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Financing Clean Coal

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1. Introduction

Clean coal technologies (CCTs) for power production attracted serious political attention in the

1980s in the aftermath of the oil crises of the 1970s. There was a worldwide movement to reduce reliance on oil, and there were reservations about the safety of nuclear power. Coal by default became the only alternative which presented a possibility for mass fuel switching. However, there was concern about the harmful emissions of coal burning, particularly the use of high sulfur and low quality coal. R&D efforts were initiated in the United States, Europe and Japan to develop technologies and devices for controlling harmful emissions and increasing the efficiency of coal combustion.

The R&D efforts on CCTs resulted in clear technological advancements, particularly in the United States where the power equipment suppliers received solid support from the U.S. Department of Energy (US DOE). However, the collapse of oil prices in 1986 changed the entire perspective about scarcity of oil resources, the attractiveness of coal as an alternative fuel, and the necessity of CCTs. Support for the development of CCTs plummeted; resources were allocated only to complete ongoing projects.

International interest in CCTs was reawakened in the 1990s due to: (a) increasing public awareness about local, regional and global environmental problems such as urban air pollution, acid rain and climate change; (b) clear realization that for countries like China and India which have large coal reserves that coal consumption would be a major part of their energy picture in the foreseeable future; and (c) rapid expansion of coal use in these countries to meet rising energy demand resulting from high rates of economic growth.

In particular, the potential of conventional and advanced CCTs in China, which has the largest coal reserves in the world and is the largest consumer of coal for electricity production in the world, are the object of intense discussion. This brief background document outlines the potential in China for one of the most promising of the advanced CCTs, integrated gasification combined cycle (IGCC). The paper first presents a short overview of advanced CCTs, and then reviews the status of IGCC technology worldwide in Section 2. Section 3 assesses the opportunities and constraints in using advanced CCTs, in particular IGCC, in China. In Sections 4 and 5, the history of U.S. and Japanese support for advanced CCTs, especially IGCC, in China is summarized. Section 6 looks at the status of the efforts in China to construct its first IGCC demonstration plant in the city of Yantai in Shandong Province. Final conclusions are drawn in Section 7.

2. Present Status of Advanced CCTs

2.1 Technical and Environmental Features

More than 90% of coal-fired power plants in the world are based on conventional pulverized coal (PC) technology. Its cost of construction, plant availability and performance can be predicted with a high degree of certainty. Its economic advantage relative to other fuels depends on the cost of coal supply and availability of other fuels in the country. PC technology cannot normally compete with natural gas-based power generation, if gas is available within a reasonable distance. In the absence of sufficient natural gas, PC technology provides an economic solution to power supply, particularly in countries where coal is domestically available.

The main shortcomings of PC technology are in two areas. First, power generation based on PC causes a formidable quantity of pollutants, including SO_2, NO_x, CO_2, particulates and heavy metals, which often adversely impact the environment. Second, PC technology is now viewed to be relatively inefficient compared with some other technologies. While the thermal efficiency of combined-cycle natural gas-based power plants has increased from 45% to 60% over the past 10 years, the thermal efficiency of PC plants has increased only from 30% to 35%.

Efforts to control emissions and increase the efficiency of the coal-based power generation are generically known as "clean coal initiatives," and include a variety of processes, devices, and technologies. Some initiatives, such as coal washing, do not involve significant technological advancement. However, emission and efficiency improvements require adoption or change in the power generation technology. These improvements are referred to as "clean coal technologies (CCTs)."

Over the past ten years, numerous R&D programs have been implemented to develop and commercialize CCTs. The products of these efforts fall into two broad categories—emission control and combustion process improvement. Emission control technologies include flue gas desulfurization (FGD) and selective catalytic reduction (SCR) devices. Technologies designed to enhance the coal combustion process (which not only reduces emissions but also increases thermal efficiency) include fluidized bed and IGCC technologies. However, they are not generally viewed as proven or mature technologies. Their capital cost is still higher than a conventional plant. In addition, their construction cost cannot be predicted with certainty, and their operational performance cannot be guaranteed. These technologies are called "advanced" clean coal technologies.

Advanced CCTs include two major categories: 1) integrated gasification combined cycle (IGCC), and 2) fluidized bed combustion (FBC). There are two major types of fluidized bed combustion—atmospheric FBC and pressurized FBC. In this paper only IGCC is discussed.

The most important reason for the recent worldwide attention to CCTs is public concern about the environmental impacts of coal use in power generation. Presently many existing and new power plants are in the process of installing emission control devices to deal with tighter environmental regulations. These control devices can be applied as a retrofit to existing facilities or integrated into new electric generating plants. These devices include SO_2 control technology, NO_x control technology, and combined SO_2 and NO_x control technology.

While the use of emission control devices is expected to expand rapidly, it is often noted that such devices cannot reduce CO_2 emissions. More generally, CO_2 reduction is possible only by increasing the efficiency of the power generation process. Therefore, advanced CCTs are considered to be more desirable options for dealing with a wide range of environmental concerns. Table 1 shows the environmental benefits of CCTs versus a conventional PC plant.

Table 1: Environmental Impacts of Coal-Based Power Generation (% of a PC plant)

	PC			
	Conventional	*w/FGD*	*PFBC*	*IGCC*
SO_2	100	6-12	5-10	1-5
NO_x	100	18-19	17-48	17-32
Dust	100	2-5	2-4	2
Solid Waste	100	120-200	95-600	50-95
CO_2	100	107	70-80	65-75
Water Consumption	100	100	70-80	50-70

Source: US Department of Energy (1997)

2.2 IGCC

IGCC is a system that combines coal gasification and combined-cycle power generation technologies. Coal gasification is a process that converts solid coal into a combustible gas composed primarily of carbon monoxide and hydrogen. The gas is then cleaned of sulfur compounds and particulate matter, and is then burned in a gas turbine to generate a first source of electricity. Exhaust gas from the gas turbine is used to produced steam to drive a steam turbine to generate a second source of electricity. Thus, IGCC integrates a coal gasification unit with a unit which combines both gas and steam turbines ("combined cycle"). Since coal gasification and combined-cycle technologies are separately used extensively, it is often argued that IGCC is a proven technology. However, power utilities still do not consider IGCC as a mature technology for power generation because there is very limited worldwide experience in construction and operation of IGCC power plants.

The main beneficial features of IGCC are that 1) the gasified coal is purified of sulfur and particulate pollutants before it is burned in the turbine, and 2) the residual heat in the hot exhaust gas is further utilized in a heat recovery steam generator to produce additional electricity and thereby increase the thermal efficiency. The thermal efficiency of IGCC is 42 to 44% compared to 35% efficiency for existing PC plants. The combined-cycle portion of an IGCC plant can be built and fueled by natural gas; the coal gasifier can be added when gas becomes unavailable or unacceptably expensive.

In an IGCC system, 99% of the coal’s sulfur compounds are removed before combustion. NO_x is reduced by over 90% and CO_2 is reduced up to 35%. Indeed, IGCC systems are among the cleanest of emerging power technologies. Since pollutants are removed before the fuel is burned in the gas turbine, smaller volumes of gas need to be treated as compared to a post-combustion FGD device. The gas stream must be cleaned to a high level not only to achieve low emissions, but also to protect downstream components, such as the gas turbine, from corrosion. IGCC systems use less cooling water and are desirable in the event that the power station is located in an area lacking adequate water.

The typical size of IGCC power plants is 200 to 500 Mw. Modular designs of 50 to 150 Mw are expected to be the basis for future IGCC power plants, with larger sizes provided by integrating multiple units. IGCC plants can burn any high hydrocarbon fuel including low and high sulfur coal, anthracite, and biomass.

There are presently five commercial scale IGCC plants in operation in the world. Three of these projects are in the U.S. and were implemented with the financial support of the US DOE Clean Coal Technology Program. The other two plants are in Europe—one in the Netherlands and one in Spain. The U.S. plants have General Electric (GE) gas turbines. The European plants use Siemens gas turbines. All IGCC plants in operation are of 250 MW capacity except the unit in Spain, which has approximately 300 MW of capacity.

Figure 1: Typical Components of an IGCC System

The construction cost has declined from about $3,000/kW in the 1980s to about $1,450/kW in 1997 and is expected to decline further to about $1,300/kW by 2000. Thermal efficiency has increased from 36% in 1990s to about 44% in 1997, and is expected to increase to about 50% in about a decade.

Figure 2: Cost Pattern for IGCC

Table 2 summarizes the estimates of capital and operating costs of coal-based power generation.

Table 2: Construction Cost of Coal-Based Power Generation

	PC	PC +FGD	IGCC	PFBC
Construction Cost ($/kW)	1,050	1,150	1,450	1,500
Thermal Efficiency (%)	34	34	42	40

Source: International Energy Agency (1996)

3. Advanced Clean Coal Technologies in China

3.1 Present Status

China is the world's second largest producer of electricity after the Unites States. Its installed power generating capacity was 218 GW in 1996 of which 75% is thermal, 24% hydro, and 1% nuclear. In terms of actual electricity generation, thermal power accounts for 80% of the total. Coal-fired power plants provide more than 90% of thermal generation, with oil based generation accounting for most of the balance. The share of natural gas-based power generation is negligible and is expected to remain so even if the country succeeds in implementing its challenging gas import projects.

The power sector's use of coal amounted to 370 million tons in 1996, which is more than one-third of the total coal consumption in the country. The amount of coal used in the power sector is large not only because of the huge size of thermal power generating capacity, but also due to the relatively low thermal efficiency of the existing plants. Although government policy emphasizes the addition of larger, more efficient units of 300 MW and 600 MW, over half of the existing capacity is still in units below 200 MW. Only 15% of installed capacity is in units of larger than 300 MW, compared to 60-80% in industrialized countries. Also of serious concern is that many of the new plants being built by the local governments are in unit sizes of 50 MW or less. The main reason is that these small units are easier to finance. At the same time, these units consume 60% more coal per unit of electricity produced compared to units of 300 to 600 MW.

The large and inefficient use of coal causes severe environmental damage. Emissions of particulates and SO_2 are creating serious local and transboundary environmental problems. Increasing levels of SO_2 and CO_2 emissions are cause for serious regional and international concern. Until recent years, the government was preoccupied with meeting electricity demand and did not assign high priority to controlling emissions. However, recently, the government has initiated serious efforts to curb air pollution related to the burning of coal, particularly to reduce the power sector's contribution to the problem. The government, for instance, has announced that it intends to keep particulate emissions below 3.8 million tones per year and SO_2 emissions below 15 million tons per year.

China has four top priorities relative to development of CCTs for power generation: IGCC, supercritical coal-fired power plant, atmospheric fluidized bed combustion, and pressurized fluidized bed combustion.

3.2 Potentials for CCTs

Growth in electricity generation averaged 8% per annum during the last 15 years. Nonetheless, electricity supply did not keep pace with growth in demand. Most areas of China suffered from severe power shortage. As a result of the current financial crisis in Asia and the rest of the world, electricity growth has slacked, and most industrialized areas even seem to be experiencing a surplus. However, if we postulate a growth scenario in which electricity demand grows at 8 to 9% per annum, China would need to add about 18-20 GW of capacity per year. The World Bank has re-examined the demand growth in light of the Asian financial crisis and concluded that electricity consumption will continue to grow at about 8% in the foreseeable future. Even with a growth rate of 7% (low-case scenario), the growth in China's power generating capacity will be about 16 GW per year. This still accounts for more than 20% of the world's new capacity. Under the base-case scenario, the projected mix of generating capacity indicates that the share of thermal power will remain stable at about 75-78%. This translates into an addition of about 15,000 MW/year to thermal capacity, or an investment of approximately $15 billion/year in thermal power. More than 90% of this investment will be directed to coal-based power generation.

There is considerable uncertainty in assessing the portion of coal-based investment that will be spent on CCTs. At least 10% of new coal plants are expected to be built with FGD equipment. However, the share of advanced CCTs such as IGCC will depend on the availability of these technologies in China. In a study of China's electricity needs, the US DOE's Lawrence Livermore National Laboratory used its power system planning model to examine the potential for CCTs (Atwood 1997). The results indicate that China could be using up to 110,000 MW of IGCC during the next 20 years. The underlying assumption is that these technologies are proven and commercially established in China. The CCT capacity has been estimated so that it would enable China to meet its emission targets. In particular, the study points out that pollution emissions corresponding with this scenario would be substantially less than the conventional technology; SO_2 would be reduced by 69%, particulates by 61%, and CO_2 by 16%.

3.3 Constraints on Application of Advanced CCTs

Despite the very positive prospects for using advanced CCTs in China, there are severe constraints in employing these technologies, including:

1. Generally, advanced CCTs are not considered proven technology. There has not been sufficient worldwide experience with these technologies to establish their critical parameters with a reasonable degree of assurance. In particular, the construction cost and construction time cannot be accurately predicted. Also, the operational performance can not be reliably assessed.
2. Even if advanced CCTs were proven, there would still be the additional challenge of importing them into China. Although the Chinese are particularly receptive and eager to import new technologies, demonstration of the viability of the new technology on Chinese soil will require a special effort.
3. Compared with the current needs, domestic and international capital resources for power sector investment in China are relatively scarce. Thus, investment decisions are biased towards solutions that take smaller up-front costs. Advanced CCTs involve higher capital costs even though they are more efficient and environmentally beneficial than ordinary PC plants. They represent a typical case of under investment by market forces.
4. The cost of the alternative, i.e., conventional PC technology, is substantially less in China. China is now able to manufacture the equipment and build pulverized coal plants at a cost lower than any other country in the world.
5. Financiers normally want to lend to projects that are based on widely tested technologies. It is very difficult to mobilize finance from private capital markets for new and unproven technologies. Multilateral lenders like the World Bank on the other hand can employ financial strategies which use their public monies to leverage greater sums of private money for investment in unproven yet environmentally beneficial technologies.

4. Foreign Support for Advanced CCTs in China

The two primary sources of financial support for the promotion of advanced CCTs in China have been the US DOE and the Japanese Ministry of International Trade and Industry (MITI). Promotion of advanced CCTs in China gives both Japan and the U.S. an opportunity not only to actively display leadership on international environmental issues such as global climate change, but also to concretely demonstrate their concern about "clean" development in countries like China. Together, Japan and the U.S. can achieve far more than either country can acting alone in addressing China's monumental coal-fired power plant related environmental problems. However, U.S.-Japan cooperation in this area is yet in a nascent state.

4.1 U.S. and Clean Coal in China

The US DOE established a Clean Coal Technology Demonstration Program in 1985. The Program is a cooperative effort between the US DOE and U.S. industry to demonstrate a new generation of technology for transforming coal into electricity. Those technologies that show the most promise for increasing the efficiency of energy use and enhancing environmental quality are to be moved into the domestic and international market place. The Program has supported 43 projects with a total capital investment of about $7.1 billion. US DOE support has varied in each project, but has not exceeded 50% of the project cost. However, overall the US DOE's support in all projects has been around 33% while the industry has funded the remaining 67% of the investment requirements.

Projects supported by the US DOE Program fall into four categories: 1) advanced power generation technologies, 2) environmental control devices, 3) coal processing (cleaning), and 4) industrial applications. A large portion (65%) of the Program concentrated on advanced power generation technologies. The predominant technologies in this sector were IGCC and fluidized bed combustion, from which IGCC has emerged as the leading technology. After a decline in interest in CCTs in the 1980s interest was renewed due to concern over not only environmental impacts of power generation in general, but also the specific impacts for those countries such as India and China who are heavily dependent on coal. Accordingly, the U.S. Congress issued a guidance in 1994 to the US DOE to disseminate CCTs to the international community as an integral part of its policy to reduce greenhouse gas emissions in developing countries.

In 1993, the U.S. Secretary of Energy, Hazel O'Leary, in talks with the Ministry of Electric Power in China noted the Chinese interest in IGCC. She promised to seek a $50 million grant from Congress to support the transfer of IGCC technology to China. In 1994, Texaco conducted an engineering feasibility study of IGCC in China. This work was included in a US-China government report on IGCC (US DOE 1996). In the meantime, US DOE's requests to Congress to support IGCC in China were repeatedly rejected. Thereafter, the focus shifted to low-cost initiatives in the areas of information dissemination and training. In this context, a US/China Energy and Environmental Technology Center (EETC) was established in Beijing in 1997. The Center is implemented jointly by the U.S. and Chinese governments and Tulane and Tsinghua Universities.

4.2 Japan and Clean Coal in China

Japanese experience with advanced CCTs is more limited than that of the United States. However, the potential for Japanese assistance to China is quite substantial. First, the Japanese power industry is devoting increasing attention to the development of CCTs. This increased attention along with strong government support promise to place Japan in a leading position in the coming decade. Second, Japan has initiated a rather comprehensive program of international cooperation in the area of new energy and environment technologies, which is most active in China. This program covers a number of activities related to CCTs.

Japanese advancements in CCTs include numerous methods and devices in coal mining, coal cleaning, and emissions control. With regard to advanced CCTs, Japan has concentrated more on PFCB rather than IGCC, though the latter has recently become a focus of R&D activities. An IGCC demonstration plant was built more than twenty years ago, but was limited in scope and success. The initial effort consisted of R&D work in the area of coal gasification and a pilot plant test in Nakoso. The pilot project was conducted from 1984 to 1989. However, numerous operational problems during the test period resulted in a negative perception about IGCC.

The new Japanese attempt to development IGCC technology started in late 1996 when nine power companies and the Japanese government decided to fund a detailed feasibility study of IGCC. This study, which is being implemented by the Tokyo Electric Power Company, is expected to provide the basis for a decision by the end of 1998 to build a demonstration project. The study examines unit sizes of 150 MW and 300 MW for the demonstration plant, and 300 MW and 450 MW for subsequent commercial plants.

Within Japan, the mandate for promotion of new energy technologies lies with the New Energy and Industrial Technology Development Organization (NEDO) which reports to MITI. NEDO is also extensively involved in international activities. Its international partners comprise two groups—industrial countries, and the developing nations of the Asia Pacific region. Cooperation in the latter area stems from the Green Aid Plan which was launched by MITI in 1992 to support efforts of developing countries in coping with energy and environmental issues.

Activities initiated under the Green Aid Plan cover a wide range of cooperation between Japan and the host country. On both sides, a mix of government, industry and academic participation is envisaged and encouraged. The first step in establishing cooperation is a policy dialogue which provides a framework for joint activities. Nevertheless, cooperation is extended into actual project implementation and/or professional training and interaction.

The Green Aid Plan and NEDO concentrate a major part of their assistance in China. Activities that have direct relevance to CCTs include coal preparation technologies in Huainan and Yanzhou, FGD systems in Sichuan and Guangxi Zhuang, and heat recovery plants in Anhui, Shanxi and Sichuan. The cost of technical cooperation, including projects expenditures, training, etc., are primarily borne by Japan, though in some cases, the state or local governments are expected to cover part of the local cost.

5. Yantai IGCC Demonstration Project

China's Agenda 21 plan identified IGCC as a top priority technology for sustainable development. In 1994 the government established an IGCC working group consisting of six (6) government agencies: State Science and Technology Commission (now the Ministry of Science and Technology), State Planning Commission (now the State Development Planning Commission), State Economic and Trade Commission, the Ministry of Electric Power, the Ministry of the Machine-Building Industry (now the State Machine-Building Industry Bureau), and the Ministry of the Coal Industry (now the State Coal Industry Bureau). When US DOE support for transfer of IGCC technology did not materialize, the Chinese government continued in its efforts to build an IGCC demonstration plant. There is currently a strong effort underway to construct such a demonstration IGCC power plant in the city of Yantai in Shandong province.

China, and the city of Yantai, are interested in IGCC because (1) IGCC is highly efficient, (2) the environmental characteristics of IGCC are outstanding, (3) water consumption is low (Shandong province is located in the water-deficient region of northern China), (4) land requirements are minimal, (5) operating costs are low, (6) adaptability to different varieties of coal is high, and (7) IGCC allows co-production and comprehensive utilization (i.e., the technology is a product of combining thermal and chemical industrial technologies).

For these reasons, starting during the 9th Five Year Plan period (1991-95), construction of an IGCC demonstration project was included in the China Energy White Paper. An IGCC demonstration power plant was also included as a priority project in China's Agenda 21. In 1993, the Ministry of Electric Power selected a complex in Beijing as the site for a preliminary study regarding an IGCC demonstration plant. The Yantai Generating Station, however, also expressed intense interest in such a demonstration project. Eventually, in October 1997, Yantai was selected by the Ministry of Electricity as the site for China's first IGCC demonstration power plant The Yantai Generating Station IGCC Demonstration Project will involve the construction of two units, each 300-400 MW, with one being built first during the current Five Year Plan period. The principal equipment will be imported from abroad, employing a combination of technology transfer and outright purchase. The plant will be constructed on the site of the dismantled main powerhouse.

The Asian Development Bank (ADB) has shown willingness to support the Yantai effort by providing funds to carry out a feasibility study. ADB's feasibility report is expected to be completed in March 1999. A decision whether to proceed with the plant with ADB help is expected by mid-1999.

6. Conclusion

Advanced CCTs, particularly IGCC, have substantial potential to improve the efficiency of coal-based power generation and to reduce the harmful impacts of power generation on the local, regional and global environment. Cost patterns indicate a rapid decline in the average cost of power generation from IGCC. The cost is expected to decline further for new plants, making IGCC eventually competitive with conventional PC steam plants. While the cost and the risk disadvantages of IGCC is high for China, the potential benefits are also high due to China's huge requirements of power generating capacity and its heavy reliance on coal as a source of electricity production. The U.S. and Japan both have programs which are aimed at aiding the transfer of advanced CCT to China. IGCC technological development in the U.S. is more advanced than that in Japan. Thus, the U.S. has made more overtures to China relative to the transfer of IGCC technologies; however, because support from the U.S. Congress failed to materialize the efforts of the US DOE have been relegated to information dissemination and training. Thus, at present neither the U.S. nor Japan are actively supporting IGCC in China. Undeterred, China has proceeded with making the construction of an IGCC demonstration power plant a high priority. Yantai in Shandong province has been selected as the site for such a demonstration project.

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