Financing Clean Coal Technologies in China

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Abbreviations and Acronyms

ADB	Asian Development Bank
AFBC	Atmospheric Fluidized Bed Combustion
AIJ	Activities Implemented Jointly
CC	Combined Cycle
CCTs	Clean Coal Technologies
CDM	Clean Development Mechanism
CIF	Carbon Investment Fund
EDPF	Energy Department Project Fund
EETC	Energy and Environment Technology Center
EIT	Economies in Transition
EPRI	Electric Power Research Institute (United States)
FCCC	Framework Convention on Climate Change
FGD	Flue Gas Desulfurization
GEF	Global Environment Facility
GHG	Greenhouse Gas
GW	Gigawatt
IBRD	International Bank for Reconstruction and Development
IFC	International Finance Corporation
IGCC	Integrated Gasification Combined Cycle
IRC	Incremental Risk Coefficient
J Exim	Export-Import Bank of Japan
JI	Joint Implementation
kcal	kilo calorie
kg	kilogram
kW	kilowatt
kWh	kilowatt hour
MIGA	Multilateral Investment Guarantee Agency
MITI	Ministry of International Trade and Industry (Japan)
MW	megawatt
NEDO	New Energy and Industrial Technology Development Organization
NEPA	National Environmental Protection Agency
OECD	Organization for Economic Cooperation and Development
OPIC	Overseas Private Investment Corporation
PC	Pulverized Coal
PFBC	Pressurized Fluidized Bed Combustion
SCR	Selective Catalytic Reduction
SNCR	Selective NonCatalytic Reduction
TDA	Trade and Development Agency
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
US AID	United States Agency for International Development
US DOE	United States Department of Energy
US Exim	United States Export-Import Bank

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Executive Summary

There is a perception in the international energy industry that the costs of clean coal technologies (CCTs) have now declined to levels that enable these technologies to compete with conventional power plants. This perception is not true. Only in the case of certain emission control devices, such as flue-gas desulfurization (FGD), have capital costs declined to the point that these devices are added to some of the new and existing plants, particularly where environmental standards have become stringent. However, in the case of advanced CCTs, which improve the entire power generation process, the capital costs and commercial risks are still higher than conventional coal plants.

Among numerous advanced technologies, two of them—integrated gasification combined cycle (IGCC) and pressurized fluid bed combustion (PFBC)—have emerged as front-runners. Between the two, IGCC is considered to have better prospects for immediate use. We have therefore placed more emphasis on the analysis of costs and risks of IGCC technology. In the IGCC process, coal is gasified and purified prior to burning thus making it possible to remove particulates, sulfur and nitrogen compounds. Also, the residual heat in the hot exhaust gas is further utilized in a heat recovery steam generator to produce additional electricity and thereby increase thermal efficiency. Thus, IGCC technology is considered to be a highly effective way of reducing local, regional and global environmental impacts of coal consumption.

The cost of building an IGCC plant has declined from $3000/kW in mid 1980s to $1450/kW in 1997. Within the same period, thermal efficiency has increased from 35% to 44%. With such impressive improvements in its application, the energy industry expected commercial viability of this technology by the mid-1990s. However, the cost of conventional technologies also declined. The cost of pulverized coal (PC) plants declined from $1650/kW in 1990 to $1150/kW in 1997. Thus, IGCC still remains at a cost disadvantage.

There are two other major disincentives to using IGCC. First, the cost disadvantage is substantially greater in a country like China, where PC plants are built at even lower costs than international experience. The capital cost of building a PC plant in China has been, in some cases, less than $500/kW; the average cost of well-designed plants (including FGD) is about $880/kW. This compares with a figure of $1150/kW for the United States. Second, the commercial risk associated with the construction and operation of IGCC is higher than conventional plants. The higher risk is itself due to the lack of sufficient experience with advanced CCTs. Worldwide, there are only five commercial-scale IGCC plants in operation. Three of these plants are in the United States, the other two plants are in Netherlands and Spain. Because of the limited number of plants, present estimates of construction cost, construction time, operational efficiency and plant availability involve considerable uncertainty. The prevailing uncertainty in these parameters is translated into commercial risks, which are in turn taken into account while making a decision regarding the choice of power plant technology.

With the present cost patterns and uncertainties, utilities do not freely choose IGCC, or any other advanced CCT, over conventional PC plants. On the other hand, selection of IGCC could bring about significant social benefits to national and international communities. In addition to increased energy efficiency, benefits include significant reduction in sulfur emissions (which contributes to problems such as “acid rain”) and greenhouse gas emissions, especially carbon.

Considering past technical improvements, IGCC has the potential to become a commercially viable technology if additional plants are built to demonstrate the reliability of cost estimates and operational parameters. This could be done by constructing more plants in industrial countries to prove the technology, and then encouraging the transfer of the proven technology to developing countries. An alternative approach is to build future demonstration plants directly in developing countries. With this approach, the encouragement and the corresponding incentive systems would need to be stronger in order to deal with the double challenge transferring an unproven technology. However, the potential commercial benefit would be also very large: the developing world represents about 80% of the market for future coal power plants. Among developing countries, China accounts for 38% of additional coal-based power capacity during the next decade. Therefore, demonstration of advanced CCTs in China represents a significant potential benefit for the country and the biggest worldwide market opportunity for these technologies.

The Potential Sources of Support

There have been two primary sources of financial support for the promotion of CCTs in general--the US Department of Energy (USDOE) and the Japanese Ministry of International Trade and Industry (MITI). However, a number of other sources, including the Global Environment Facility (GEF), the World Bank Group, and the Asian Development Bank (ADB), could potentially provide support to CCT projects.

The USDOE established a Clean Coal Technology Demonstration Program in 1985. The program has supported 43 projects with a capital investment of about $7.1 billion. These projects are all located in the US and include advanced CCTs as well as environmental control devices, coal cleaning and industrial processes. Support from the USDOE has covered about one-third of project costs while the US industry has funded the remaining two-thirds. The program has been very successful technically resulting in the development of a number of devices and advanced technologies. Among advanced technologies, IGCC has emerged as a leading technology, though project replication has remained limited due to soft energy prices.

Public awareness of environmental issues has created a new momentum for the CCT program, including a more positive view in regard to the export of advanced CCTs to countries like China and India. Accordingly, the USDOE embarked on a systematic dialogue with US industry and Chinese relevant agencies to establish a program of support in implementing advanced CCTs in China. As a result, USDOE prepared a plan in 1995 for a joint initiative with Chinese which would provide: (a) education and technical support in the form of training, information dissemination, etc.; (b) cost sharing of engineering and design studies; and (c) contribution of 10-25% to the funding of actual demonstration projects. Unfortunately, the US Congress did not approve funding for the proposed initiative and the USDOE has since focused on lower cost activities in the areas of information dissemination and training. In this context, a US/China Energy and Environment Technology Center (EETC) was established in Beijing in 1997 to enhance the competitiveness and adoption of US technology in China. The Center sponsors study tours, meetings, research, etc.

The decision by the US Congress to decline funding of the DOE's initiative hinged upon the perception that financial support for CCTs can be mobilized through already existing mechanisms such as the US Export-Import Bank, the Overseas Private Investment Corporation, USAID, and the Trade and Development Agency. However to date, no significant funds have been channeled from these agencies to CCT projects 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 substantial. Japan places strong emphasis on international cooperation and has a practical presence in the development of industrial and environmental technologies in China. Japanese advancements in CCTs include numerous methods and devices in coal mining, coal cleaning, and emission control. In regard to advanced CCTs, Japanese experience has concentrated more on PFBC rather than IGCC. But recently the Japanese have become convinced that IGCC has good prospects for large scale application. Thus, the government and the power industry are paying more attention to this technology. A new attempt towards development of IGCC started in 1996 with cooperation of nine power companies and financial support from MITI. An undergoing feasibility study is expected to provide the basis for a decision by end 1998 to build a demonstration project.

Within Japan, the mandate for promotion of CCTs lies with the New Energy and Industrial Technology Development Organization (NEDO) which reports to MITI. NEDO is also extensively involved in international activities, including promotion of CCTs in the developing countries of Asia Pacific. NEDO's work in this area is covered under the Green Aid Plan which was launched in 1992 and supports development of environmental control devices and processes in China.

Multilateral agencies such as the World Bank and ADB have a potential interest in promoting CCTs. Being development institutions, these agencies are interested in projects that transfer technology to developing countries. They are also eager to show their support for activities that aim to address local, regional, and global environmental problems. CCTs fit the profile. In addition, participation of the World Bank and/or ADB in a project provides comfort for other financiers and donors to come in a project. However, for a project to become acceptable to multilateral institutions, certain criteria, including technical and financial viability, have to be met. Advanced CCTs may not pass these tests.

Both the World Bank and ADB have extensive involvement in the energy sector of China. They have targeted in their operations various environmental concerns. In the power sector, the World Bank finances one or two projects a year. It places special emphasis on sector reform and energy conservation. It has helped the Chinese government in the design and implementation of the regulatory framework of the power sector and rehabilitation of electricity generation and transmission facilities. The ADB finances two to three projects a year, while concentrating more on rehabilitation, efficiency improvement, technology development and environmental protection.

Finally, carbon reduction funds represent an important potential source of support for advanced CCTs. Because of their higher thermal efficiency, advanced CCTs offer the potential to reduce CO_2 emissions. The main principle underlying the carbon reduction funds is that, if a country undertakes an investment that is not a least cost option but results in reduced CO_2 emissions, the country should be compensated for the incremental cost by the world community because the more expensive project imparts benefits to the global environment.

Currently, the most important source of support for carbon reduction projects is the Global Environmental Facility (GEF). GEF support is provided under four distinct programs: (i) energy efficiency promotion; (ii) renewable energy development; (iii) technology promotion; and (iv) short-term response projects. In the first three categories, the objective is to reduce the cost and increase the market share of energy supplies that have global environmental benefits. Thus, GEF support is viewed in a long-term framework, considering the fact that the main benefit would be coming in the form of future repeating projects. In the fourth category, however, the objective is to achieve carbon reduction through a specific project. In this category, GEF support is provided to projects that can achieve carbon emission reduction at the cost of $10/tonne or less. GEF has provided support to energy efficiency projects in China. Its program includes a comprehensive assessment of energy efficiency potentials which would, as a by product, result in a reduction of CO_2 emission.

Another source of financial support under the category of carbon reduction funds is the so-called Joint Implementation (JI) initiative that originated within the Framework Convention on Climate Change (FCCC) in 1992 and Kyoto Protocol in December 1997. The Protocol sets quantified carbon emission limitations and reduction commitments for OECD countries and economies in transition (EITs). As an instrument for achieving the emission targets, the Protocol allows for JI: OECD countries may finance emission reductions outside their own borders in order to obtain credit towards their reduction obligations with a view to limit the costs of complying with their commitments.

Although the concept of JI is theoretically simple, there is substantial skepticism regarding the practicality of the idea. There have been numerous attempts to clarify the parameters and implementation arrangements. A pilot program has been initiated to stimulate experience in this area on a voluntary basis with no internationally certified credit accruing to any party during the pilot phase. A further step was taken in 1997 by the creation of the Carbon Investment Fund (CIF) under the sponsorship of the World Bank. Under CIF, the World Bank will act as a market intermediary between governments and/or companies. Investors would put their money in the fund. The World Bank would invest the funds in projects that result in carbon emission reductions. Investors receive the rights to resulting credits in return for their investment in the fund.

The Proposed Financing Mechanism

In this paper we present a methodology for assessing the incremental costs and incremental risks of advanced CCTs compared with conventional PC plants. The results of these calculations indicate that implementation of an IGCC plant in China would involve an incremental cost of 32% and an incremental risk of 23% compared with the base option of constructing a conventional PC plant. Both of these disadvantages of IGCC would be substantially reduced after implementation of several demonstration projects. However, in order to provide incentives for implementing the demonstration projects, the government of China and the international aid community should provide financial support for: (a) dissemination of relevant information; (b) preparation of projects; and (c) investment in constructing the first few plants.

have concluded that (a) information dissemination is currently receiving sufficient support, (b) project preparation is not receiving any significant support but can be financed by the ADB, the World Bank and the Japanese NEDO, and (c) plant construction has no real source of serious support at the present time. The lack of support for plant construction stems from the fact that the required assistance would be very large and that financiers have an interest to actually avoid rather than support such projects. Financiers provide loans at certain interest rates. They do not receive additional rewards if the project does better than expected. They do not want to get any lower return if the project fails. Thus, they do not wish to be exposed to project risks; they normally avoid financing projects that are based on unproven technology. Even the ADB and World Bank, which often provide comfort against political risks, are not willing to provide protection against commercial risks. Their view is that commercial risks should be managed by project sponsors.

In order to provide incentives for the implementation of an IGCC plant in China, the additional cost of this technology should be compensated by a direct financial grant. However, the appropriate mechanism for dealing with the additional risks would be a well-designed guarantee facility. Our proposed financing scheme encompasses both of these components.

The first IGCC demonstration project in China would have a capacity of 300-400 MW and would cost about $450 to $600 million. The required direct financial contribution to compensate for the additional cost of IGCC would be about $75 million. This amount can be contributed in the form of a grant or a (albeit larger) concessionary loan. For example, a $200 million loan from the ADB or the World Bank would provide an effective financial contribution of $75 million based on the difference in interest and maturity period of such a loan compared with an average commercial loan.

In order to compensate for the additional risks involved in the construction and operation of the first IGCC plant, we would need to establish a $30-50 million guarantee facility. This facility would remain as a contingent fund and would not be disbursed if the construction and operation proceed according to the plan. The transaction arrangements of the guarantee facility should be designed considering the requirements of the project sponsors and financiers.

After reviewing the activities, mandates and the interests of potential sources of financial support we have arrived at a proposed financing scheme as follows:

(a) The ownership structure of the demonstration project should include a public utility and a private sector consortium, which would itself comprise domestic and foreign private investors. This arrangement would enable effective utilization of comparative advantages of various parties, and access to official and private sources of finance. Project sponsors should be able to provide at least 30%, or about $150 million, of the project cost from their own resources.

(b) The guarantee facility should be funded by the GEF. The mandate of the GEF enables it to take certain commercial risks, particularly those related to transfer of technology and demonstration plants. The idea of using GEF funds in a guarantee facility has the potential attraction that the money may not be actually disbursed; it could be returned to the GEF or used in other demonstration projects.

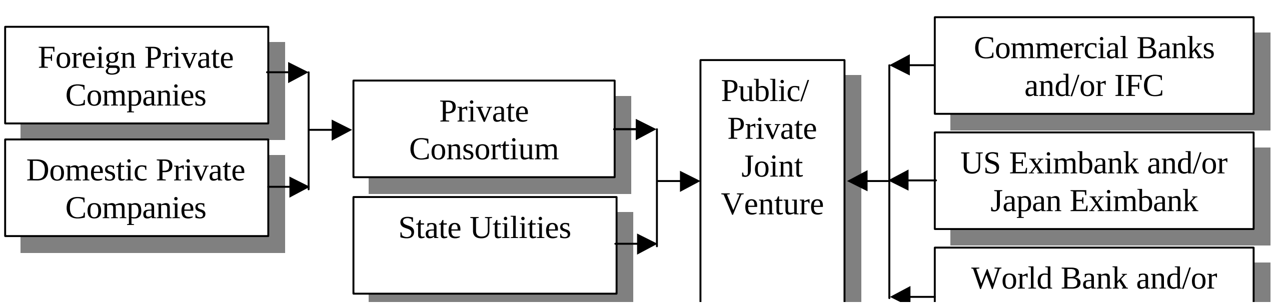
(c) With the support of the government, the World Bank and/or the ADB should be asked to provide loan(s) of at least $200 million. The participation of these agencies would provide the required financial support and also would facilitate participation of other financiers.

(d) The World Bank or ADB should be asked to manage the guarantee facility. A general concern would arise regarding the possibility of abusing the facility. That is, project participants may revert to the facility too easily to bail themselves out of normal financial challenges. The management of the facility by the World Bank or ADB would provide comfort to the project participants and the GEF that the facility would not be withdrawn unless under the envisaged contingent conditions.

(e) The US Eximbank and the Japanese Eximbank should be asked to provide the balance of the financial requirements. These banks provide loans for purchase of equipment and services supplied by their own nationals. Participation of American and Japanese private partners in the project ownership would facilitate access to the funding from these institutions. The Japanese Eximbank provides also untied funds, which could be used to purchase equipment and services based on international competitive bidding.

(f) Commercial lenders should be asked to fill the remaining financial gap if any. These financiers would come in easily if multilaterals and bilaterals are already participating and a guarantee facility is included in the financing scheme. Should the financial gap be large, project sponsors may approach the IFC to provide financial support from its own resources and to mobilize funds from commercial lenders.

Recommended Financing Scheme for the First IGCC Plant in China



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Introduction

Background

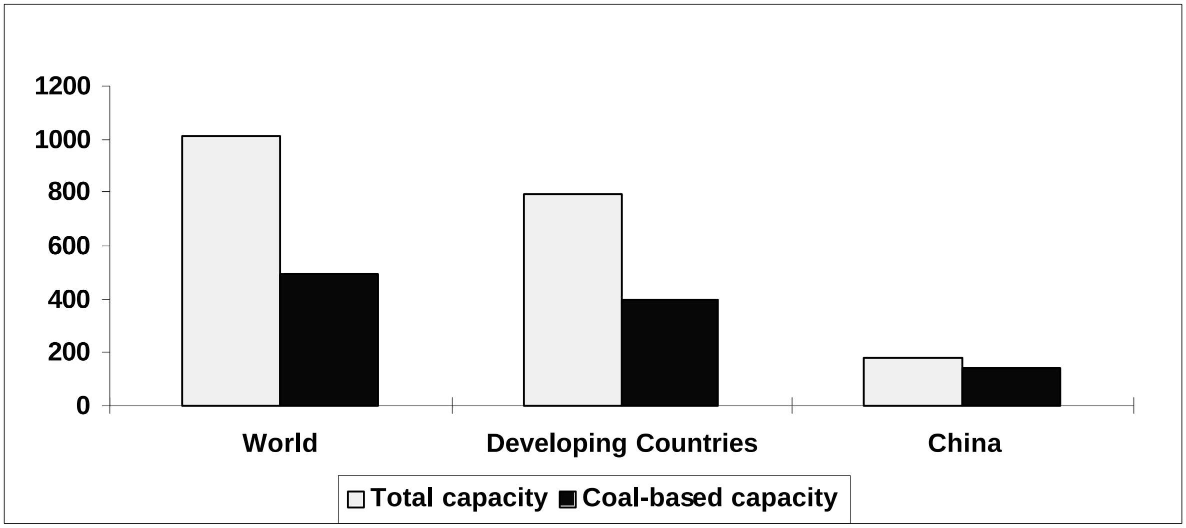
Clean coal technologies (CCTs) for power production attracted serious political attention in the 1980s in the aftermath of the oil crises of the 1970s. There was a worldwide movement to reduce reliance on oil, and there were reservations about the safety of nuclear power. Coal by default became the only 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. The concern was mostly limited to local environmental impacts. 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 efficiency improvement objective was related to the then high energy prices.

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 US Department of Energy (USDOE). 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.

Interest in the international community in the CCTs was reawakened in the 1990s due to: (a) increasing public awareness about local, regional and global environmental problems; (b) clear realization that for certain countries like China and India there was no realistic alternative to coal consumption; and (c) rapid expansion of coal use in these countries to meet the energy demand resulting from high rates of economic growth.

Presently, CCTs are at a cross-road. Technological advancement has paved the way for major breakthroughs, and emission control devices have become commercially viable, but advanced CCTs are one step away from being proven and commercially viable. Thus, common-sense urges that governments and the international community support a push towards establishing the viability of the most promising of these technologies. A further extension of the same logic implies that it may be more rewarding to demonstrate the commercial viability of these technologies directly in countries like China and India which offer vast potential markets for advanced CCTs. However, the financing mechanism for building further demonstration projects is missing. The USDOE which was in the past the major source of financial support for CCTs is no longer appropriated financial resources for this purpose. Other interested parties, the Japanese, the multilaterals and governments have not yet geared up to the matter. As a result there is now little financial assistance but a strong political support for promoting advanced CCTs.

Figure 1: Addition to Power Generating Capacity During 2000-2010 (GW)



Source: International Energy Agency (1996)

The Objective and Road-Map of the Study

The objective of this study is to develop a financing scheme for promotion of advanced CCTs in China. This is in effect done based on capitalizing on the political support for these technologies and utilizing all the sources that can be influenced by the interested parties. The development of the financing mechanism is also based on the innovative approaches to project finance which have emerged in the recent years in relation to private sector participation in infrastructure investments.

The road-map of the study is as follows. First, a review of the present status of available CCTs examines the stage of technological development, the environmental aspects, and the cost patterns associated with each CCT. The review shows which technologies are already in common use and which ones need some degree of public support prior to being viewed as proven and commercially viable.

Second, an assessment is made of the opportunities and constraints in using CCTs in China. The market prospects for CCTs in China are enormous, but there are also major challenges in utilizing these technologies. The challenge relates to (a) the fact that the CCTs are not yet proven even in industrial countries; (b) the uncertainties involved in transferring a technology from industrial to developing countries even if the technology was proven; and (c) the current situation in which China builds its conventional power plants at very low cost, which means that at least the first few CCT plants would have to tolerate a serious cost disadvantage. Still, China represents perhaps the best opportunity for taking advantage of the benefits of constructing demonstration CCT plants. Third, we develop an estimate of the range of financial support that would be needed to encourage an economically rational shift from conventional coal technology to advanced CCTs.

The financial support would need to compensate the project sponsors for the additional cost, and the additional risk of advanced CCTs. We present a measure of these important parameters.

Fourth, we investigate the potential sources of financial support for promotion of CCTs. We review the mandates and activities of the relevant American and Japanese agencies, the multilaterals, and the new initiatives such as the Global Environmental Facility, the Joint Implementation and the Carbon Investment Fund. We present an assessment of the interest and fitness of various agencies to the promotion of CCTs in China.

Finally, we bring together the results of all of the above reviews to design a financing scheme for the initial CCT demonstration projects in China. The scheme presented here is feasible, in the sense that it fits the mandates and interests of the proposed parties, and is effective in terms of providing sufficient support to encourage a switch from conventional to CCT technologies.

2

The Present Status of Advanced Clean Coal Technologies (CCTs)

Technical Features

More than 90% of coal-fired power plants in the world are based on conventional pulverized coal (PC) technology. This is a proven technology. Its cost of construction, plant availability and performance can be predicted with a high degree of certainty. Its economic advantage depends on the cost of coal supply and availability of other fuels in the country. It 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, heavy metals, etc., 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 gas-based power plants have increased from 45% to 60% over the past 10 years, the thermal efficiency of PC has increased only from 30% to 35%. Because of its lower thermal efficiency, PC technology uses larger volumes of fuel and imposes further environmental damage.

The competitive pressures from gas-based combined cycle plants, and the increasing public awareness of environmental issues, have resulted in efforts to control emissions and increase the efficiency of the coal-based power generation. These efforts are generically known as “clean coal initiatives,” and include a variety of processes, devices, and technologies. Some of these initiatives, such as coal washing, do not involve significant technological advancement and are being incorporated in the coal preparation process. However, emission and efficiency improvements of the coal-burning process 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 initiated and implemented to develop and commercialize CCTs. These efforts or more precisely, the products of these efforts, fall into two broad categories. First, some proven technologies have been incorporated into devices that can be added onto a PC plant to control its emissions. These include flue gas desulfurization (FGD), and selective catalytic reduction (SCR) facilities. Both FGC and SCR are being used by power plant operators to cope with more stringent emission standards. Second, some new technologies have been developed to enhance the coal combustion process. The technologies in this second category not only reduce the emissions, but also increase the thermal efficiency. However, they are not generally viewed as proven or mature technologies. Their capital cost is still higher than a conventional plant. Their construction cost cannot be predicted with certainty. Their operational performance cannot be guaranteed. These technologies are called "advanced" clean coal technologies.

The use of emission control devices such as FGD is new and very limited in China. Utilization of FGD will be of significant benefit to in addressing local and regional environmental problems. It is therefore, important to encourage existing and new plants to consider installing FGD. However, some important steps have been taken already which may well result in a rapid expansion of FGD utilization in China. First, emission standards have become much more stringent forcing plant operators to consider FGD and other emission control devices. Second, the cost of FGD has fallen to affordable levels; the average cost of installing FGD was more than $200/kW until the early 1990s; it has now declined to less than $100/kW. Third, a Japanese sponsored technical assistance program has enabled the Chinese to produce FGDs domestically. Although Chinese government policy and bilateral support should continue to reinforce the use of FGD and other emission control devices, these are considered proven and viable technologies. They do not involve any significant technological risk and will be adopted where needed.

On the other hand, the use of advanced clean coal technologies involves substantial risk and will not be adopted by private or state-owned utilities unless certain incentives and comforts are put in place.

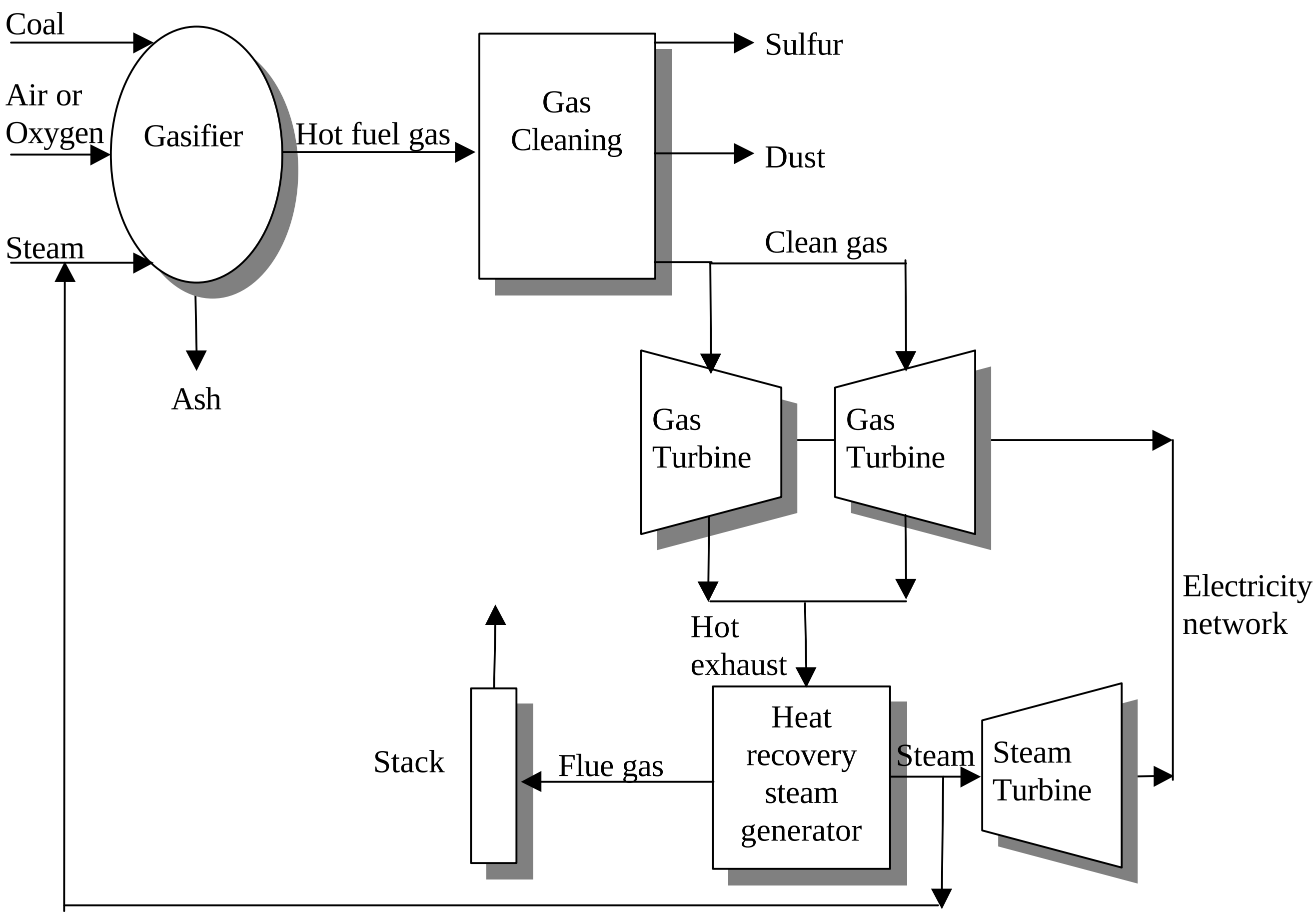
Advanced CCTs include two major categories: integrated gasification combined cycle (IGCC), and fluidized bed combustion (atmospheric [AFBC] and pressurized [PFBC]).

IGCC is a system that combines coal gasification and combined-cycle power generation technologies. 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.

There are presently five commercial scale IGCC plants in operation in the world. Three of these projects are in the US and were implemented with the financial support of the USDOE Clean Coal Technology Program. The other two plants are in Europe—one in the Netherlands and one in Spain. The US plants have General Electric (GE) gas turbines: he 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.

The main desirable features of IGCC are that (i) the gasified coal is purified before it is burned in the turbine; thus it is possible to remove particulates, sulfur and nitrogen compounds; and (ii) 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.

Figure 2: Typical Components of an IGCC System



Fluidized bed technology combusts coal (or other fuels) within a mixture of limestone or inert materials while suspended over jets of air. This turbulent mixture of air and materials produces a “fluidized bed” which provides efficient combustion with relatively low emissions of sulfur and nitrogen oxides. The coal/limestone mixture is kept suspended by blowing air upwards through the bottom of the combustor floor. This results in retaining a high thermal inertia, quickly heating the fuel to the ignition temperature, and circulating the fuel particles long enough for complete combustion.

Fluidized bed combustion is categorized according to its operating pressure. Atmospheric fluidized bed combustors (AFBC) operate under normal atmospheric pressure conditions, while pressurized fluid bed combustors (PFBC) operate at pressures 6 to 16 times higher. The AFBC has a long history with sporadic use in the industrial sector. On the other hand, PFBC is viewed as much more desirable technology. Its thermal efficiency is about 40% and expected to improve to 44% in the next 10-15 years. It is therefore, viewed as the prime competition for IGCC. However, there is limited worldwide experience in construction and operation of PFBC. Some considerable effort is being spent by industry in the US, UK, Sweden, Spain, Germany and Japan to develop and test PFBC technology at commercial scales. There are presently five commercial scale PFBC projects operating worldwide. These plants are located in the US, Sweden, Spain and Japan. All plants are based on ABB's P200 PFBC module that provides 80-100 MW of capacity. The plant in the US operated for four years (1991-95) and was shut down in March 1995. The shut down was envisaged in the original planning for demonstration of PFBC. The plant in Sweden is a combined heat and power operation and provides electricity and district heat. It operates only during the cold season (October-May) of the year. The plant in Spain works on a full dispatch basis. It has demonstrated the adaptability of PFBC to using lower quality coal. The plant in Japan has accumulated more than 10,000 hours of operation. In addition, Japan is taking a leading role in developing large-scale units. The Karita PFBC plant, which was completed in December 1997, includes one 360 MW plant, the largest PFBC unit in the world. Most of the PFBC plants have encountered a variety of technical problems. Most technical problems, however, have been resolved. Nevertheless, there is still substantial potential for technological advancement to increase further the efficiency of PFBC and also to demonstrate a "problem-free" plant in operation.

Environmental Aspects of Clean Coal Technologies

The most important reason for the recent worldwide attention to CCTs is public concern about the environmental impacts of coal use in power generation. Environmental concerns not only encourage the use of CCTs but to some extent determine the type of CCT that should be selected in a given circumstance.

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. Removal of SO_2 takes place after the flue gas exits the boiler; the process is called flue gas desulfurization (FGD). The most common method is based on flue gas scrubbing using lime or limestone (wet scrubbers) which can capture 95% or more of the SO_2 in the flue gas before it exits the stack. The main drawback of the FGD process is that it compounds the ash disposal problem that is normally an environmental problem in certain locations and in cases of low quality coal.

Modification of the combustion process or, by post-combustion processes that may be based on selective catalytic reduction (SCR) or selective noncatalytic reduction (SNCR) can accomplish control of NO_x emissions. SCR is the most effective method and can achieve 80 - 90% reduction in NO_x emissions. In the SCR process, ammonia is injected into the flue gas and is passed through a catalytic reactor where the ammonia reacts with NO_x to produce nitrogen and water. The SCR process is being used in plants that use low sulfur coal, but it has not been demonstrated on boilers burning high sulfur coal. This latter limitation has triggered initiatives to develop combined SO_2/ NO_x reduction devices. The combined processes are now used on a commercial scale in the

US, Denmark and Italy. The combined processes have also incorporated in them means of controlling particulate emissions and thereby facilitating ash disposal.

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 clean coal technologies, such as IGCC and PFBC, are considered to be more desirable options for dealing with all types of environmental concerns. 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. Sulfur compounds, nitrogen compounds and particulates are removed before the fuel is burned in the gas turbine; that is, before combustion air is added. For this reason there is a much lower volume of gas to be treated than in a post-combustion scrubber. 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 erosion and 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.

In PFBC technology, SO_2 and NO_x emissions are reduced by controlling combustion parameters and by injecting a sorbent, such as crushed limestone, into the combustion chamber along with coal. Coal mixed with limestone is suspended on jets of air in the chamber. At combustion temperature of 1400-1800^oF, the fluidized mixing of coal and sorbent enhances both coal combustion and sulfur capture. The limestone captures sulfur released when the coal is burned before it escapes from the boiler. The sulfur then chemically combines with the limestone to form a new solid waste product, a mixture of calcium sulfite and calcium sulfate. The solid waste may be easily disposed of in a landfill or possibly sold for industrial and agricultural applications. In this way, more than 90% of sulfur emissions are reduced. Also NO_x emissions are reduced by some 60-80% because the operating temperature range is much less than the temperature of a conventional boiler and is below the threshold where thermally induced NO_x is formed.

Table 1 shows the environmental impacts of clean coal technologies versus a conventional PC plant.

Table 1: Comparison of 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)

Economics of Clean Coal Technologies

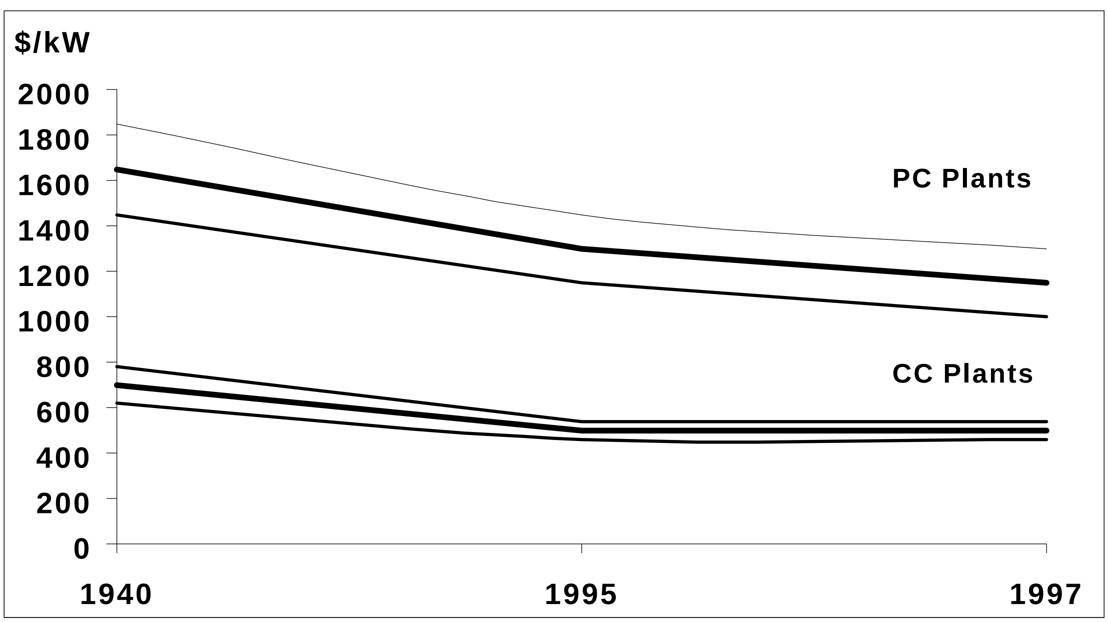
Power generation technology has gone through unprecedented change during the 1990s. The change has been lead by natural gas-based combined cycle technology, which has improved dramatically over the last 10 years. Other technologies have also improved in order to survive the increasingly competitive market of power generation technology.

There are three global trends in power generation technology. First, cost of plant construction is declining. Second, thermal efficiency is increasing. Third, reliability of plant construction and operation is improving.

Figure 3 shows the cost patterns for two proven and widely used technologies—conventional pulverized coal (PC) and combined cycle gas (CC) plants. Over the last ten years, the cost of plant construction has declined by about 30% for PC and 29% for CC. It is also of interest to note that the range of variation in the cost of construction has declined enabling utilities to predict with a higher degree of certainty their investment costs. The thermal efficiency has also improved. The efficiency of conventional PC technology has increased from 32% to 35%. The efficiency of combined cycle plants, which had increased from 40 to 48% in the 1980s, made a further quantum jump to almost 60% in the recent plants. Thus, CC technology remains at a very significant advantage due to its low capital cost and high thermal efficiency. The use of CC would, of course, require a stable supply of natural gas. Even if the price of gas is in the vicinity of $3.50 to $4.00/MMBTU, the gas-based CC could remain as the preferred option. Nevertheless, in many countries, domestic gas is not available and gas imports not affordable. A coal-based plant is often then the next best option.

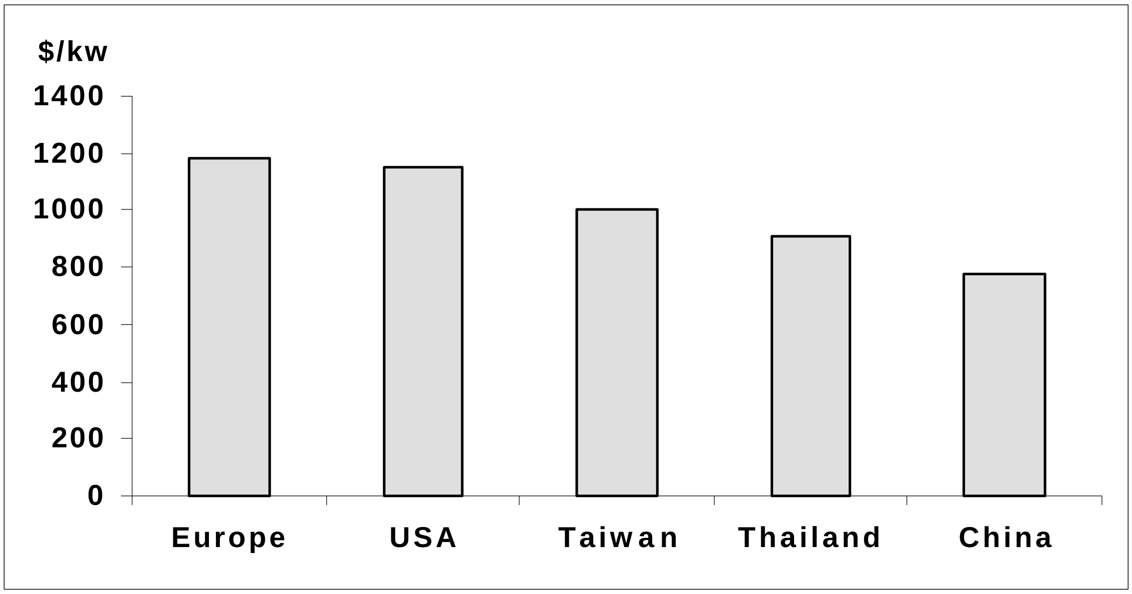
Figure 3: Cost Patterns for Conventional Pulverized Coal and Combined Cycle Gas Plants

Source: Kennedy (1997)



As a further background note, we need to point out that the cost of plant construction does vary depending on the plant location. Figure 4 indicates that the cost of constructing a PC plant in China can be 32% less expensive than in the US. The difference in the unit costs is due to differences in economic conditions particularly costs of labor and raw materials.

Figure 4: Cost of Construction: Conventional Coal Plant (with FGD)

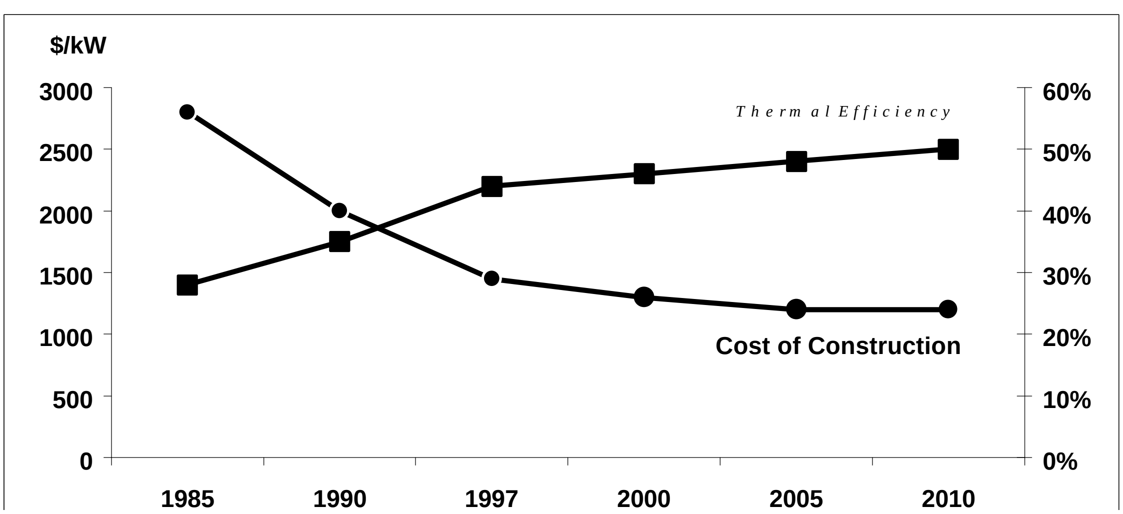


Source: US Department of Energy (1997), World Bank, ADB

The cost patterns of clean coal technologies are not yet reliably established due to the limited number of observations. Nevertheless, there is sufficient evidence that cost per unit has declined dramatically as the technology is advancing through its demonstration phase, and as plant size increases to a large commercial scale.

Figure 5 shows the general cost pattern for IGCC. 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 5: Cost Pattern for IGCC



Source: Ferrier (1998)

The cost of PFBC technology has declined in much the same way as IGCC, though there is less certainty in regard to the cost estimates and projections of improvement in thermal efficiency.

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

Potential Use of Clean Coal Technologies in China

The 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.

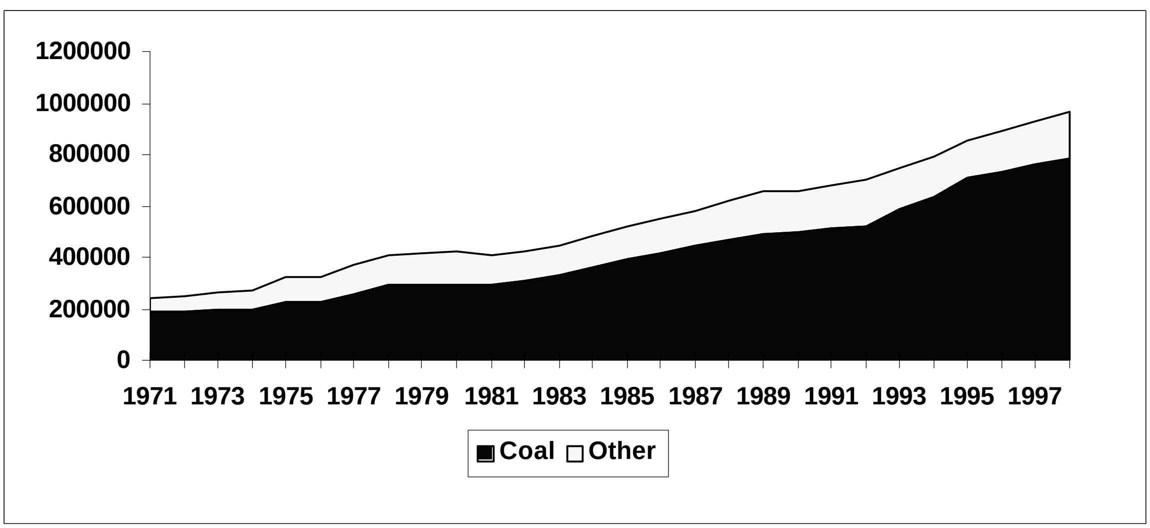
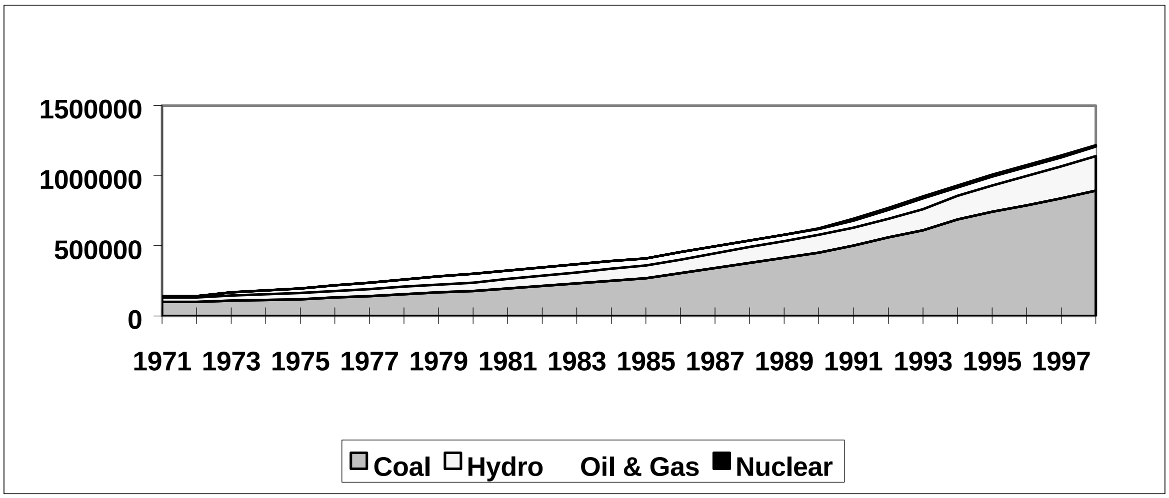


Figure 6: Energy Consumption in China (000TOE)

Source: International Energy Agency (1996)

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 not only large because of the huge size of thermal power generating capacity, but also due to the relatively low thermal efficiency of the existing plants. Although the government policy emphasizes the addition of larger, more efficient units of 300 MW and 600 MW, over one 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.

Figure 7: Fuel Use in Power Generation in China (Gwh)



Source: International Energy Agency (1996)

The large and inefficient use of coal causes severe environmental damage. Emissions of particulates and SO_2 have created serious local 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 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. There has been some progress in the control of particulates through deployment of electrostatic precipitators. However, installation of SO_2 control devices is not yet a common practice partly due to the fact that coal in many parts of China has a low sulfur content. In the regions where coal has a high sulfur content, particularly southwest China, several pilot FGD projects have been implemented. Still the power sector's total emission of SO_2 amounts to 6 million tons/year. The power sector represents an area where significant SO_2 reduction can be achieved rapidly. Thus, the use of FGD is expected to expand as utilities try to meet the more stringent emission standards. The capital cost of FGD is also declining to affordable levels, which will encourage expanded use of this technology.

The availability of finance significantly influences the choice of plant. Until the 1980s, the power sector was fully controlled, managed and funded by the central government. Thus, decisions about the choice of power plant were made within a centralized system and based on economic and political considerations. The system has now become much more decentralized, less vertically integrated, and open to the private sector. Power sector reform has resulted in an overhaul of the regulatory and legal systems and diversification of sources of financing. In particular, provincial and local governments have taken an active role in the power sector. Private sector funding is also increasing rapidly. The share of central government in financing of the power sector has declined from 91% in 1980 to 33% in 1996. Local and provincial governments now provide about 50% of the investment funds. The central government still pursues strategic directions in the mix of generating capacity. In particular, investments in hydro and nuclear, which involve long gestation lags, are supported by the central government. On the other hand, local governments and the private sector select the type of plants that have a low, up-front cost. That is, a plant with lower capital cost is selected even though it may be inefficient and involve a higher operating cost. There are even cases where investors have built plants that they knew would not meet the emission standards; they preferred to pay the emission penalties which would be incurred after the plant went into operation rather than spend more up-front funds on a better plant which would meet the emission standards.

Potentials for Using CCTs

Growth in electricity generation averaged 8% per annum during the last 15 years. Despite this rapid expansion in power generation, electricity supply has not kept pace with growth in demand; most areas of China continue to suffer from severe power shortage. The growth in electricity demand is expected to continue at 8 to 9% per annum. To keep pace with this demand growth, China would need to add some 18-20 GW of capacity per year. Thus, China's electric power construction program from the 1990s will be the world's largest. The World Bank has re-examined the demand growth in light of the East Asia 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.

Table 3: Mix of Installed Power Generating Capacity

Year	*1971*	*1975*	*1980*	*1985*	*1990*	*1993*	*1995*	*2000*	*2005*	*2010*
Installed Capacity (MW)	*27010*	*43000*	*67000*	*87053*	*137891*	*171882*	*193491*	*260159*	*339212*	*442287*
Fuel Mix (%):										
Coal	72%	60%	59%	65%	72%	73%	73%	72%	72%	72%
Oil	7%	17%	21%	13%	7%	9%	8%	6%	4%	3%
Gas	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%
Nuclear	0%	0%	0%	0%	0%	0%	2%	2%	2%	2%
Hydro	22%	23%	19%	22%	20%	18%	19%	22%	23%	24%

Source: Razavi, et. al (1997). Von Hippel (1998)

There is a considerable degree of uncertainty in assessing the portion of coal-based investment that would be spent on CCTs. At least 10% of new coal plants are expected to be equipped with FGD. However, the share of advanced CCTs such as IGCC and PFBC will depend on the availability of these technologies in China. In a study of China's electricity needs [see Atwood (1997)], the DOE's Lawrence Livermore National Laboratory used its power system planning model to examine the potentials for CCTs. The results indicate that China could be using up to 110,000 MW of IGCC and 55,000 MW of AFBC 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%.

In summary, even if advanced CCTs account for only 10% of new generating capacity in China, there may develop a CCT market of at least 30,000 MW over the next 20 years. This means that a demonstration plant of 300 MW could open the possibility of replicating the plant at least one hundred times during the next 20 years. This is clearly a minimum market potential. Should advanced CCTs be established as economic and reliable technology, the replication potential could be substantially greater.

Constraints in the Application of CCTs

Despite the very positive prospects for using CCTs in China, there are severe constraints in employing these technologies. The most important constraints are as follows:

1. 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, particularly plant availability can not be reliably assessed.

2. even if CCTs were proven technology, there would still be an additional challenge of importing the technology to China for the first time. Although Chinese are particularly

receptive and eager to import new technologies, demonstration of the new technology would require a special effort.

3. compared with the current needs, capital resources are relatively scarce. Thus, investment decisions are biased towards solutions that take smaller up-front costs. CCTs do involve a higher capital cost though would result in more efficient operations. They represent a typical case of under investment by market forces.

4. the cost of the alternative, i.e. conventional pulverized coal technology, is somewhat less than advanced CCTs, but in the case of China, the cost is substantially less. 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 particularly unproven technologies.

China's Experience with CCTs

The power sector in China is under three distinct pressures. First, there is yet a strong demand to increase the generating capacity in order to meet the rapid growth in electricity consumption. Second, there is widespread effort to restructure the sector so that the responsibility and investment commitments move away from the central government to the local governments and the private sector. Third, there is a nationwide attempt to reduce the environmental impacts of energy consumption; the power sector has been identified as the most important area in which significant improvements are achievable.

The above three factors will not necessarily combine to move the power sector in the same direction. There will be trade-offs at least in the short to medium terms. For example, local governments and the private sector could become preoccupied more with accessing funds rather than protecting the environment. Under such circumstances, the government and the international community can play an essential role in introducing the "win-win" solutions, and also in encouraging decisions that impart social benefits. Application of CCTs in China is a case in point where the government and certain bilateral and multilateral agencies have started to pay attention even though actual achievements are still quite modest.

Applications of CCTs have been initiated in five categories. First, the government has encouraged coal washing and preparation techniques. The Japanese have played a role in introducing these technologies. Second, FGDs have been developed domestically and installed on a number of power plants. Again, Japanese support has been very important. The strongest encouragement, however, has come from the more stringent environmental standards imposed by several local governments in the Sichuan, Shandong, and Shanxi provinces, and Shanghai municipality. Third, there is an increasing emphasis on modernization of existing power plants. Most existing equipment in coal-fired power generating units with capacities less than 300 MW are of local manufacture. The generic problem associated with such equipment can be traced to design inadequacy, material deficiencies, fabrication quality controls, installation problems, operation, and maintenance problems. The main objective of modernization is to maximize combustion efficiency in the boilers, to optimize steam flow path in turbines, and to minimize power consumption in boiler and turbine generator auxiliaries. A recent study, which was supported by the Asian Development Bank (ADB), has identified 300 power plants throughout China that would yield significant energy savings through modernization/rehabilitation investments. The ADB and World Bank would be likely sources of finance for such investments.

Fourth, since last year a systematic effort has started to introduce widespread use of super-critical coal-fired power plants. This technology is about 10% more efficient than the (subcritical) conventional plants. There is, however, a perception that supercritical technologies are both more expensive and involve more risk than subcritical technologies. The ADB is supporting the construction of 2 X 600 MW supercritical units in the Anhui Fuyang plant.

Fifth, there is a widely publicized effort to promote the use of IGCC technology. The high exposure emerged due to the anticipation of a sizeable program of assistance from the US DOE, and the envisaged comprehensive cooperation between the two countries. Unfortunately, the program did not materialize **(see Chapter 5)** but still the Chinese are pursuing the matter with serious interest. In the meantime, the ADB has shown willingness to support the effort by providing finance to carry out a feasibility study of a 200 to 400 MW IGCC to be located in Yantai in Shandong province. A decision whether to proceed with the plant is expected by mid-1999.

The efforts in support of CCTs in China are all of recent origin. They are based on collaboration among the utilities, government and external source of support. There are at least two points worth considering. First, policy makers and utilities are becoming familiar with the spectrum of CCTs; it is thus timely to “push the envelope” and bring to their attention the advanced CCTs. Second, the present momentum in improving energy efficiency, which stems from local, regional, and global environmental concerns, has attracted political attention to policies and projects that can address these concerns. This political attention provides a unique opportunity for introducing advanced CCTs that indeed require strong public support and close cooperation with external suppliers, operators and financiers.

4

The Need for Financial Support

Financing a power project in a country like China is quite a challenge because domestic capital resources are not sufficient to fund the huge investment requirements of the power sector, and foreign capital can be mobilized only under certain conditions. To assess the attractiveness of the conditions, project sponsors and financiers look, in principle, at two important project characteristics. First, whether the expected streams of project costs and revenues yield a satisfactory rate of return, and second, whether the likelihood of a downward move in the rate of return is minimized, i.e. risks are well managed. Both of these requirements particularly the latter, introduce a bias against using new technologies.

Barriers in International Transfer of Technology

International Transfer of Technology occurs every day and in every field. Scholars and practitioners of many disciplines, e.g., economics, political science, management, engineering, marketing, law, business and finance, etc have studied it. Yet there are no coherent, overarching theories that can satisfactorily explain various aspects of international technology transfer.

The literature offers different perspectives of technology transfer by viewing it as a commodity, or knowledge, or a socio-economic process. In classical economics, technology transfer is viewed as a commodity, e.g. obtaining a design document, or purchasing new vintage equipment. More recent studies propose that technology transfer is knowledge and is brought about through a learning process; purchase of machines and blueprints by itself does not constitute technology transfer. The contemporary advocates of international transfer of technology view the concept to encompass a combination of hardware, services, and knowledge. They also propose the term "technology cooperation" as a replacement for technology transfer, because the latter does not satisfactorily represent the two-way relationships involved in the matter. This contemporary view adds many dimensions to the phenomenon, most of which are not well understood.

In the business/finance literature, transfer of technology is viewed in relation to costs and revenues of the new versus the "base" technology, and the corresponding risks and uncertainties. The terms "risk" and "uncertainty" are sometimes used interchangeably. However, in decision analysis, the term "uncertainty" refers to the probability of an occurrence, while "risk" refers to the severity of loss that will be a consequence of such an occurrence. Thus, in order to make a business decision, one would need to know (a) the risk that the new technology may fail to produce the targeted output in a timely fashion and at the projected cost; and (b) the manners in which the risk can be systematically reduced and managed.

One useful approach to risk management is the so-called "problem framing." Within this framework, the choice of technology is divided into three categories:

(a) Type I situation where the host country/company has prior experience with the technology. This would be a case of "relative certainty" and would apply to the base technology, i.e. the technology that is already in use;

(b) Type II situation where the host country/company has no prior experience with the technology, but is fully aware of various aspects of it. This would be a case of "controlled uncertainty," where the country/industry/company has a good knowledge of the new technology except that they have not incorporated such technology into the existing production processes.

(c) Type III situation where the host country/company has no prior experience with the technology and is not familiar with it. This would be a case of "uncontrolled uncertainty," where the objectives and requirements of technology transfer are ill defined.

The above approach emphasizes that the distinction between Type II and Type III situations is critical; and thus any attempt to transfer technology should be first aimed at shifting from a Type III to a Type II situation. The obvious results of this process would be accumulation of knowledge and skills. A company in Type II situation would have a "mind set" for a systematic and efficient transfer of technology, but would not have such a mind set as long as it is in the Type III situation. The significance of having the mind set is seen in the company's ability to control uncertainties, or their corresponding risks, by careful planning, systematic fact finding efforts, and putting in place contingency plans where risks are not covered.

In order to apply the "problem framing" approach to the case of CCTs, we need to recognize that:

(a) information dissemination, training, communication and knowledge sharing are integral components of the technology transfer process. The significance of these efforts is in creation of comfort for using CCTs and the mind set for making the relevant business decisions;

(b) along with developing the mind set, there will be a need for assessing the risks of using CCTs and investigating various options to reduce and manage these risks; and,

(c) after we have made all attempts to deal with the risks, there will still remain some incremental risks and/or costs of CCTs which need to be offset by some type of financial support in order to put the financial aspects of CCTs at par with the conventional coal technologies. The incremental risks and costs should be analyzed in relation to national, regional, and global benefits of using CCTs in order to allocate the costs to the appropriate potential sources of financial support.

Assessment of the Risks of CCTs

In order to assess the incremental risks of CCTs, one should identify the risks of the base plant, e.g. conventional coal plant, as well as the relevant CCT, e.g. the IGCC technology.

The major categories of risks for thermal power plants include:

Preparation/ implementation stage:	Legal problems in awarding contracts Difficulties in bid evaluation Delays in procurement Change in project scope and equipment specification Change in the plant site Disagreement with financiers
Construction/ operations stage:	Shortage of skilled labor Labor disputes Redoing the work that is considered substandard Equipment failure during testing Contractor inefficiency Shortage of materials and fuels
Uncontrollable events	Need to redesign due to natural disasters Accidents Political turmoil Unusually bad weather

The above risks would be relevant to both the base technology and the CCT. However, most risks in the fist two categories may be more severe for the CCT compared with a conventional plant.

The next stage in analyzing the risks is to investigate all avenues for risk reduction. The risk reduction measures fall into three categories:

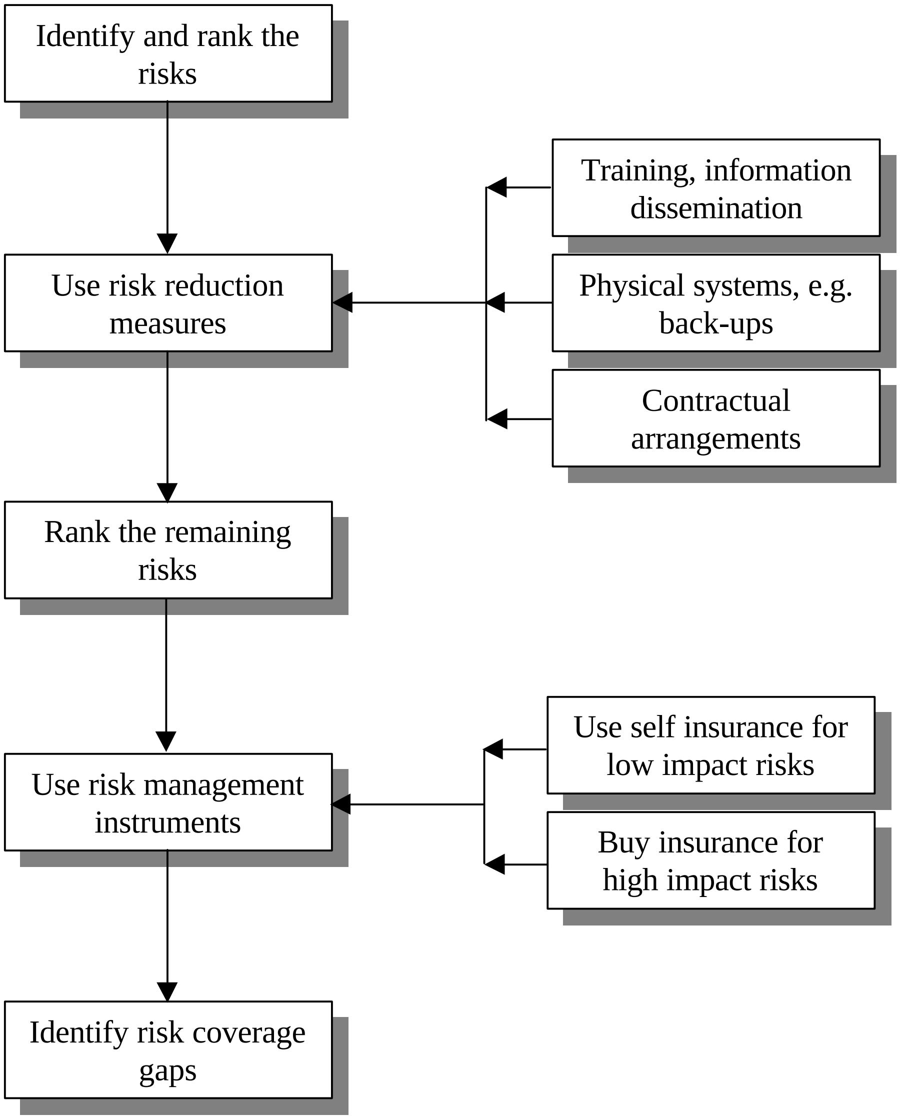
(a) A rather inexpensive, but very effective way to reduce risks is through training and dissemination of procedures, processes and other information.

(b) For severe risks, one should put in place contingency plans including physical systems, e.g. equipment duplication to provide backup in the event of a failure; and

(c) Contractual arrangements are widely used to reduce the risks of cost overruns, underperformance, fuel shortage, etc.

After studying all risk reduction avenues, one should consider risk management trade-offs and instruments. There are a variety of instruments on the market, or through government-sponsored funds, and multilateral and bilateral agencies, which provide, in essence, some type of insurance against different forms of risks. Also, an option open to many companies, particularly electric utilities, is self-insurance, which can be in the form of a captive insurance company or other internal funding mechanisms.

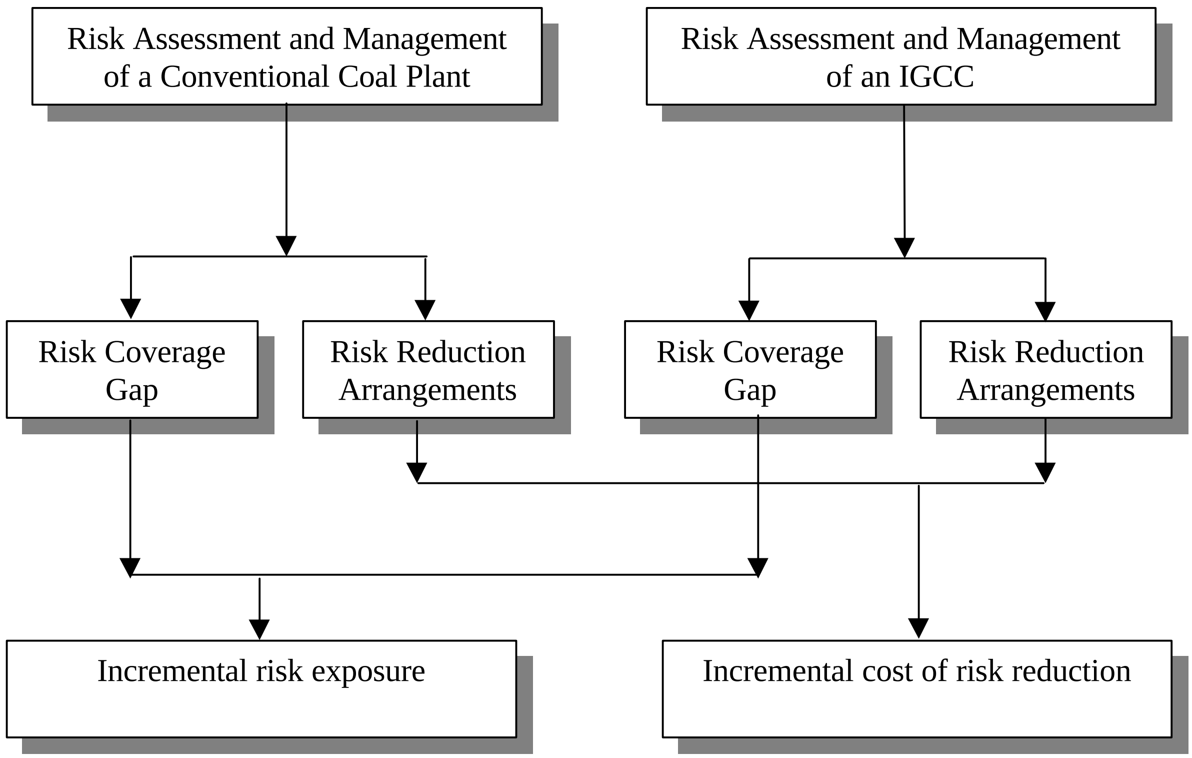
Figure 8: Risk Reduction Process



Finally, analysis of project risks should identify the risks that are not covered, i.e. the risk coverage gap. Risk reduction and risk management often do involve costs. In certain cases the cost of risk reduction is so high that one would accept to leave some of the risk uncovered.

The above steps should be pursued for both the base technology and the CCT. Then the results are compared in order to assess the incremental risk exposure, as well as the incremental cost of risk reduction (Figure 8). It may be possible for the company to employ sufficient additional risk reduction instruments to eliminate the incremental risk exposure of the CCT. Then the main difference would be in the cost of risk reduction. However, in practice, some incremental risks may remain uncovered and result in further riskiness of using CCTs. This is particularly true if the worldwide experience with the technology is limited as is presently the case with IGCC and other advanced CCTs.

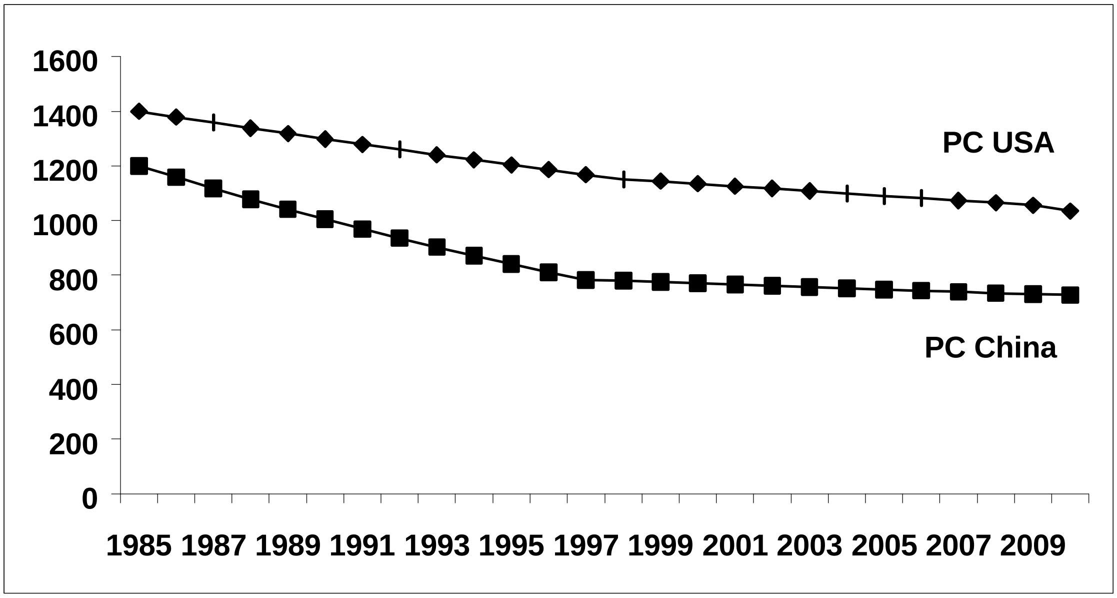
Figure 9: Methodology for Assessing the Incremental Risks of Clean Coal Technologies



Compensating for Incremental Costs and Risks

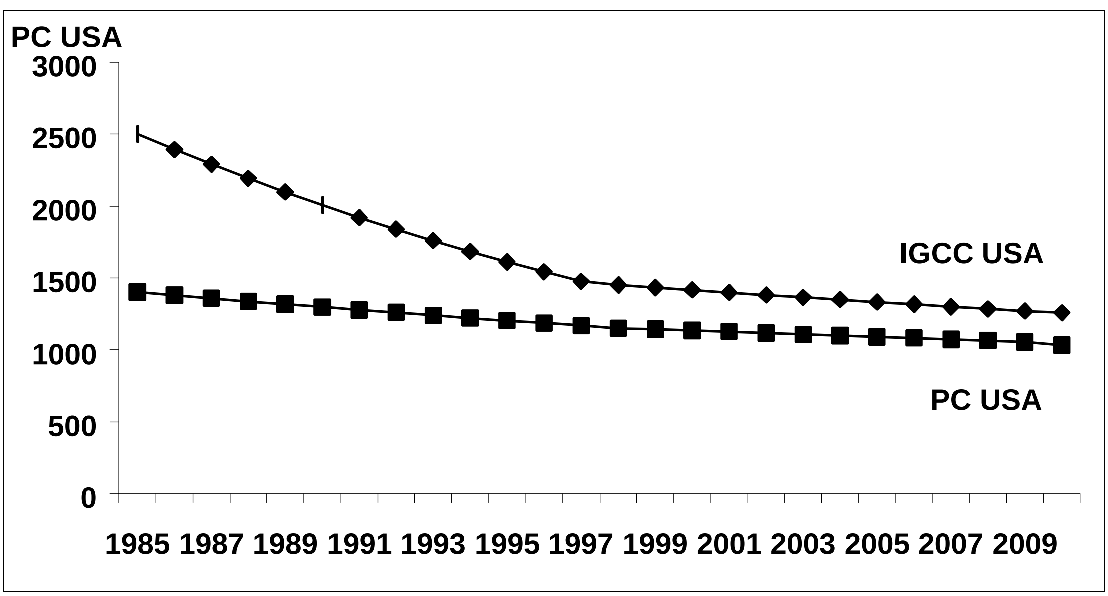
Although there are not sufficient time series data to construct reliable cost estimates of various types of coal-based power plants, two relative patterns can be detected. First, the cost of construction of conventional coal-based power plants has declined over the past ten years. The cost decline has occurred in the international markets, as well as in China, while the overall cost levels in China are lower than the international average (Figure 10). China's lower cost of plant construction is by and large due to the lower cost of labor and raw materials and somewhat due to lower quality of the equipment. The cost advantage may shrink as the Chinese economy is increasingly exposed to international market conditions and as the standards of quality are raised.

Figure 10: Cost of Conventional Coal Plant in China and the US
($/kW)



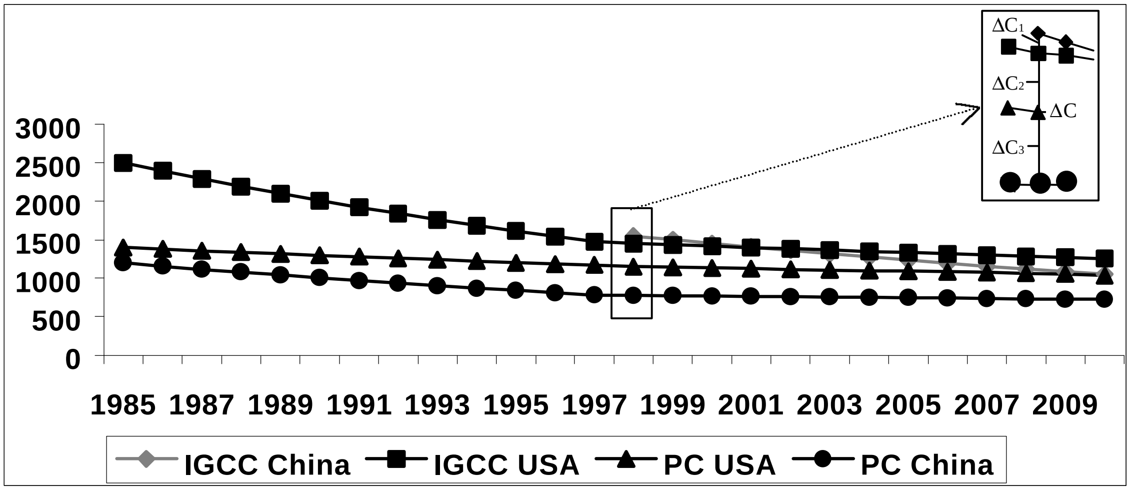
Sources: Compiled from Ferrier (1998), International Energy Agency (1996) and Kennedy (1997), World Bank, ADB

Figure 11: Cost of Conventional Coal Plant and IGCC in the US
($/kW)



Sources: Compiled from Ferrier (1998), International Energy Agency (1996) and Kennedy (1997)

Figure 12: Capital Cost Comparisons



($/kW)

Second, the average cost of construction of an IGCC plant is higher than a conventional steam plant, but the cost difference has shrunk noticeably over the last 10 years. The cost of construction of an IGCC plant is expected to decline further (Figure 11). Combining the above cost patterns (Figure 12) depicts the relative costs of building an IGCC versus a conventional plant in China. The cost of building the first IGCC in China could be higher than that of building an IGCC in the United States due to implementing IGCC in a new business environment. Over time, the cost of IGCC in China will decline to levels below the international average. However, initially, from the Chinese point of view, the cost differential between PC and IGCC could amount to:

(Equation A) $$\Delta C = \Delta C_1 + \Delta C_2 + \Delta C_3$$

Where

ΔC_1 = Transitional cost due to implementing IGCC in a new business environment (China)

ΔC_2 = the cost differential between IGCC and PC on an international basis

ΔC_3 = the cost advantage due to lower cost of land, labor and raw materials.

Equation (A) provides certain conceptual guidelines regarding allocation of costs to various sources of financing:

(a) The cost differential between implementing an IGCC and PC in China is mostly transitional and would be reduced over time after sufficient experiment and learning. However, the nature of transition varies for each component. For ΔC_2, the transition would take place in the international market as new IGCC plants are built at lower costs and within more reliable implementation plans. For ΔC_1, the transition would need to take place in China as new demonstration projects are built in China to enable the country to build subsequent plants at lower costs. For ΔC_3, the transition would be related to the opening of the Chinese economy to free market forces and its impact on the cost of labor and raw materials.

(b) There is a view in the US industry and more strongly among relevant Chinese authorities that certain components of IGCC can be built domestically. With that assumption, the cost of building an IGCC in China could be less than building the same plant in the US, i.e. ΔC_1 would be zero or negative. Although there is sufficient experience to justify this view, it may be wiser to build the first demonstration project using imported equipment. The objective of the demonstration project is not only to show that IGCC works, but more importantly to show that it can be constructed at a firmly projected cost and within a firm timetable, and that the plant would operate at certain plant factor and thermal efficiency. Relying on domestically produced components may jeopardize the demonstration effect because of delays and operational problems. It is, therefore, advisable to build the first demonstration plant on a turnkey basis while introducing domestically produced components systematically in the subsequent plants.

(c) Each of the cost differential components justifies a specific type of financial support. With regard to ΔC_1, i.e. the cost of introducing a new technology in the Chinese power sector, one could justify support from the government and public interest agencies in China. For ΔC_2, i.e. the incremental cost of IGCC over PC, one could justify support from bilateral and multilateral agencies. In this regard, implementing an IGCC plant in China is viewed as increasing the worldwide experience with IGCC technology, which imparts benefit to the entire international community. For ΔC_3, i.e. the cost advantage emerging from the lower cost of labor and raw material in China, it is perhaps reasonable to expect the companies, including the utility, manufacturer, and contractor to provide financial support.

Financial support for using IGCC in China is not only justified based on the incremental costs of this technology, but also because of the incremental uncertainties and risks.

Calculation of the Incremental Costs and Risks

In order to provide a range of magnitudes for financial support to the application of IGCC in China, we need to estimate the average costs, and variances of power generation in various cases, i.e. PC and IGCC in China versus the same technologies in the US. We use the following measure of cost of power generation:

$$\text{Levelized Cost} = \frac{\sum_{t=0}^{n} (CAC_t + OMC_t + FUC_t)/(1+r)_t}{\sum_{t=0}^{n} [CAP_t(1-a)*CF*8760]/(1+r)_t}$$

where

CAC	=	Capital cost
OMC	=	Operations and maintenance cost

FUC	=	Fuel cost
CAP	=	Capacity of the power plant
a	=	Rate of auxiliary power use
CF	=	Plant availability (capacity factor)
r	=	discount rate

The levelized cost is then calculated for each situation based on the assumptions contained in Table 4. These figures have been constructed based on the data from the US DOE, ADB, World Bank and industry estimates. In the construction of the capital cost estimates, we have attempted to base the figures on consistent assumptions regarding environmental impacts. As an example, the cost of construction of PC units in China averages around $680/kW. However, units built at this cost do not meet the same environmental standards as the units built in the US or Japan. We have instead used a figure of $880/kW that would include the cost of an FGD unit and other adjustments to bring the emissions on par with US built equipment. This figure is in line with the average cost of power plants financed by the World Bank and the ADB in China in the last 5 years. Indeed, the most recent coal-based plant financed by the World Bank in China, which has just started construction, is expected to cost $920/kW. This plant includes numerous safeguards and is perhaps somewhat above the normal practice, which may be expected of private investor. In a similar fashion, we have estimated the cost of an IGCC plant in China. The cost for the first demonstration unit is based on the assumption that equipment will be mostly imported. Clearly, this assumption is somewhat speculative. Nevertheless, as will be demonstrated later, the relative economic positions of various technologies are clear. One may, of course, examine, as we will, the range of variations in the underlying assumptions and arrive at implications regarding the magnitude of support that would be needed to compensate for economic disadvantages of IGCC.

Table 4: Principal Assumptions Underlying Calculation of Incremental Costs and Risks

	PC w/ FGD (US)	*PC w/ FGD (China)*	*IGCC (US)*	*IGCC (China)*
Capital cost ($/kW)	1150	880	1450	1500
Coal Price ($/ton)	42	42	42	42
Heating content (kcal/kg)	6,200	6,200	6,200	6,200
Thermal efficiency (%)	35	32	44	41
Operations and maintenance cost (¢/kwh)	0.5	0.4	0.5	0.4
Plant capacity (MW)	500	500	500	500
Auxiliary power use (%)	6.5	7.5	14.5	15.5
Plant availability (%)	75	70	70	70

Source: Ferrier (1998), International Energy Agency (1996), Kennedy (1997), DOE (1996 and 1997) and World Bank and ADB Project Appraisal Reports

Based on the above assumptions, we calculate the levelized cost as well as the potential risk of power generation for each technology. Calculation of risk takes account of possibilities of cost overrun, increase in construction time, and shortfalls in operational efficiency and availability of the plant. For each risk factor, the risk margin represents the industry's assessment of potential failure in the corresponding factor. The overall risk margin is based on a worst-case scenario where the plant would experience cost overrun, completion delay, and operational problems all together. In practical experience, these risk factors are often correlated; a plant involving unsatisfactory construction experience normally faces operational problems as well.

The results of the calculation of economic risks are summarized in Table 5. These results indicate that for China:

(a) the expected cost of power generation from an IGCC plant is about 32% higher than a conventional PC plant; the incremental cost ratio is 1.32; and

(b) the risk involved in construction and operation of a PC plant is equivalent to a 14% increase in the cost of power generation; the risk for an IGCC plant is equivalent to a 40% increase in the cost of power generation; the incremental risk ratio is 1.23.

The above two ratios are very important in designing the financing scheme for the IGCC plant. The incremental cost ratio determines the amount of direct contribution that should be made to the financial resources available to the project sponsors. The incremental risk ratio determines the size of a guarantee facility which should be put in place to meet the cost overruns in the event that any of the risk events materializes.

Table 5: Calculation of Levelized Costs and Economic Risks

	PC w/FGD (US)		*PC w/FGD (China)*		*IGCC (US)*		*IGCC (China)*	
Factor	*Avg.*	*Variation*	*Avg.*	*Variation*	*Avg.*	*Variation*	*Avg.*	*Variation*
Capital Cost ($.kW)	1,150	(+150)	880	(+150)	1,450	(+200)	1,500	(+250)
Construction time (yrs.)	5.0	(+0.5)	5.0	(+0.5)	5.0	(+1.0)	5.0	(+1.5)
Thermal Efficiency (%)	35	(-1)	32	(-1)	44	(-4)	41	(-5)
Plant Avaialbility (%)	74	(-5)	70	(-5)	70	(-10)	70	(-10)
Delivered cost of power generation (¢/kWh)	4.7	(+0.66)	4.4	(+0.60)	5.7	(+1.84)	5.8	(+2.33)

For IGCC vs PC in China, the incremental cost ratio and incremental risk ratio are calculated as follows:

Incremental cost ratio=5.8/4.4=1.32
Risk factor for PC=(4.4+0.60)/4.4=1.14
Risk factor for IGCC=(5.8+2.33)/5.8=1.40
Incremental risk ratio=1.40/1.14=1.23

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Major Sources of Support for Clean Coal Technology

There have been only two primary sources of financial support for the promotion of CCTs—the US DOE and the Japanese MITI. Other sources of support include the European Commission and governments of Germany, Denmark, Spain, Italy, France, and the Netherlands. The US DOE has provided some $3 billion in support of CCTs in the US. It recognizes that the promotion of these technologies in developing countries could result in significant benefits to these countries and to the US suppliers of corresponding equipment or services. However, the US DOE has not been able to secure the required budget from the US congress and has therefore limited its international promotion of CCTs to information dissemination and technical cooperation. Other US agencies such as the Export-Import Bank and US AID are supposed to complement the efforts of US DOE.

Japanese support for CCTs has in the past been limited to R&D efforts but is now extending into commercial scale projects. The Japanese are also interested in extending effective support to developing countries of the Asia Pacific region.

In addition to the above existing sources, there are a number of potential sources of support for promotion of CCTs. They fall into two categories. First, climate change initiatives such as the Global Environmental Facility and Joint Implementation may be interested in supporting CCTs because of the efficiency improvement of some of these technologies. Second, multilateral agencies such as the World Bank and Asian Development Bank are eager to support projects that aim at protecting local, regional and global environments.

Support from the United States

The US DOE established a Clean Coal Technology Demonstration Program in 1985. The Program is a cooperative effort between the US DOE and US 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: advanced power generation technologies, environmental control devices, coal processing (cleaning), and industrial applications. Investment costs in these categories were as follows:

	$ Million
Advanced power generation	4,600
Environmental control devices	686
Coal processing (cleaning)	519
Industrial applications	1,300
Total	7,100

As indicated by the above figures, 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. The selection of projects for support by the Program was based on competitive bidding. The Program's accomplishments were not viewed favorably as energy prices fell and the economic incentive for improving energy efficiency weakened during the second half of the 1980s. Moreover, exporting CCTs to foreign markets was not likely to happen because of the higher costs and risks of these technologies. However, public awareness of environmental concerns and particularly the regional and global dimensions of environmental issues generated new momentum for the CCT Program. The new momentum included a more positive view in regard to the export of the technologies to countries like China and India, which continue to rely on coal for power generation and which may enact more stringent environmental standards. Accordingly, the US 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. Congress also requested DOE to solicit statements of interest in commercial projects employing CCTs in countries projected to have significant growth in greenhouse gas emissions, and then identify in a report to the Congress the extent to which various Federal incentives would accelerate the commercial availability of these technologies in an international context.

The US DOE requested the industry to submit expressions of interest and proposals for projects that would employ a CCT, that would be sponsored by a US company, and that would be constructed in a developing country where coal use is significant. Thirty-three entities responded to the DOE's request with 77 proposals for projects in the Asia Pacific, Eastern Europe, and the FSU. Projects which were of particular interest to the US DOE were those which could reduce CO_2 emissions, which is primarily possible through improvements in thermal efficiency. These included 14 IGCC and 8 PFBC projects.

The total cost of projects proposed in the letters of interest amounted to $7.1 billion. Respondents asked for some $1.4 billion in Federal incentives. Federal support was requested in three areas:

(a) funding of initial project development, including prefeasibility and feasibility studies, engineering, technology demonstration, and market analysis. The requested funding was $156 million.

(b) funding of projects which would, in effect, support the purchase of equipment and services from US companies. The requested funding in this category was $1.2 billion.

(c) other assistance including general export assistance to US business, and technical assistance to the host country. The requested federal support in this category was $35 million.

More than 25% of the proposals were aimed at projects in China. Among the projects proposed for China, there were six (6) IGCC plants proposed by Foster Wheeler, Bechtel, and Texaco, and two PFBC projects proposed by Foster Wheeler and DB Riley International. All of these proposals asked for Federal support in the project development and demonstration phases and also technical assistance to the host country. Except for Texaco, all other companies asked for Federal support of 10-35% of the actual project cost. Texaco did not ask for a direct Federal contribution to the project cost, but asked for funding during the feasibility and project development phases as well as US government support in coordinating project finance.

Subsequent to the review of the proposals from industry, the US DOE prepared a report to Congress in 1995 and proposed an initiative for US government support for the promotion of CCTs in developing countries. The initiative aimed at providing support in three areas:

(a) providing educational and technical support in the form of training, information dissemination, etc.;
(b) cost sharing of definitional studies including engineering, design, risk analysis, etc.; and,
(c) financial support to showcase projects by providing 10-25% of the project cost.

The 1995 initiative requested a $75 million budget necessary to support a small number of operations in China and Eastern Europe. Unfortunately, Congress did not approve this additional allocation of financial resources to the Program. The US DOE's effort, thereafter, shifted. It has, since then, focused on low-cost initiatives in the areas of information dissemination and training. In this context, a US/China Energy and Environment Technology Center (EETC) was established in Beijing in 1997 to enhance the competitiveness and adoption of US clean energy and environmental technology in China. The Center is implemented jointly by the US and Chinese governments and Tulane and Tsinghua Universities. The Center has established a web site for information dissemination, organized bilateral meetings, workshops and study tours, and sponsored research on CCTs. It is hoped that the activities of the Center will create comfort and conviction among the policy makers to adopt CCTs.

The lack of significant US government support for export of CCTs to China has disappointed many in the US and China. Nevertheless, there are several other US government agencies that are viewed as appropriate sources of financial support for exporting US technology to developing countries.

The decision by the US Congress to decline funding of the DOE's initiative hinged upon the perception that financial support for CCTs should be mobilized through already existing mechanisms in other federal agencies that have mandates in this area. There are at least four federal agencies that are considered relevant.

1. The Export-Import Bank of the United States (US Exim) provides loans, loan guarantees, and insurance to facilitate US exports.

2. The Overseas Private Investment Corporation (OPIC) provides assistance to qualified overseas ventures with significant US participation. Its primary business is in loan guarantees and insurance, though it does also provide loans. However, OPIC assistance is not available for certain countries including China.

3. The Agency for International Development (US AID) provides assistance to the energy sector of developing countries mostly through its Energy Development Project Fund (EDPF). The Fund helps in policy reform, institutional development, and technical and environmental improvements. It sponsors training and studies and provides technical assistance to the host governments and public and private utilities in each of these areas. Some aspects of EPDF's activities facilitate access to finance, but do not provide substantial contributions to the financing of actual projects costs. US AID has some other programs, such as Center for International Power Development, which provides assistance to private power developers in feasibility studies and other preparatory work. The US AID contribution is normally up to 50% of the cost. Another relevant program is the US AID Climate Change Action Plan. Through this program, US AID intends to ensure that at least $1 billion of US development assistance over the next five years is spent on slowing down the growth of greenhouse gas emissions in developing countries. The US AID approach will emphasize the transfer of technologies, policy and regulatory reform, and human and institutional development that will simultaneously promote development and reduce growth in emissions. The plan recognizes explicitly the significance of financial support for the transfer of clean technologies. However, the envisaged support is in the form of assisting countries in implementing reform and in establishing a suitable business environment so that technologies can be transferred through market mechanisms. The need for extending financial support in the form of loans and guarantees is recognized. However, Congress would need to grant US AID the authority to engage in credit programs before the agency can use credit to advance transfer of clean technologies. US AID is not presently active in China.

4. The Trade and Development Agency (TDA) funds technical forums, orientation visits, design engineering, financial packaging, and overall feasibility studies. These activities are normally funded with the hope that when the project reaches implementation stage, it will use US goods and services. Nevertheless, TDA's support in each project is normally limited to $500,000 to $1,000,000.

The activities of the above four agencies cover a rather wide range that could, in theory, be effective for promoting CCTs. However, according to a study by the General Accounting Office, these agencies do not function in a coordinated and consolidated manner and, therefore, their overall impact is not as significant as those of the bilateral agencies of Japan, France, and

Germany. Indeed, the US Congressional response to the DOE's request emphasized, in essence, the need for coordination of existing channels rather than adding a new mechanism for the financial support of CCTs in developing countries.

Japanese Program of Assistance

The 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, the Japanese experience has concentrated more on PFCB rather than IGCC, though the latter has recently become a focus of R&D activities.

The Japanese experience in PFBC is most notable in the Wakamatsu plant on the island of Kyushu. This plant has been in operation since 1996 and has been used to test a variety of imported coals. The operational experience has also helped identify design problems and appropriate remedies. The most recent PFBC application was completed in December 1997 in the Karita plant. This plant, with 360 MW capacity, is the largest PFBC plant in the world and is expected to become a focal point for research on PFBC technology.

Like many other parts of the world, the Japanese have now become convinced that IGCC has significant immediate prospects for large-scale application. Thus, the power industry and the government are now paying more attention to this technology. Indeed, an IGCC experiment was initiated 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 test was conducted from 1984 to 1989. Substantial information about IGCC was compiled. However, numerous operational problems during the test period resulted in a rather 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, flue gas desulfurization 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.

Carbon Abatement-Related Funds

Because of their higher thermal efficiency, CCTs offer a possibility of reducing CO_2 emissions. Since this feature offers a potential global environmental benefit, CCTs may qualify for financial support from carbon reduction funds.

The main principle underlying the carbon reduction funds is that if a country undertakes an investment that is not a least cost option, but results in reduced CO_2 emissions, the country should be compensated for the incremental cost by the world community based on the justification that the more expensive project imparts benefit to the global environment.

The first and presently most important source of support for carbon reduction projects is the Global Environmental Facility (GEF). This facility was formed initially as a pilot program at the World Bank through inter-agency arrangements between the UNDP and UNEP. The participating nations, consisting of 18 OECD and 8 developing countries, contributed about $2 billion to be allocated to projects and activities that aim at protecting the global environment. After its pilot phase, GEF was restructured in 1994 and established as a permanent mechanism with a broader objective of “international cooperation for the purpose of providing new, and additional grant and concessional funding to meet the agreed incremental costs of measures to achieve agreed global environmental benefits in the areas of biological diversity, climate change, international waters, and ozone layer depletion.”

Under the climate change part of its mandate, GEF finances efforts in improving energy efficiency and reducing CO_2 and methane emissions. In doing so, it insists on supporting projects that are:

(a) consistent with national, and where appropriate, regional plans and concerns;
(b) in need of incremental funding to become financially viable, but sustainable after receiving the initial support;

(c) important in reducing uncertainty and risk.

The above preferences fit well with the promotion of CCTs. Presently, adoption of advanced CCTs is not likely to be financially viable unless supported by some promotional initiatives. Implementation of CCT demonstration projects in China will reduce the extent of uncertainty and risk for future plants in China and the rest of the world. Finally, the projected cost patterns indicate that after implementing a few CCT demonstration projects, China is likely to construct CCTs at reduced costs which would make future plants financially viable. It is, of course, noted that not all CCTs qualify for assistance from GEF. Only technologies such as IGCC that result in lower CO_2 emissions due to higher efficiency would be of interest to GEF. Technologies such as FGD, which are beneficial to local and regional environments, are not relevant to GEF support.

GEF has provided substantial support to energy efficiency improvement activities in China. Most of this support has been in conjunction with World Bank projects and programs. However, there has not yet been any direct support for promoting advanced CCTs in China or other countries.

The second potential source of financial support under the category of carbon reduction funds is the so-called Joint Implementation (JI) that originated within the Framework Convention on Climate Change (FCCC), which was adopted at the 1992 Earth Summit in Rio de Janeiro. Numerous follow-up activities between 1992 and 1997 paved the way for the Kyoto Protocol that was adopted in December 1997. The Protocol sets quantified carbon emission limitation and reduction commitments for OECD countries and economies in transition (EITs). These parties agreed that they would reduce their overall emissions of six greenhouse gases by an average 5% below 1990 levels in the commitment period 2008 to 2012. The EU, US and Japan agreed that, for them, such reductions should be targeted at 8, 7, and 6% respectively. As an instrument for achieving these targets, the Protocol allows for JI: OECD countries may finance GHG reductions outside their own borders in order to obtain credit towards their reduction obligations with a view to limit the costs of complying with their commitments. JI can take place between OECD countries and with EITs. JI involving developing countries can only take place under the Clean Development Mechanism and after the year 2000. However, a number of initiatives are already under way to identify suitable projects in developing countries because of the expectation that carbon reduction in these countries can be achieved at lower costs than in the industrial countries.

In order to meet the carbon emission restricted target, each country is expected to choose some way of rationing carbon emissions to the relevant sectors and firms. Two distinct methods are envisaged for this purpose.

(a) *Cap and Trade Regime.* The government allocates for each time period a fixed amount carbon emission permit to each firm. The emission allowance is determined based on historic averages of the firm's production and carbon emissions. The firm can use up the permit, save, or trade part of it. In addition, carbon credits from other countries can be imported to supplement domestic permits. This means the firm can provide funds for carbon reduction investments in another country, take the credit, and import it into its own country.

(b) *Carbon tax.* The government imposes a tax on all carbon emissions. This most probably will translate into a surcharge on the fuel price. Each firm will be allowed to substitute carbon credits for the carbon tax. Thus, as long as the firm can obtain carbon credit at a cost lower than carbon tax, it will continue to do so. One way to obtain carbon credit would be to invest in carbon reduction alternatives inside its own operation or in other operations in the country. Another way to obtain carbon credit would be to import it from other countries.

The concept of carbon credit through joint implementation is theoretically sound. It is a trade process that would result in more effective carbon reduction investments. The basic component of the carbon credit process is that a company, which would ordinarily choose "decision A" because it best fits the interest of the company, would now choose "decision B," which could be of a higher cost but would produce lower carbon emissions. The reduction in carbon would benefit the global environment and the company would receive a credit for the amount of carbon reduction. These credits can be traded among companies or internationally. The credit will have a domestic and international price. If credits are traded freely, the domestic and international prices would converge. Regardless of the international trade aspect, a company would undertake the carbon reduction "decision B" only if the additional cost of investment does not exceed the market price of carbon credit. Thus, at the margin, the cost of carbon reduction would be about the same as the market price of carbon credits, and, therefore, investments in carbon reduction would flow to the most effective applications.

Despite the simplicity of the concept, implementation of a carbon credit system would involve very serious challenges due to numerous problems in practical assessment and use of carbon credits. First, clear rules must be established to show that the claimed reductions are beyond the reductions that would have taken place without forming a joint implementation arrangement. In order to determine the "additionality," there should be clear and internationally recognized procedures for establishing the base line alternative. It is also necessary to have some monitoring mechanism to ensure that after a plant is constructed, it does indeed produce less carbon emission, i.e. to validate the additionality. Second, it is necessary to determine the role of each government in allocation of carbon credits, assessment of additionality, and rules of trading carbon credits. Third, it is essential to have clear rules for international trade and also international recognition of the value of carbon credits.

Implementation of the above requirements will be very complex because carbon credits will exist against a counterfactual and have no intrinsic worth as a consumable good or an input to production. Genuine reductions in emissions may benefit the public, but will have no market value until authorities through a certification process recognize them. Conversely, bogus reductions, if improperly certified, would yield a market value. The exact features of carbon credit are not found in any other market, which implies that one cannot easily derive lessons of relevant experience. However, it has been suggested that carbon emissions may have similarities with the money market; thus governments and the international community should play roles in the carbon credit market that parallel the roles they play in the financial markets. Also, it has been suggested that the US Acid Rain Program may provide some valuable lessons. This program began in 1995 to establish a cap and trade for controlling SO_2 emissions. It aims at ultimately reducing SO_2 emissions by 40% below the 1980 level during 1995-2010. The allowance to trade emission rights received some initial public criticism, but became more acceptable due to the immediate reduction of overall SO_2 emissions after the introduction of the program. The program requires 110 power utilities operating in the eastern and mid-western US states to limit emissions from their coal-fired boilers. In Phase II of the program, which will be implemented in the year 2000, the coverage will extend to 2,050 electric utility boilers in the US. These boilers account for about 99% of SO_2 emissions in the power sector. The program is administrated by the US Environmental Protection Agency and involves 150 full-time staff. The success of the program is indicated by several criteria including a decline in the price of SO_2 emission permits from $150/ton in 1995 to $104/ton in 1997.

While all the relevant experiences are being studied extensively, the international community is working hard to push the joint implementation concept to a practical stage. A pilot program called Activities Implemented Jointly (AIJ) has been initiated to stimulate experience in this area. The term AIJ was deliberately chosen to differentiate a yet-to-be-implemented comprehensive JI program and the pilot program that is primarily a voluntary practice by the involved countries with no internationally certified credit accruing to any party during the pilot phase. A further step towards facilitating JI was taken by the creation of the Carbon Investment Fund (CIF) under the sponsorship of the World Bank. Under CIF, the World Bank will act as a market intermediary (honest broker) between governments and/or private entities. The investors (government or private party) would put their money in the fund. The World Bank would then invest these funds into projects that would result in carbon emission reductions. The investors would receive the rights to resulting credits in return for their investment in the fund. These credits can be used in meeting the carbon emission targets committed under the Kyoto Protocol. Initially, the fund would make marginal investments in planned World Bank projects to reduce greenhouse emissions from these projects. The baseline for establishing the amount of emission reduction would be the technology of similar World Bank projects elsewhere. CIF is expected to pave the way for eventually full-fledged global emission permit trading regimes. Presently CIF has received about $75 million in funding from public and private investors. Its activities at the first stage would be in the EITs. But it is expected that either the CIF or the GEF would be named to operate the Clean Development Mechanism (CDM) that would extend the carbon reduction investments to developing countries. Thus, there is an active effort to establish dialogue with developing countries and to identify projects to be supported by CDM as it becomes effective in 2000.

World Bank and Asian Development Bank

The World Bank Group consists of the International Bank for Reconstruction and Development (IBRD), International Finance Corporation (IFC) and the Multilateral Investment Guarantee Agency (MIGA). The IBRD, also called the World Bank, provides loans to governments or state agencies. IFC lends to and/or invests in private sector projects. MIGA insures private sector projects against political risks. The three agencies have a rather wide range of instruments to address various project needs and concerns. The overarching mandate of the World Bank Group is poverty alleviation and promotion of safe and sound economic growth. This mandate is often translated into certain thematic objectives and orientations. Presently, the World Bank Group heavily emphasizes initiatives that are aimed at preserving environmental safety and at encouraging private sector participation in ownership and management of infrastructure services.

Promotion of CCTs fits in several of the objectives of the World Bank Group, and can be supported by a number of the Group's instruments. First, as a development agency, the World Bank is interested in projects that result in transfer of technology to developing countries. Second, the World Bank is under pressure from the international community to pay more attention to environmental issues and is eager to support projects that deal with local, regional, and global environmental concerns. However, in order to make a project acceptable to the World Bank, project sponsors should demonstrate that the project is economically and financially viable. Advanced CCTs may not pass this test. It would then be necessary to provide other support for the project. The World Bank would also want to see that the project serves as an effective demonstration of the new technology with predictable potential for replication. This requirement should not create any problem in the case of CCTs though project sponsors should explicitly account for it in the project's conceptual design. Finally, if the private sector or a joint venture of public/private entities sponsors the project, then both World Bank and IFC resources could be mobilized. In any case, participation of the World Bank in a project normally facilitates access to other sources of finance and even grant facilities.

The World Bank provides substantial support to the power sector in China. Its strategy in the recent years concentrates on encouraging sector reform, tariff adjustment and energy efficiency improvement. It finances one or two power projects annually and is willing to support environmentally beneficial projects.

The ADB pursues a mandate quite similar to that of the World Bank Group while specializing and concentrating on the developing countries of Asia. Its organizational structure is also similar to the World Bank Group with the difference that it does not have a separate agency for dealing with the private sector. The ADB itself handles both public and private sector loans. This often facilitates support to the power sector particularly in the event that a project is sponsored by a public/private joint venture. The ADB is very active in the power sector of China. It provides support to power plant rehabilitation and efficiency improvement projects. The ADB is a bit ahead of the World Bank Group in terms of its involvement and support of CCTs. In 1988, it financed a 2 X 600 MW supercritical coal-fired power plant in Anhui Fuyang that promises to have higher efficiency than a subcritical conventional plant. It is also financing a feasibility study of an IGCC plant to be located near Beijing.

6

Recommended Financing Schemes for CCTs.

The Structure of the Financing Scheme

In the course of this paper we demonstrated that :

(a) 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.

(b) Cost patterns indicate a rapid decline in the average cost of power generation from CCTs. The cost is expected to decline further for new plants, making CCTs eventually competitive with conventional pulverized coal (PC) steam plants.

(c) Nevertheless the average cost of power generation from CCTs is presently higher than that of PC technology. In the United States, the cost of power generation is ¢5.7/kwh for an IGCC plant compared with ¢4.70/kwh for a PC plant.

(d) While the higher cost of power from CCTs puts these technologies at a disadvantage, a more serious discouragement is the higher risk associated with the adoption of CCTs. The main risk factors include capital cost over-run, construction delay, and shortfalls in plant availability and performance. Our analysis indicates that in the United States the economic risk of building an IGCC plant is 16% higher than a PC plant.

(e) The cost and the risk disadvantages of CCTs are substantially higher when we consider these technologies for China. We estimate that for China the average cost of power generation from an IGCC plant would be 32% higher than power from a PC plant; the overall risk factor would be 23% greater.

(f) While the cost and risk disadvantages present a serious discouragement for utilizing CCTs in China, the potential benefits are also quite high due to China's huge requirements of power generating capacity and its heavy reliance on coal as a source of power electricity production.

Considering the above, the government of China and the international aid community have recognized the need for extending financial support to the CCT projects.

Financial support for transferring CCTs to China would be required for three distinct activities: (a) information dissemination; (b) project preparation; and (c) project implementation. These three phases were recognized to be practically relevant in a survey that the US DOE carried out on the US CCT industry regarding areas in which they needed financial support in order to export these technologies to developing countries [US Department of Energy (1995)].

With regard to the first phase, i.e. information dissemination, serious efforts are ongoing. The primary sources of support are the USDOE and the Japanese NEDO. There could be some synergy between the two efforts and some potential gain between US and Japanese support. However, cooperation does not seem to be critical and may not be practical considering the differences in the styles of the US and Japanese aid agencies.

The second phase, i.e. project preparation, includes design and engineering studies that would establish the technical parameters of the project, and its economic and financial viability. This phase is not receiving sufficient support. The USDOE has had difficulty in providing support, which was envisaged at an earlier stage. However, the most appropriate sources of support are the ADB and the World Bank. These agencies can justifiably finance project preparation activities under their existing operations. Indeed, the ADB is already financing a feasibility study of an IGCC plant under a grant facility. In addition, NEDO is in a position to provide technical and financial assistance in feasibility studies of advanced CCTs.

The third phase, i.e. project implementation, would include the cost of equipment and construction. There is no significant financial support for this phase of the project. The problem arises because the size of the required support is very large and financiers would actually want to avoid, rather than support, such projects. Even ADB and the World Bank, which often provide comfort against political risk, are not willing to provide protection against commercial risks. Their view is that project sponsors should manage commercial risks.

In order to design a financing scheme for IGCC projects we need to take account of the perspectives of the project sponsors, financiers, the government and the donors' community.

Project sponsors need to be convinced that the risk-reward profile of the project justifies investing their own money in the form of project equity, and borrowing from others in the form of debt financing. Project sponsors would be concerned about commercial risks as well as political risks. Political risks can be handled by some bilateral and multilateral agencies. Commercial risks of a conventional project can be largely managed through contractual arrangements. However, commercial risks of a new technology such as IGCC can not be managed through the available facilities; project sponsors will be bearing the risks.

Financiers provide loans at certain interest rates. They will not receive additional rewards if the project does better than expected. They do not want to get any lower return if the project fails. Thus, they do not want to be exposed to project risks. They normally avoid financing projects that are based on unproven technology.[1]

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[1] One could theoretically envisage devising a commercial financing instrument, e.g. a junk bond, which would provide finance at higher interest rates to take account of the higher commercial risks of an IGCC plant. In practice, however, this is not likely to materialize because the higher financing cost would put the project at a further disadvantage compared with the PC alternative. The demonstration plant does not represent a commercially viable project. The justification for government and international support for the demonstration project is its external benefits of providing comfort for implementation of repeating projects, and also environmental benefits that are not directly captured by project sponsors.

The government of China is extremely supportive of any project that brings in new technologies. Nevertheless, the present fiscal constraints force the government to limit its financial contribution to such projects.

The donors' community is generally concerned about the environmental aspects of coal use in China and supports the idea of utilizing IGCC technology. However, each entity has its own mandate and thereby constraints in providing financial support.

As mentioned earlier, an IGCC project in China would generate power at a cost that is 32% higher than a conventional plant. In addition an IGCC plant would be exposed to a commercial risk which is 23% higher than that of a conventional plant.

In order to provide incentives for the implementation of an IGCC plant, the additional cost of power generation should be compensated by a direct financial grant. However, the appropriate mechanism for dealing with the additional risks would be a well-designed guarantee facility. Thus, we need to incorporate into our financing scheme a direct financial support and a guarantee facility.

The first IGCC demonstration project in China would be of 300-400 MW size and would cost about $450 to $600 million. The direct financial contribution to compensate for the additional cost of power generation would be about $75 million. The financial contribution can be either in the form of a grant or a larger concessionary loan. For example, a $200 million loan from the ADB or the World Bank would provide the $75 million financial contribution based on the difference in the interest payment and maturity period of such a loan and a commercial loan. It should be noted that loans from the ADB and World Bank are not subsidized. These institutions borrow money on the capital markets and lend the money at their borrowing costs. However, since they are highly creditworthy, they borrow funds at good rates, and since they are non-profit, their added margin is small. More importantly, their loans to China have a maturity period of 20 years compared with the maturity periods of 5 to 10 years of commercial loans. Overall, the loans from ADB and the World Bank to China would have an effective discounted cost, which is about 35% less than the average alternatives on the international commercial markets.

Table 6: Present and Potential Sources of Support for IGCC in China

Project Stage	*Sources of Support*
Stage 1: Information Dissemination	Government of China
Technical discussion meetings	US DOE
Training and capacity building	NEDO
Establishing viability of technology	
Stage 2: Project Preparation	Government of China
Feasibility study	World Bank
Engineering design	ADB
Determining the ownership and financial structures	NEDO
Stage 3: Project Implementation	Government of China
Equipment supply	GEF
Plant construction	World Bank
Plant operation	ADB
	US Eximbank
	Japan Eximbank
	IFC
	Commercial Banks

The additional risk of the IGCC plant would require a guarantee facility of about $30-50 million. This facility would remain as a contingent fund and would not be disbursed if the construction and operation proceed according to the plan. The transaction arrangements of the guarantee facility should be designed considering the requirement of the project sponsors and financiers.

In order to identify the potential agencies for direct financial support and the guarantee facilities, we would need to start with the design of the project ownership structure. Project ownership can be wholly public or private, and in the latter case can be wholly domestic or foreign. Each type of ownership brings in certain advantages. Complete public ownership is viewed not desirable because of potential inefficiencies and the burden on government budget. However, a certain degree of public participation may facilitate access to bilateral and multilateral support. In contrast a complete private ownership ensures efficient construction and operation of the plant but would limit the project's access to government support and, thereby, the assistance from official aid agencies. Thus, a joint venture between public and private sector represents the most suitable ownership structure.

The private sector partner may be domestic or foreign. Again, the experience in China indicates that consortiums comprised of both foreign and domestic private companies provide the highest potentials for success.

Project sponsors should be able to fund about 30%, or about $150 million, of the project cost from their own resources. The remaining 70%, or some $300-400 million, should be borrowed from financiers. With some degree of government support, the project debt can be financed by the ADB, the World Bank, US Exim bank and the Japanese Exim bank. Between the World Bank and the ADB, at least one should be in the project in order to encourage the Exim banks to participate. Between the two Exim banks normally only one would participate. The Japan Exim bank is perhaps more advantageous because it can provide tied and/or untied loans. The tied loan would finance the cost of purchasing Japanese equipment and services. The untied loan would finance the lowest bid equipment purchase regardless of the nationality origin of the supplying company.

Should a financial gap remain, project sponsors would approach commercial financiers for further borrowing. In the event that the project has already been accepted by the World Bank, ADB and one of the Eximbanks, private lenders feel more comfortable to participate. However, they normally insist that project risks are fully covered through some insurance or guarantee schemes.

The most appropriate source for funding the guarantee facility is the GEF. As explained in the last chapter, GEF's mandate enables it to take certain commercial risks particularly those related to technology transfer and demonstration plants. The suitability of the project for the GEF mandate is best described in the following quote from the World Bank's Energy and Environment Strategy:

> "GEF resources have enabled the Bank to support technologies and techniques that, at their present costs of production or deployment, would not otherwise meet present Bank economic investment criteria. The GEF has also enabled the Bank to overcome real or perceived risks, both internal and existing in client countries, that have limited the willingness to engage in new forms of energy lending. Finally, and perhaps as important as its dollar resources, the presence of GEF has provided a rationale for doing things that would otherwise not find support in a relatively conservative banking environment."

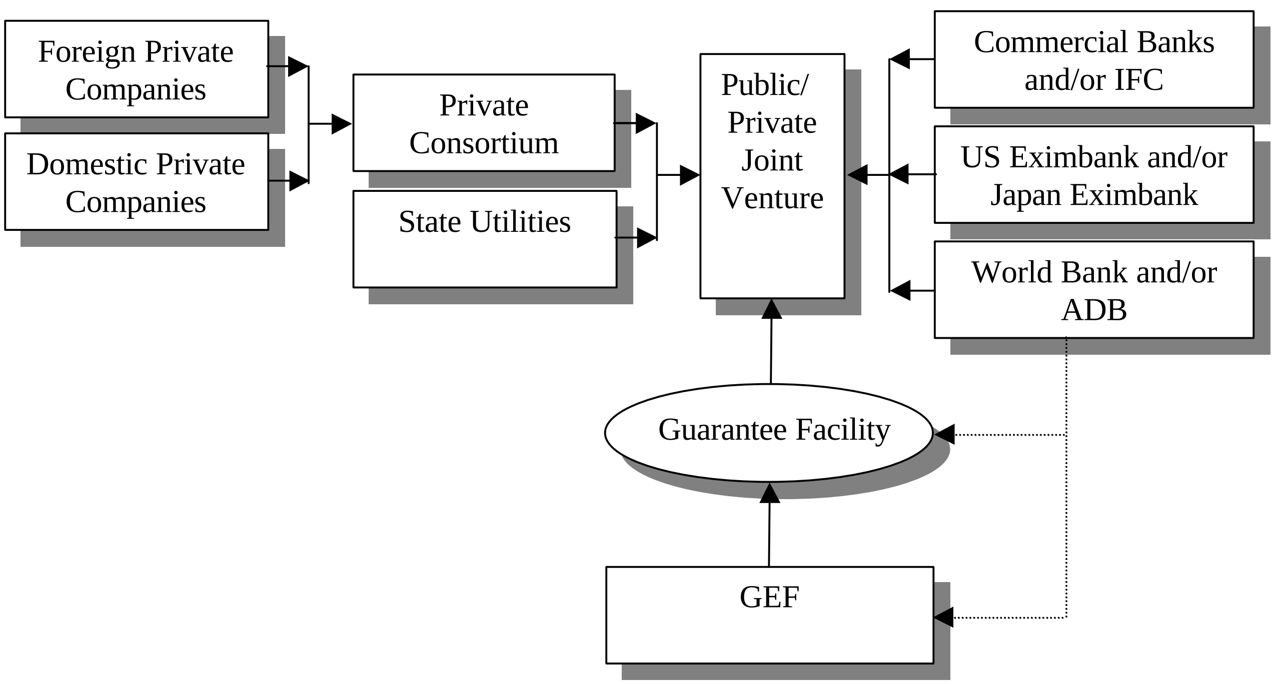
GEF support is provided under four distinct programs: (i) energy efficiency promotion; (ii) renewable energy development; (iii) technology promotion; and (iv) short-term response projects. In the first three categories, the objective is to reduce the cost and increase the market share of energy supplies that have global environmental benefits. Thus, the GEF support is viewed in a long-term framework, considering the fact that the main benefit would be coming in the form of future repeating projects. In the fourth category, however, the objective is to achieve carbon reduction through a specific project. In this category, the GEF support is provided to projects that can achieve carbon emission reduction at the cost of $10/tonne or less.

Although GEF has not previously provided support to CCTs, the promotion of IGCC falls into category (iii) of GEF-supported activities. In this category, GEF does not impose a carbon reduction cost cut-off because it considers the main benefit in repeating future projects. However, just to have a feel of direct carbon reduction benefit, we have assessed the carbon savings over the life of the plant at 4.2 million tons. The unit cost of carbon reduction for a $30 million GEF facility would be $7.1/tonne. Even in a discounted form, the unit cost remains attractive at $17/tonne.

Clearly, in this case the GEF achievement is more important in two other areas than direct savings of carbon emissions. First, the likelihood that implementation of the demonstration plant would lead to the construction of repeating IGCC plants is high. Second, the idea of using the GEF funding in a guarantee facility has the additional advantage that the money may not be disbursed; it would be then returned to the GEF or used in other demonstration projects. There is actually a precedent for using the GEF resources in a guarantee facility. In 1997, the GEF provided $5 million to an energy efficiency program in Hungary. The money was used to provide partial credit guarantees to support energy efficiency transactions by other financial intermediaries. The guarantee facility is, in this case, managed by the IFC. When a guarantee is made, the program money will be reserved dollar-for-dollar to cover the guarantee liabilities. At the end of the program's life, remaining funds will be returned by IFC to the GEF unless another approach is warranted and approved by the GEF Secretariat.

Finally, it is worth nothing that GEF does not have explicit ceilings for its support to various countries. Its support is considered in regard to the size of the country, the country's need for assistance, and the significance of the country in the context of global environmental concerns. All these considerations put China in a favorable position for receiving GEF support.

Figure 13: Recommended Financing Scheme for the First IGCC Plant in China



Implications Regarding Institutional Arrangements

Over the past 20 years, China has developed an environmental protection system employing a broad set of control instruments administered through environmental protection bureaus at all levels of government. A national environmental action plan has been developed to coordinate environmental improvement efforts. However, despite this proactive approach, China has had mixed success in limiting environmental pollution. In particular SO_2 emissions have not been effectively constrained. An important factor responsible for this mixed success is the weakness of institutional structure and regulation governing the environmental matters.

In the present institutional set-up the regulation of point source pollution lies with the National Environmental Protection Agency (NEPA), which is the secretariat of the State Council Environmental Protection Committee. NEPA drafts national regulation and other aspects of environmental policy for consideration by the State Council and National People's Congress. However, NEPA lacks implementation authority, a power left to the local environmental protection bureaus that work at provincial and municipal levels. Provincial governments are authorized to set local environmental standards in the absence of pre-emptive national standards or impose more stringent standards than those required by the national government. The provincial governments are also authorized to determine a pollution levy fee chargeable against pollutants that exceed the permitted standards. In many cases, the penalty fees are too low and utilities choose to pay the fee rather than invest in cleaner generation technologies. The present institutional set-up is also considered deficient because many utilities are partly or fully owned by local governments and therefore the enforcement of environmental standards by the local bureaus, which are also budgeted by the local governments, are not sufficiently strict. NEPA has recognized these problems and is trying to remedy them through preparation of clear regulations, standards and enforcement procedures. These institutional improvements are expected to have a positive impact on CCT prospects in the country.

The second aspect of the institutional arrangement that is relevant to CCTs is the organizational changes of the power sector. Reform in China's power sector during the last 10 years has resulted in a sector structure that is largely unrecognizable from that in the early 1980s. In 1980, the power sector was fully controlled, managed and funded by central government departments. Today the sector is largely decentralized, less vertically integrated and open to a wide range of investors. The initial reforms were aimed at mobilizing additional investment capital to finance the rapid growth in power supply capacity. Later stages of the reform pursued a wide range of activities to increase the efficiency of investments and operations. An important accomplishment has been to increase tariffs to levels that enable the utilities to achieve acceptable self-financing targets for their future investments. Accordingly, contribution from the central governments to power sector investments has declined from 91% in 1980 to abut 30% in 1996; provincial and local governments and private investors have taken a major role in funding power sector investments.

Corresponding with the reform agenda, the organization of the power sector has changed significantly. In the period 1988-92, the Ministry of Energy maintained primary responsibility within the central government for policy, planning and regulation of the power sector. In 1993, the Ministry of Energy was dissolved and a new Ministry of Electric Power was established. It was abolished in 1997 in favor of creating the National Power Company (NPC). In the new organization, the regulatory and oversight functions have been assigned to the State Development and Planning Commission (SDPC), State Economic and Trade Commission, and the China Electricity Council. Thus, SP's **[??]** role has become limited to ownership and operation of state power facilities. These facilities include the national transmission grid and other specific assets.

However, provincial power companies have become the relevant utilities in charge of management and operations of the bulk of the country's power system.

Attention to advanced CCTs was initiated in 1994 when the Chinese government formed an IGCC leading group consisting of six government agencies—State Science and Technology Commission, State Planning Commission, State Economic and Trade Commission, the Ministry of Electric Power, the Ministry of Machinery Industry, and the Ministry of Coal Industry. The group established a relationship with the US DOE to start a cooperative effort that was initially at a political level. The cooperation was successfully extended to technical aspects when the Chinese Academy of Science and Tulane University proposed an evaluation of the technology by a joint group of Chinese and American technical experts. The joint technical group completed its evaluation of the IGCC application at end 1996. The evaluation resulted in a very positive prospect for the application of IGCC in China and cooperation between the US and Chinese parties. The Chinese side also took the prospects sufficiently seriously by including in the development plan of the Ministry of Power, a demonstration IGCC plant of 200-400 MW for commissioning between 2000 and 2005.

Although the Chinese were initially counting only on the US DOE for assistance in implementing an IGCC demonstration project, they have now opened discussion with others—notably the ADB and the Japanese NEDO regarding support for the IGCC technology. In both cases the Ministry of Power, and now the SP, is the direct counterpart while SDPC is also heavily involved.

Preparation of an IGCC demonstration project should start with a policy dialogue between the SPC and NPC. While NPC could actually become a project participant, provincial utilities should also be considered as potential partners. The ownership structure of the project should be designed to utilize the potential synergy among project participants. A critical aspect of the institutional arrangement would relate to the functioning of the guarantee facility. In the event that the new technology did not work as anticipated, this facility, if designed properly, would provide for a contingent source of relief. This comfort is important for project sponsors and more particularly for the financiers who wish to avoid project risks. It would facilitate participation by even the World Bank and ADB, who would be interested in supporting CCT projects but are not supposed to take commercial risks.

A general concern with regard to the guarantee instrument is that it may be abused. That is, project participants may revert to the guarantee facility too easily to bail themselves out of normal financial challenges. Thus, the institutional arrangement needs to be designed so that the guarantee facility remains as the source of last resort and that project participants revert to the facility only if there is a clear failure with the new technology. The legal structure of the facility should spell out the conditions under which a contingency can be declared and resources withdrawn. It is also important to have the World Bank or the ADB play a central role in managing the guarantee facility. Such an arrangement would provide comfort for project participants, and also for the GEF to provide the financial resources for the guarantee facility.

Annex 1-Calculation of Levelized Cost for PC in the US (The Base Case Scenario)

Year	*Capital Cost ($ Million)*	*Fuel Cost ($ Million)*	*O&M Cost ($ Million)*	*Total Cost ($ million)*	*Gross Power Generation (Gwh)*	*Net Power Generation (Gwh)*
0	57.5	0.0	0.0	57.5	0	0
1	143.75	0.0	0.0	143.8	0	0
2	143.75	0.0	0.0	143.8	0	0
3	143.75	0.0	0.0	143.8	0	0
4	86.25	27.3	8.2	121.8	1643	1536
5	0	43.7	13.1	56.9	2628	2457
6	0	54.7	16.4	71.1	3285	3071
7	0	54.7	16.4	71.1	3285	3071
8	0	54.7	16.4	71.1	3285	3071
9	0	54.7	16.4	71.1	3285	3071
10	0	54.7	16.4	71.1	3285	3071
11	0	54.7	16.4	71.1	3285	3071
12	0	54.7	16.4	71.1	3285	3071
13	0	54.7	16.4	71.1	3285	3071
14	0	54.7	16.4	71.1	3285	3071
15	0	54.7	16.4	71.1	3285	3071
16	0	54.7	16.4	71.1	3285	3071
17	0	54.7	16.4	71.1	3285	3071
18	0	54.7	16.4	71.1	3285	3071
19	0	54.7	16.4	71.1	3285	3071
20	0	54.7	16.4	71.1	3285	3071
21	0	54.7	16.4	71.1	3285	3071
22	0	54.7	16.4	71.1	3285	3071
23	0	54.7	16.4	71.1	3285	3071
24	0	54.7	16.4	71.1	3285	3071
25	0	54.7	16.4	71.1	3285	3071
26	0	54.7	16.4	71.1	3285	3071
27	0	54.7	16.4	71.1	3285	3071
28	0	54.7	16.4	71.1	3285	3071
29	0	54.7	16.4	71.1	3285	3071
30	0	54.7	16.4	71.1	3285	3071
NPV	431	322	97	849	19335	18078
Levelized cost (US$/kWh)	0.024	0.018	0.005	0.047		

Assumptions

Capital Cost ($/kW)	1150	
Construction Time (years)	5	(w/ production starting at 50% and 80% on year 4 and 5 before full capacity on year 6)
Thermal Efficiency (%)	35	
Plant Availability (%)	75	
Discount rate (%)	10	

Annex 2 – Calculation of Levelized Cost for PC in China (The Base Case Scenario)

Year	*Capital Cost ($ Million)*	*Fuel Cost ($ Million)*	*O&M Cost ($ Million)*	*Total Cost ($ million)*	*Gross Power Generation (Gwh)*	*Net Power Generation (Gwh)*
0	44	0	0.00	44	0	0
1	110	0	0.00	110.00	0	0
2	110	0	0.00	110.00	0	0
3	110	0	0.00	110.00	0	0
4	66	27.9	6.13	100.04	1533	1418
5	0	44.7	9.81	54.47	2453	2269
6	0	55.8	12.26	68.08	3066	2836
7	0	55.8	12.26	68.08	3066	2836
8	0	55.8	12.26	68.08	3066	2836
9	0	55.8	12.26	68.08	3066	2836
10	0	55.8	12.26	68.08	3066	2836
11	0	55.8	12.26	68.08	3066	2836
12	0	55.8	12.26	68.08	3066	2836
13	0	55.8	12.26	68.08	3066	2836
14	0	55.8	12.26	68.08	3066	2836
15	0	55.8	12.26	68.08	3066	2836
16	0	55.8	12.26	68.08	3066	2836
17	0	55.8	12.26	68.08	3066	2836
18	0	55.8	12.26	68.08	3066	2836
19	0	55.8	12.26	68.08	3066	2836
20	0	55.8	12.26	68.08	3066	2836
21	0	55.8	12.26	68.08	3066	2836
22	0	55.8	12.26	68.08	3066	2836
23	0	55.8	12.26	68.08	3066	2836
24	0	55.8	12.26	68.08	3066	2836
25	0	55.8	12.26	68.08	3066	2836
26	0	55.8	12.26	68.08	3066	2836
27	0	55.8	12.26	68.08	3066	2836
28	0	55.8	12.26	68.08	3066	2836
29	0	55.8	12.26	68.08	3066	2836
30	0	55.8	12.26	68.08	3066	2836
NPV	$329.7	$328.5	$72.2	$730.4	18046	16692
Levelized cost (U$/kWh)	0.020	0.020	0.004	0.044		

Assumptions

Capital Cost ($/kW)	880	
Construction Time (years)	5	(with production starting at 25% and 70% on 3rd and 4th year before full capacity on 5th year)
Thermal Efficiency (%)	32	
Plant Availability (%)	70	
Discount rate (%)	10	

Annex 3 – Calculation of Levelized Cost for IGCC in the US
(The Base Case Scenario)

Year	*Capital Cost ($ Million)*	*Fuel Cost ($ Million)*	*O&M Cost ($ Million)*	*Total Cost ($ million)*	*Gross Power Generation (Gwh)*	*Net Power Generation (Gwh)*
0	72.5	0	0.00	72.5	0	0
1	181.25	0	0.00	181.25	0	0
2	181.25	0	0.00	181.25	0	0
3	181.25	0	0.00	181.25	0	0
4	108.75	20	7.67	136.71	1533	1311
5	0	32	12.26	44.74	2453	2097
6	0	41	15.33	55.93	3066	2621
7	0	41	15.33	55.93	3066	2621
8	0	41	15.33	55.93	3066	2621
9	0	41	15.33	55.93	3066	2621
10	0	41	15.33	55.93	3066	2621
11	0	41	15.33	55.93	3066	2621
12	0	41	15.33	55.93	3066	2621
13	0	41	15.33	55.93	3066	2621
14	0	41	15.33	55.93	3066	2621
15	0	41	15.33	55.93	3066	2621
16	0	41	15.33	55.93	3066	2621
17	0	41	15.33	55.93	3066	2621
18	0	41	15.33	55.93	3066	2621
19	0	41	15.33	55.93	3066	2621
20	0	41	15.33	55.93	3066	2621
21	0	41	15.33	55.93	3066	2621
22	0	41	15.33	55.93	3066	2621
23	0	41	15.33	55.93	3066	2621
24	0	41	15.33	55.93	3066	2621
25	0	41	15.33	55.93	3066	2621
26	0	41	15.33	55.93	3066	2621
27	0	41	15.33	55.93	3066	2621
28	0	41	15.33	55.93	3066	2621
29	0	41	15.33	55.93	3066	2621
30	0	41	15.33	55.93	3066	2621
NPV	$543.2	$238.9	$90.2	$872.4	18046	15429
Levelized cost (US$/kWh)	0.035	0.015	0.006	0.057		

Assumptions

Capital Cost ($/kW)	1450	
Construction Time (years)	5	(with production starting at 50% and 80% on 4th and 5th year before full capacity on 6th year)
Thermal Efficiency (%)	44	
Plant Availability (%)	70	
Discount rate (%)	10	

Annex 4 – Calculation of Levelized Cost for IGCC in China

Year	Capital Cost ($ Million)	Fuel Cost ($ Million)	O&M Cost ($ Million)	Total Cost ($ million)	Gross Power Generation (Gwh)	Net Power Generation (Gwh)
0	75	0	0.00	75	0	0
1	187.5	0	0.00	187.50	0	0
2	187.5	0	0.00	187.50	0	0
3	187.5	0	0.00	187.50	0	0
4	112.5	22	6.13	140.41	1533	1295
5	0	35	9.81	44.66	2453	2073
6	0	44	12.26	55.83	3066	2591
7	0	44	12.26	55.83	3066	2591
8	0	44	12.26	55.83	3066	2591
9	0	44	12.26	55.83	3066	2591
10	0	44	12.26	55.83	3066	2591
11	0	44	12.26	55.83	3066	2591
12	0	44	12.26	55.83	3066	2591
13	0	44	12.26	55.83	3066	2591
14	0	44	12.26	55.83	3066	2591
15	0	44	12.26	55.83	3066	2591
16	0	44	12.26	55.83	3066	2591
17	0	44	12.26	55.83	3066	2591
18	0	44	12.26	55.83	3066	2591
19	0	44	12.26	55.83	3066	2591
20	0	44	12.26	55.83	3066	2591
21	0	44	12.26	55.83	3066	2591
22	0	44	12.26	55.83	3066	2591
23	0	44	12.26	55.83	3066	2591
24	0	44	12.26	55.83	3066	2591
25	0	44	12.26	55.83	3066	2591
26	0	44	12.26	55.83	3066	2591
27	0	44	12.26	55.83	3066	2591
28	0	44	12.26	55.83	3066	2591
29	0	44	12.26	55.83	3066	2591
30	0	44	12.26	55.83	3066	2591
NPV	$561.9	$256.4	$72.2	$890.5	18046	15249
Levelized cost (US$/kWh)	0.037	0.017	0.005	0.058		

Assumptions

Capital Cost ($/kW)	1500	
Construction Time (years)	5	(with production starting at 50% and 80% on 4th and 5th year before full capacity on 6th year)
Thermal Efficiency (%)	41	
Plant Availability (%)	70	
Discount rate (%)	10	

(The Base Case Scenario)

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