important in selecting the location and size of coal-fired power plants.

China's coal related environmental impacts have become an international concern. SO₂ and NO_x emissions caused by coal combustion have caused concern in neighboring countries; CO₂ emissions, which contributed to global warming, have caused even more international concerns.

However, in the foreseeable future China cannot reduce its coal consumption. The only feasible choice is developing CCTs and increasing coal utilization efficiency. Therefore, clean coal is the future of China's energy. Developing CCTs which are suitable for the Chinese situation is an important medium to long term Chinese strategy.

II. China's Thermal Coal Resources and Demand and Supply Analysis

"Thermal Coal" in this report is defined as coals used to generate power and thermal energy through direct combustion, which exclude coals used to produce coke, coal gas, and coals used as raw materials.

1. Thermal Coal Resources

By the end of 1992, China's proven thermal coal reserves reached 718.6 billion tons, accounting for 72.9 percent of total proven coal reserves. Proven Reserves with Detailed Exploration (PRWDE), which are equivalent to the World Energy Conference

definition of Proved Amount in Place, accounted for 30 percent of Proven Reserves. Recoverable Reserves (recoverable based on current economic and technological conditions) accounted for one-third of PRWDE.

China's thermal coal reserves mainly include non-caking coal, long flame coal, anthracite, and lignite (Table 2).

Thermal coal reserves are mainly located in North China and Northwest China, which account for 45.8 and 38 percent of the national total thermal coal reserves respectively. The top seven provinces are: Inner Mongolia, Shaanxi, Shanxi, Xinjiang, Guizhou, Ningxia, and Yunnan. Non-caking coal reserves are mainly located in Northwest China and the west part of Inner Mongolia; major coal fields include Dongsheng, Shenfu, Lingwu, and Huangling. Long flame coal reserves are mainly located in Inner Mongolia (Zhungeer), Xinjiang, Liaoning (Tiefu, Fuxin, and Fushun), and Henan (Yima). Weakly caking coal reserves are mainly located in Shanxi (Datong). Meager coal reserves are mainly located in Shandong (Zibo), Shanxi (Xishan), and Jilin (Tonghua). Anthracite reserves are mainly located in Shanxi (Yangchen, Gaoping, Yangquan, and Jinchen), Guizhou (Zhijin-Nayong), Sichuan (Junlian, Furong, and Songzhao), and Henan (Jiaozuo, Yongchen). Lignite reserves are mainly located in the northeast part of Inner Mongolia (there are 7 coal fields with reserves above 5000 Mt each) and Yunnan (Shaotong).

2. Qualities of Thermal Coal

In 1992, the average sulfur content of China's commodity thermal coal was 1.09 percent; the average ash content was 20.26 percent; the average total moisture was 10.25 percent; and the average calorific value was 25.16 MJ/kg (6010 Kcal/kg). According to the coal quality data base, the average sulfur content of China's thermal coal reserves is 1.15 percent, and the average ash content is 16.84 percent (Table 3 and 4).

The quality of China's commodity thermal coal is not high, because only a small share of thermal coal is washed (only 80.4 Mt in 1992). Coal quality statistics reported by coal suppliers are different from that measured by coal users. While the average ash content reported by the Ministry of Coal Industry is 20.26 percent, the ash content measured by users is 26-27 percent. Among the 29 major thermal coal mining areas in 1992, 9 of them had sulfur contents above 1 percent: Furong 3.68 percent, Songzhao 3.59 percent, Tongchun 2.53 percent, Zibo 2.43 percent, Xinglong 2.00 percent, Yima 1.79 percent, Xishan 1.39 percent, Yangquan 1.28 percent, and Pingzhuang 1.18 percent.

3. Current Situations of Supply and Demand of Thermal Coal

3.1. Thermal Coal Production

In 1992, China's thermal coal production reached 586.6 Mt, accounting for 52.5 percent of total coal production (see Table 3). In addition, 8.98 Mt of mixed coal, 16.05 Mt of medium sized lump coal, and 3.66 Mt of peat produced in metallurgical coal processing

plants were used as thermal coal.

Among the thermal coal output in 1992, 38.61 percent was raw coal (without processing); 24.68 percent was mixed coal, grains, and fines (sized); 24.41 percent was lump coal (sized); 4.91 percent was lump coal (washed); and 7.39 percent was grains and fines (washed). Ninety-five percent of run-of-mine coal which was not being processed was produced by local mines.

3.2. Thermal Coal Consumption

The thermal coal consumption structure in 1991 was as follows: electricity generation 34.2%, construction materials 11.7%, other industries 29.7%, railway 2.3%, and residential and commercial 22.1%.

3.3. Problems

(1). The share of washed coal is too low. In 1992, only 12.3 percent of thermal coal output was washed.

(2). The coal supplies do not match the design requirement of the coal combustion facilities. Most coals supplied to power plants and industrial boilers do not match design requirement, and the qualities of the coal supplied are very unstable. For example in Douhe (Hebei), China's largest thermal power plant, less than 40 percent of coal supply can meet the design requirements; in coal-deficient areas, the situation is even worse. Almost all industrial boilers burn whatever is available, which causes much lower thermal efficiencies and capacities than designed specifications.

(3) A large amount of metallurgical coal is burned as thermal coal. In 1991, about 70 percent of China's metallurgical coal was burned as thermal coal -- at least one-third of the high quality metallurgical coal was burned as thermal coal. In addition "antique" coke production consumed about 45 Mt of metallurgical coal.

4. Projection of Thermal Coal Supply and Demand by 2000

It is projected that China's coal consumption will reach 1,400 Mt by 2000, and that thermal coal will account for 80 percent. With the thermal coal production base gradually moving westward, the shares of different coals and coal qualities will change substantially. The general trend is that the quality of thermal coal will increase gradually. Along with the large scale development of coal mines in Shenwu (Shaanxi), Dongsheng and Zhungeer (Inner Mongolia), Lingwu (Ningxia), and Huating (Gansu), average sulfur and ash contents will tend to decrease.

The sulfur content of Shenwu and Dongsheng coal fields is less than 0.5 percent, while ash content is less than 10 (but the ash melting point is less than 1250 degree centigrade). Coal production in these two coal fields is projected to reach 30 Mt each by 2000. Lignite production in the east part of Inner Mongolia and Yunnan will increase substantially. It is projected that China's lignite production will reach 78 Mt by 2000 and 152 Mt by 2010. The average sulfur content of lignite is about 0.5 percent in China.

III. Current Situation and Future Trend of CCTs in China and Abroad

Based on China's actual situation, 10 CCTs are selected in this report: coal preparation, briquetting, coal water slurry, advanced combustion facilities, fluidized bed combustion, integrated gasification combined cycle, flue gas desulfurization, coal gasification, coal liquefaction, and fuel cells. In addition to these 10 technologies, the technology of coal-fired magnetic fluid electricity generation has been included as one of China's high technology R&D projects.

1. Coal Preparation

1.1. Technology Description (standard definition)

1.2. Environmental Effects (standard definition)

1.3. Current Situation of Development

China's coal preparation technologies used are rather backward. In 1992, China had 190 major coal preparation plants, with an annual processing capacity of 263.8 Mt, of which there were 74 thermal coal preparation plants, with an annual capacity of 109.1 Mt. In addition, China also had 145 small preparation plants, with an annual capacity of 30 Mt. In 1992, major plants washed 207.96 Mt of raw coal, of which thermal coal accounted for 80.36 Mt; small plants washed 20 Mt. Washed coal accounted for only 20.5 percent of total raw coal. The reasons for this low percentage of washed coal are: (1) weak environmental regulations and emission standards with respect to coal burning facilities; (2) irrational relative coal prices among coal products; and (3) the

recovery rate of thermal coal washing is relatively low.

Since the 1980s, China imported some large-scale coal preparation equipment, for example the 15 Mt washing capacity in Pingshuo Coal Preparation Plant. China also developed and manufactured some advanced equipment, such as the Three-Products Heavy Medium Swirler. However, the overall technology level for coal washing is still very low. The relatively advanced heavy medium coal washing accounts for only 23 percent of washing capacity. China's average washing efficiency is 85 percent, compared to 95 percent in developed countries. China's production efficiency of coal preparation plants is only 1/10-1/20 of that in developed countries.

New coal preparation technologies which need further development and research include: (1) high efficient coal washing technologies for hard-to-process coals; (2) high precision washing for tiny fines; (3) dry preparation for water deficient areas in the west and for lignite; (4) new processes for high sulfur coals; (5) improved equipment reliability; and (6) automatic measurement and recording of process parameters.

2. Briquetting

2.1. Technology Description (omitted)

2.2. Environmental Effects

The coal briquettes used in China's residential sector are mainly honeycomb briquettes. Using advanced stoves, the thermal efficiency to burn honeycomb briquettes is 100 percent higher than

burning raw coal. Using honeycomb briquettes can reduce coal consumption by 20-30 percent, reduce particulate and SO₂ emissions by 40-60 percent, and reduce CO emissions by 80 percent. Using briquettes in industrial furnaces, kilns, and steam locomotives can reduce coal consumption by 15 percent, reduce particulate emissions by 50-60 percent, and reduce SO₂ emissions by 40-50 percent. Briquetting in the residential sector has the highest energy conservation rate among all CCTs, and the relative environmental benefits are also very high.

2.3. Current Situation of Development

China's briquetting technologies have reached international levels. In 1990, 40 Mt of coal briquettes were sold to urban residents, of which 38 Mt were honeycomb briquettes. In recent years, briquette processing has developed very rapidly in rural areas. According to the rural energy statistics published by the Ministry of Agriculture, 5,897 new briquetting plants were constructed in 1992, with an annual briquette production of 24.82 Mt.

Industrial briquette production has also increased. Currently there are 800 sets of briquetting facilities in chemical fertilizer factories in operation. In 1987, China completed a demonstration project able to produce 200,000 tonnes of briquettes for use in locomotives. The project is not in operation because its operating costs are too high. Three demonstration projects able to produce 550,000 tonnes of briquettes per year for industrial boilers have

been built in Handan, Laoyang, and Congqing.

Even in the long-term briquettes will continue to be the major fuel of Chinese households. There are also huge market potentials for industrial users. China should continually develop cheaper and more available bonding materials, advanced stoves, new processes of briquetting for industrial users, and industrial boilers with burn briquette.

3. Coal Water Slurry (CWS)

3.1. Technology Description (omitted)

3.2. Environmental Effects

Coal used to produce CWS generally has an ash content less than 8 percent and a sulfur content less than 0.5 percent; therefore using CWS emits less particulate and SO₂. The NOx emissions are also less than using raw coal, because the temperature in the CWS combustion center is lower than that of coal or oil combustion. The environmental impacts associated with CWS transportation are also less than that of coal transportation.

3.3. Current Situation of Development

China's CWS research, development, and demonstration have achieved great progress. CWS has reached the commercial production stage. China's CWS production technology has reached the international level. There are currently 6 CWS plants, with an annual production capacity of 1 Mt (Yanzhou and Beijing 0.25 Mt each). China has built several commercial level CWS utilization

projects for industrial boilers, furnaces, and kilns. The project to convert the Baiyanghe (3X50 MW) oil-fired power plant in Shandong Province to CWS is now underway. CWS has large market potential. If even a small portion of the existing 6,000 MW oil-fired boilers, the 5,000 oil-fired furnaces and kilns, and numerous oil-fired industrial boilers were converted to burn CWS, the demand for CWS would be tens of million tonnes. Using the 1990 shadow prices, when the price of fuel oil is 2.25 times higher than that of CWS, CWS becomes cheaper to use.

The research, development, and demonstration of CWS technologies should focus on increasing comprehensive matching ability, developing super-clean CWS, developing commercial level demonstration projects to produce CWS using peat and without additives, and demonstrating CWS pipe-line transportation projects.

4. Advanced Combustion Facilities

4.1. Technology Description

Advanced combustion facilities include low NOx burner, limestone injection into furnace (LIF), and advanced boilers.

4.2. Environmental Effects

Two-thirds of China's urban NOx emissions are caused by coal combustion. Using low NOx burners can reduce NOx emissions by at least 50 percent. Limestone injection into furnace can reduce SO₂ emissions by 50-90 percent and NOx emissions by 50-70 percent.

4.3. Current Situation of Development

All of China's 300-600 MW generating units manufactured using technologies imported from the United States (CE) have adopted the US's low NOx burner. After adopting the low NOx burner, NOx emissions decreased from 850 mg/m³ (using traditional burner) to 600 mg/m³. China is now utilizing the TRW burner technology imported from the United States. The 100-300 MW units, which account for 25-30 percent of China's thermal power capacity, are not installed with low NOx burners yet. The NOx emissions of such units is in the range of 800-1100 mg/m³.

In recent years, China developed several new pulverized coal burners which performed well in stabilizing combustion and reducing NOx emissions. The swirl burner has been installed in 159 boilers in 72 power plants; the boat-form burner has been used in 108 boilers in 56 power plants -- these burners can reduce NOx emissions by 30-60 percent. The passive combustion stabilizer has been used in 12 boilers in 10 power plants.

The LIF technology is a cheaper technology suitable for medium to low sulfur coals. The development of LIF in China has reached the intermediate test stage. With this technology, SO₂ emissions can be reduced by more than 40 percent.

NOx emissions caused by coal consumption are major sources of China's air pollution and acid rains. The capital costs and operating costs of the commercial level low NOx burners are very low. For example, the capital cost to install the boat-form burner in 670 t/h boilers accounts for only 0.18 percent of the price of

the boiler. However, China does not have environmental regulations and emission standards with respect to NOx.

The advanced boilers now being developed in China can increase thermal efficiency by 10 percent, reduce particulate emissions by 60 percent, and reduce SO₂ emissions by 40 percent.

5. Fluidized Bed Combustion (FBC)

5.1. Technology Description (omitted)

5.2. Environmental Effects

FBC can reduce SO₂ and NOx emissions by more than 50 percent. When the Ca/S ratio equals 2, the desulfurization efficiency of bubbling FBC (BFBC) can reach 80 percent, and the desulfurization efficiency of circulating FBC (CFBC) can reach 90 percent. With FBC, NOx emissions are less than 200 mg/m³.

5.3. Current Situation of Development

China's research on FBC technology started in early 1960s. Currently China has 3000 BFBC boilers in operation, most of these boilers have a capacity below 10 t/h. China has 20 boiler manufacturers that are able to produce 200 FBC boilers annually. The capacities of these boilers are 2, 4, 6, 8, 10, 20, 35, 75, and 130 t/h. Now there are eighteen 75 t/h CFBC boilers in operation. The technology level is equivalent to the technologies of developed countries during the 1980s, but none all of them are equipped with desulfurization facilities. China is now developing a 220 t/h CFBC system.

In order to speed up the application of the CFBC technology, the Neijiang Power Plant in Sichuan Province is importing the 410 t/h CFBC technology from Ahlstrom, Finland -- this type of boiler will be manufactured in Dongfang Boiler Works. The Beijing Boiler Works has imported the CFBC boiler manufacturing technology from Babcock of Germany to produce 75 and 130 t/h CFBC boilers. In 1992, Tsinghua University developed a trigeneration (coal gas-steam-electricity) FBC boiler.

In Jiawang Power Plant, Jiangsu Province, the Southeast University is developing a 15 MW pressurized fluidized-bed combustion (PFBC) project. The PFBC system can increase electricity generation efficiency by 2 percentage points, with SO₂ emissions less than 400 ppm and NOx emissions less than 200 ppm.

China has made substantial success in developing FBC technologies. For a 100 MW power plant, the capital cost is about the same as a pulverized coal system with FGD. Research and development in the FBC area should focus on improving and standardizing existing CFBC boilers, developing 670 t/h CFBC boilers, developing trigeneration FBC technology, developing second generation PFBC-CC, and constructing a 100 MW PFBC-CC demonstration project.

6. Integrated Gasification Combined Cycle (IGCC)

6.1. Technology Description (omitted)

6.2. Environmental Effects

According to the experience in the United States, an IGCC

power plant consuming high sulfur coal (3.5% sulfur) can reduce SO₂ emissions by 70 percent relative to pulverized coal system with FGD and 50 percent relative to AFBC; NOx emissions can be reduced by 60 and 25 percent respectively; and solid wastes can be reduced by 60 and 75 percent respectively.

6.3. Current Situation of Development

China started to consider developing IGCCs in the late 1970s; however, since capital costs are too high and the technology is very complicated, the R&D of IGCC technology was not conducted. In recent years, the R&D on some individual technologies involved in the IGCC system were conducted. The development of these individual technologies provided the basis for developing the IGCC system.

Now developing IGCC has been placed on the agenda. It has been considered to build a 200-250 MW IGCC demonstration project in Yanzhou (Shandong Province), the first phase will build a 100 MW unit, with investment of 500-550 million yuan or to cooperate with the United States to build a 200-400 MW demonstration power plant.

7. Flue Gas Desulfurization (FGD)

7.1. Technology Description (omitted)

7.2. Environmental Effects (omitted)

7.3. Current Situation of Development

China's FGD development is still in the early stage. In 1991, China's thermal power capacity was 113.6 GW, which generated 552.5

TWh of electricity. Thermal power plants consumed 325.9 Mt of coal (average ash content 28 percent, sulfur content 1.2 percent) and 15 Mt of oil. Total particulate emissions from thermal power plants were 3.64 Mt and SO₂ emissions were 4.59 Mt. Currently, 90 percent of thermal power plants have installed particulate control equipment, and particulate emissions are basically under control. Between 1980 and 1990, coal consumption in the power sector increased by 90 Mt, while particulate emissions increased only 90,000 tonnes.

Flue gas desulfurization has also been introduced. In Luohuang Power Plant, Sichuan Province, Mitsubishi limestone/gypsum wet flue gas desulfurization (FGD) facilities were imported from Japan and installed on two 360 MW generating units -- each one is able to handle 1,087,200 m³/h flue gas with a desulfurization efficiency of over 95 percent. Capital cost of the FGD equipment was 393 yuan/kW, accounting for 11.75 percent of total capital costs of the power plant. The desulfurization cost was 11.06 yuan/MWh (372 yuan per tonne of SO₂). The Ministry of Electric Power Industry plans to install FGD using loans from Germany, and is now conducting feasibility studies in Dongjiao Power Plant (Beijing), Banshan Power Plant (Zhejiang), and Congqing Power Plant (Sichuan).

A industrial test level domestic spraying dryer absorption (SDA) FGD system able to handle 70,000 m³/h of flue gas was installed in the late 1980s. Its desulfurization efficiency can reach 78-84 percent when the Ca/S ratio equals 1.5. A similar FGD system is being installed in a 210 MW unit in Huangdao Power Plant

(Shandong) supported by Japan.

In Douba Power Plant, Sichuan Province, an intermediate test level FGD project, which also produces phosphate ammonia fertilizer as by-product, able to handle 5,000 m³/h flue gas was installed. Overall desulfurization efficiency can be maintained above 95 percent.

8. Coal Gasification

8.1. Technology Description (omitted)

8.2. Environmental Effects (omitted)

8.3. Current Situation of Development

In 1990, China's total coal gas consumption was 23.59 billion cubic meters (BCM), of which 20.25 BCM were used as fuel or raw material in industry, only 3.34 BCM were used in the residential and commercial sector. Most of China's coal gas is coke oven gas.

Coal gas produced in medium and small cities is basically water gas. Now a water gas partial methanization process has been developed. The fluidized bed and water gas two-stage gasification processes are under development.

Currently, industrial fuel gas is basically producer gas, which has low thermal efficiency and emits serious pollution. The two-stage producer gas process is now under commercial level demonstration.

For synthetic raw material gas, the Texaco gasification technology has been imported.

For coal gas in large cities, Lurgi technology and major

equipment have been imported. The problems of imported technology are high investment needs and high operating costs.

9. Coal Liquefaction

9.1. Technology Description (omitted)

9.2. Environmental Effects (omitted)

9.3. Current Situation of Development

China resumed research of coal direct liquefaction in 1980. Three sets of small testing equipment were imported from the United States, Germany, and Japan. Based on testing data and the experience of the United States, it is economically feasible to build two-stage liquefaction plants or coal-oil co-refineries in China.

Substantial R&D has been conducted on indirect liquefaction. An intermediate test level project able to process 2,000 tonnes has recently been completed. When the coal price is 90 yuan/t, the cost of the synthetic gasoline produced is 1800-1900 yuan/tonne.

China has mastered the technology to produce fuel methane from coal. The problem is that there is not a sufficient supply of MTBE and its price is too high.

10. Fuel Cells

10.1. Technology Description (omitted)

10.2. Environmental Effects (omitted)

10.3. Current Situation of Development

China started its research on fuel cells in the 1960s, but

research stopped in the 1980s. Currently there is no research on fuel cells in China.

IV. Evaluation of China's CCTs

1. The Principles of Technology Selection

1.1. Balanced Emphases on Environmental Protection and Energy Conservation

In developed countries, the principle target to develop CCTs is to reduce pollution. In order to meet increasingly stringent environmental standards, large amounts of capital are invested. Some CCTs cannot increase thermal efficiency and some CCTs are very expensive -- for example, wet FGD. The situation in China is different. Coal demand is increasing rapidly, coal utilization efficiency is very low, and there is not sufficient capital to spend on environmental protection; therefore, the overall target should be increase thermal efficiency first and also give consideration to environmental protection.

1.2. Developing Cheaper Technologies

Capital availability is the major restriction in China's CCT development. China cannot afford to use the expensive technologies developed in industrialized countries.

1.3. Focusing on the Power Sector and Industrial Boilers

In 1991, 74 percent of China's electricity was generated using coal. A total of 325.9 Mt of coal was used in the power sector,

accounting for 30 percent of total coal consumption. By 2000, the power sector's share in coal consumption is projected to reach 40 percent. The power sector is the largest source of air pollution. Industrial boilers (including space heating boilers) accounted for about one-third of total coal consumption.

2. Methodology of Evaluation and the Index System

We use the following four indexes to evaluate each technology: environmental effects, energy conservation rate, maturity of technology, and economics.

2.1. Environmental Effects

According to average emissions of SO_2 , NO_x , and TSP in flue gas, CCTs are categorized into four classes. Technologies with emissions below emission standards are categorized as "excellent"; technologies which just meet emission standards are defined as "good"; technologies which are close to meeting emission standards are "medium"; and technologies far from meeting emission standards are "poor".

The TSP emission standards used in this study are the State Air Pollutant Emission Standards for Coal-Fired Power Plants (GB13223-91) implemented on August 1, 1992. When the ash content of the coal consumed is 20-25 percent, the maximum particulate emissions are: 500 mg/m^3 for existing power plants which have installed electric precipitators; and 300 mg/m^3 for new and expanding boilers of 670 t/h in urban areas.

Currently, China only has regulations to limit total emissions of SO_2 in a power plant (t/h) and the ambient air daily average SO_2 concentration; there are no flue gas SO_2 emission standards. China has no NOx emission regulations.

Emission standards in developed countries are generally very stringent. For example, the emission standards of 300 MW (and above) new power units in Germany are: SO_2 400 mg/m^3 , NOx 200 mg/m^3 , TSP 50 mg/m^3 ; the emission standards of new power plants constructed after September 18, 1978 in the United States are: SO_2 747-1474 mg/m^3 , NOx 614-737 mg/m^3 , TSP 37 mg/m^3 . In the near to medium future, China cannot adopt such stringent emission standards. China will use the emission standards of Taiwan: SO_2 2145-4000 mg/m^3 , NOx 600-850 mg/m^3 .

2.2. Energy Conservation Rate

The energy conservation rate is based on the thermal efficiency differences between the CCTs and existing technologies to calculate the potential percentage of energy consumption reduced.

2.3. Maturity of Technology

The maturity of technology is categorized into five groups: laboratory, intermediate test, demonstration, commercial demonstration, and commercialization.

2.4. Economics

The investment and costs of unit capacity are calculated. The indexes used in the calculations, such as prices and exchange rate, are based on the data provided in "Indexes Used in Economic Analyses and Evaluations For Construction Projects" provided by the State Planning Commission in 1990. Costs calculations are based on the methodology used in the U.S. CCT programs.

3. The Results of Evaluations

The results of evaluations are listed in Table 6-9.

4. Comprehensive Evaluation and Priorities

The four sets of indexes are given a weight of 0.25 each. Environmental effects, energy conservation rate, and economics are divided into 4 classes, and maturity is divided into 5 classes.

To evaluate the economics, the ten CCTs are divided into three groups: (1) the technologies which can reduce emissions of pollutant, including coal preparation, advanced combustion facilities, and FGD; (2) the technologies which can produce clean fuels, including briquetting, coal water slurry, coal gasification, and coal liquefaction; and (3) the technologies used to generate electricity or produce steam, including FBC, IGCC, and fuel cells. The evaluation of economics is classified as "excellent", "good", "medium", and "poor". The economics of the first group of CCTs are based on the costs to reduce unit pollutants; the economics of the second and third groups of CCTs are based on their projected production costs and their competitiveness with respect to regular

technologies in 10 years (Table 10). The results of the evaluation are listed in Table 11.

V. Overall Design of China's CCT Program

1. Target

(1) The general target of China's CCT program is to convert coal into a clean, highly efficient, and reliable energy source; to expand coal utilization; and to reduce its environmental impacts.

(2) Another target is to start commercial utilization of existing technologies (after improvement) before 2000, and to realize commercial utilization of new technologies under development in the 2000-2010 period.

(3) Other goals by 2000 include to popularize the utilization of coal preparation, briquetting, and FGD, to reduce SO₂ emissions by 8.6 Mt/year, to restrain SO₂ emissions from the power sector at the 1990 level, and to save 75 Mt of coal per year.

(4) By 2010, the Chinese government wants to popularize the utilization of CCTs, and to restrain SO₂ emissions from all coal combustion facilities at the 2000 level.

(5) Final goals by 2010 include to substitute 10 Mt per year of oil by CWS, and to realize commercial production of coal liquefaction.

2. Priorities

According to the overall evaluation, the 10 CCTs are categorized into two classes: (1) technologies which have reached

or are close to commercialization, including coal preparation, briquetting, coal water slurry, advanced combustion facilities, and AFBC; (2) technologies which are under R&D or planning, including coal gasification, PFBC, IGCC, FGD, coal direct liquefaction, and fuel cells.

China's CCT program should give priority to the first class of CCTs in the next two years, and the R&D of the second class of CCTs should be strengthened during the 1995-2000 period.

3. CCT R&D and Demonstration Program

The R&D and demonstration projects of the 10 CCTs are listed in Table 12, along with the budget of each project.

During the 1994-2000 period, China will conduct 40 CCT R&D and demonstration projects. The total budget of these projects is 2.714 billion yuan, of which 475 million yuan will be spent in the 1994-1995 period (Table 13).

During 2001-2005, China is expected to spend 7.5 billion yuan in CCT projects, of which 80 percent will be used in the commercial demonstration of IGCC, coal liquefaction, and the second generation of PFBC technologies.

4. Implementation of the CCT program and Policy Measures

4.1. Establish a United Government Agency

The CCT program needs cooperation among many sectors; therefore, we suggest a CCT leadership group be established in the State Council which includes representatives from the related

departments of the State Planning Commission, the State Science and Technology Commission, and the State Economic and Trade Commission.

4.2. Included in State Plans

CCT projects should be included in the state science and technology, economic, and social development plans, as well as related plans in the State Planning Commission, the State Science and Technology Commission, and the State Economic and Trade Commission.

4.3. Adopt a Bidding System

R&D and intermediate test projects should select research institutions and enterprises with a bidding system, and demonstration and commercial demonstration projects should select implementing enterprises with a bidding system.

4.4. Acquisition of CCTs

To promote the R&D of CCTs, we suggest to establish the China CCT Center.

4.5. The Sources of Capital

The capital needed to develop CCTs should come from the following sources: (1) the state budget; (2) investment from enterprises and local governments; (3) policy loans; (4) oil product consumption taxes; (5) fines from excess SO₂ emissions; and (6) foreign capital.

4.6. International Exchange and Cooperation

China is the largest coal consuming country in the world. The international community has been greatly concerned by the clean and efficient utilization of coal in China. China should strengthen its international exchange and cooperation in the CCT area, exchange personnel and information, strive for more international aids, import foreign technologies and capital, conduct cooperation in research and demonstration, produce and operate CCT equipment through joint ventures, and export the CCTs in which China has relative advantages.

4.7. Formulate and Improve Related Regulations and Standards

The following laws and standards should be formulated or Improved: (1) <<the Air Pollution Protection Law>> currently being revised, (2) <<the Energy Conservation Law>>, <<the Law of Coal>>, and <<the Law of Electric Power>> currently being formulated; (3) special taxes to promote clean and efficient utilization of coal should be implemented; (4) efficiency standards for coal burning facilities should be formulated; (5) NO_x emission standards should be formulated and SO₂ emission standards of coal burning facilities should be revised; and (6) pollution fees of industrial boilers and kilns should be revised.

Table 1. Definition of Chinese Coal Products

	Volatile matter (d.a.f.) (%)	Bond index (G)
Long flame coal	Larger than 37	Less than or equal to 35
Non-caking coal	20--37	Less than or equal to 5
Weakly caking coal	20--37	5--30
Meager coal	10--20	Less than or equal to 5
Anthracite	Less than or equal to 10	
Lignite	Larger than 37	

Table 2. China's Thermal Coal Reserves by Type in 1992

	Thermal Coal Reserves (Billion Metric Tons)	Share In Thermal Coal (%)	Share In Total Reserves (%)
Long flame coal	123.33	17.16	12.51
Non-caking coal	147.92	20.58	15.00
Weakly caking coal	16.86	2.35	1.71
Meager coal	53.41	7.43	5.42
Anthracite	116.11	16.16	11.78
Lignite	123.12	17.13	12.49
Unidentified	137.85	19.18	13.98
Total	718.59	100.00	72.88

Note: Unidentified coals are produced by TVP mines. Total thermal coal reserves include 1,802 Mt natural Coke.

Table 3. China's Thermal Coal Quality and Production in 1992

	Sulfur (%)	Ash (dry) (%)	Moisture Total (%)	Moisture Air dry (%)	Volatile (d.a.f.) (%)	Calorific (MJ/Kg)	Production (Mt)
Long flame coal	1.18	21.50	13.50	7.02	42.26	22.34	87.15
Non-caking coal	0.67	12.21	11.30	4.74	32.58	26.79	13.70
Weakly caking coal	0.74	9.40	9.00	2.59	31.32	29.60	76.30
Meager coal	2.20	27.83	5.40	1.21	16.34	24.39	54.19
Anthracite	1.07	20.55	6.30	2.32	8.68	26.48	220.96
Lignite	0.51	28.62	30.80	13.33	48.08	16.90	47.27
Unidentified							87.07
Average	1.09	20.26	10.25	4.12	23.23	25.16	586.64

Note: Unidentified coals are produced by TVP mines.

Table 4. Sulfur and Ash Contents of Thermal Coal Reserves by Region (%)

	North	Northeast	East	Central South	Southwest	Northwest	Average
Sulfur	1.05	0.49	1.12	1.27	2.52	0.97	1.15
Ash	17.41	20.72	16.71	18.05	21.37	12.61	16.84

Table 5. Current Situation of CCTs (Omitted)

Table 6. Environmental Effects of CCTs

Technology	Classes	Desulfur. (%)	Pollutants in Flue Gas			Reduction (%)			Compared With
			SO2	NOx	TPS	SO2	NOx	TPS	
Advanced Coal Preparation	M-G	50-80				>50			
Briquetting	M-G	40-80							
Honeycomb Briquette			5mg/MJ	38mg/MJ	50mg/CM	40-60	55	40-60	
Industrial Briquette			27mg/MJ	137mg/MJ	450mg/CM	60	25	60	
Coal Water Slurry	G		103mg/MJ		130mg/MJ	63		87	
Low NOx burner	G			<600mg/CM			30-60		
FBC	E	>90							
BFBC, CFBC			<400mg/CM	<200mg/CM	<150mg/CM	50	50		PC+FGD
PFBC-CC			<400mg/CM	<150mg/CM	<50mg/CM				
IGCC	E	>95	30-53mg/MJ	28-40mg/MJ	4mg/MJ	70	60	90	PC+FGD
FGD	E								
WET (Imported)		96	400mg/CM		40mg/CM				Sulfur 4%
Dry (Domestic)		80	940mg/CM						
Coal Gasification	G-E	85-99	Very Little	Very Little	Very Little				
Coal Liquefaction	E	100	Very Little	Very Little	Very Little				
Fuel Cells	E	100	Very Little	Very Little	Very Little				

Note: E--Excellent, G--Good, M--Medium, P--Poor.

Table 7. Energy Conservation Rate of CCTs

Technology	Energy Conservation Rate (%)	Compared With	Conservation Potential (Substitution Potential)
Coal Preparation	10--12	Raw Coal	40-60 Mt/year by 2000
Briquetting			
Honeycomb Briquette	20--30	Raw Coal	20-30 Mt/year by 2000
Industrial Briquette	15	Raw Coal	1.5 Mt/year by 2000
Coal Water Slurry	2 t CWS for 1 t fuel oil		Substitute 10 Mt oil by 2010
Advanced Boiler	5--10	Regular Boilers	
FBC	10	Regular Boilers	
IGCC	10	PC power plant	
Coal Gasification			
Town Gas	20--30	Raw Coal	
Industrial Fuel Gas	10--20	Raw Coal	
Fuel Cells	System Efficiency May Reach 47.5%		

Table 8. Maturity of CCTs

Technology	Maturity
Coal Preparation	C (Mostly), LAB-ITM (Some)
Briquetting	
Honeycomb Briquette	C
Industrial Briquette	DEM
Coal Water Slurry	CDEM
Low NOx Burner	C
FBC	
BFBC	C (Industrial Boiler), CDEM (130 t/h Power Plant Boiler)
CFBC	CDEM (75 t/h)
PFBC	ITM (15 MW) Under Construction
IGCC	CDEM by 2000 (100-200 MW)
FGD	
WET (Imported)	C
Dry (Domestic)	ITM
Coal Gasification	
Water Gas PM	DEM
Two Stages Water Gas PM	ITM
Lurgi (Imported)	C
Shell/Prenflo (Imported)	CDEM by 2000
Texaco (Imported)	C
Coal Liquefaction	
Direct	LAB
Indirect	
MFT	ITM
Coal-Methanal	CDEM
Fuel Cells	Research

Note: PM--Partial Methanization, C--Commercial Level, ITM--Intermediate Test Level, DEM--Demonstration, CDEM--Commercial Demonstration, LAB--Laboratory.

Table 9. Economics of CCTs

Technology	Investment	Units	Costs	Units	Notes
Coal Preparation					
Thermal Coal	40--50	yuan/ton/year	4--5	yuan/ton	Domestic equipment
Metallurgical Coal	60--70	yuan/ton/year	7--8	yuan/ton	
Briquetting					
Honeycomb Briquette	60	yuan/ton/year	127	yuan/ton	Annual capacity 0.25 Mt For 670 t/h boiler (0.18%) Domestic 100 MW units GE 200 MW unit
Boiler Briquette	100	yuan/ton/year	140	yuan/ton	
Coal Water Slurry	152	yuan/ton/year	162	yuan/ton	
Advanced Combustion Facilities	200,000	yuan			
CFBC	4000	yuan/kW			Luohuang 393 y/kW (0.011 y/kWh) Spraying Dryer Absorption
IGCC	1400	US\$/kW			
FGD					
WET (Imported)	>600	yuan/kW			
Dry (Domestic)	280	yuan/kW			
Coal Gasification					
Water Gas PM	1000	yuan/CM/d	0.6-0.8	yuan/CM	
Two Stages Water Gas PM	1300	yuan/CM/d	0.8-1.0	yuan/CM	
Lurgi	1500	yuan/CM/d	0.7-1.0	yuan/CM	
Coal Liquefaction					
Direct					
Coal-oil co-refinery	400	US\$/ton	135	US\$/ton	Capacity: coal 0.46 Mt, oil 0.43 Mt
Liquefaction with hydrogen	5720	yuan/ton	1250	yuan/ton	Capacity: lignite 0.5 Mt, anthracite 0.17 Mt
Indirect					
MFT	5000	yuan/ton	1900	yuan/ton	Capacity: 0.1 Mt, coal price 90 yuan/t
Alcohol-ether fuel	400-500	yuan/ton	1600-1900	yuan/ton	Capacity: 0.01 Mt

Note: PM--Partial Methanization

Table 10. China's CCT Evaluation Index System

Environmental Effect					
Class	Excellent	Good	Medium	Poor	
Scores	100	75	50	25	
Energy Conservation Rate					
Class (%)	≥ 20	≥ 15	≥ 10	< 10	
Scores	100	75	50	25	
Maturity of Technology					
Class	C	CDEM	DEM	INT	LAB
Scores	100	80	60	40	20
Economics					
Class	Excellent	Good	Medium	Poor	
Scores	100	75	50	25	

Note: C--Commercial Level, ITM--intermediate test,, LAB--laboratory, DEM--Demonstration, CDEM--Commercial Demonstration.

Table 11. Overall Evaluation of CCT Priorities in China

Technology	Single Index Scores				Weighted Average
	EE	ECR	MOT	ECON	
Briquetting	62	75	80	95	78.0
Coal Preparation	62	55	85	95	74.3
Advanced Combustion Facilities	75	50	70	100	73.8
Coal Water Slurry	75	62	80	75	73.1
Coal Gasification	90	90	50	50	70.0
FBC	90	50	60	75	68.8
IGCC	100	62	20	50	58.0
FGD	90	0	80	50	55.0
Coal Liquefaction	90	25	40	62	54.8
Fuel Cells	100	50	20	25	48.8

Note: EE--Environmental Effect, ECR--Energy Conservation Rate, MOT--maturity of Technology, ECON--Economics.

Table 12. R&D and Demonstration of China's CCT Projects

Technology	Development Period	Budget (Million Yuan)
Total Budget		2714
Coal Preparation		190
Heavy Medium Swirler for Tiny Fines	1994-1997	40
High Gradient Magnetic Dressing	1994-1997	30
Dressing by Flotation (Tiny Bubble)	1994-1998	60
Selective Flocculation	1994-1998	10
Tiny Fines High Efficient Dehydration	1994-1997	20
Dry Dressing	1994-1997	30
Briquetting		31
New Bonding Materials	1994-1997	2
Industrial Briquette	1994-1998	15
Perfection of Shapping Equipment	1995-2000	3
Coal and Briquette Drying	1994-1998	5
Biological Briquette	1994-1996	3
High Pressure Shapping	1996-2000	3
Coal Water Slurry		187
CWS Using Different Coals (Tests)	1994-1996	3
Additives for Coals Hard to Make CMS	1994-1996	1
Tiny Fines to Make CMS	1995-2000	11
Super-Clean CMS	1995-2000	2
CMS Combustion Technology	1994-1997	150
CMS Pipe-line Transportation Equipment	1994-2000	20
Advanced Combustion Facilities		26
Low NOx Burner	1995-2000	18
Improvement of Boilers	1994-1998	8
FBC		765
Improvement of Existing FBC Technologies	1994-2000	21
CFBC for Power Plants	1994-2000	158
CFBC for Tri-generation	1995-2000	56
Second Generation PFBC-CC	1995-2000	530

Table 12. R&D and Demonstration of China's CCT Projects (Continued)

Technology	Development Period	Budget (Million Yuan)
IGCC Demonstration	1995-2000	550
FGD		128
Limestone Injection Into Furnace	1994-2000	17
Spraying Dryer Absorption FGD	1995-1998	56
Circulating Bed Process	1995-2000	55
Coal Gasification		81
Improvement of Water Gas	1994-2000	10
Two Stages Water Gas and Methanization	1994-2000	31
Coal Gas High Temperature Cleaning	1994-2000	18
IGCC Coal Gasification (Shell/Prenflo, Texaco)	1994-2000	22
Coal Liquefaction		735
Coal-Oil Co-Refinery Demonstration	1994-2000	200
Synthetic Gasoline From Coal	1996-2000	500
Alcohol-Ether Fuel	1994-1997	35
Fuel Cells		21
PAFC	1995-2000	6
MCFC	1995-2000	11
SOFC	1995-2000	4

Table 13. China's CCT R&D Projects During 1994-1995.

Technology	Scale	Budget (Million yuan)
Coal Preparation	R&D, ITM, and DEM	60
Briquetting	R&D, ITM, and CDEM	12
Coal Water Slurry	R&D, Tests, and CDEM	60
Advanced Combustion Facilities	R&D, and DEM	9
FBC	R&D, Test Production, and DEM	250
IGCC	FEA and PD	10
FGD	R&D, ITM, and DEM	40
Coal Gasification	R&D, and SST	11
Coal Liquefaction	FEA, PD	18
Fuel Cells	R&D	5
Total		475

Note: R&D--research and development, SST--small scale test, ITM--intermediate test, DEM--demonstration, CDEM--commercial demonstration, FEA--feasibility study, PD--project design.