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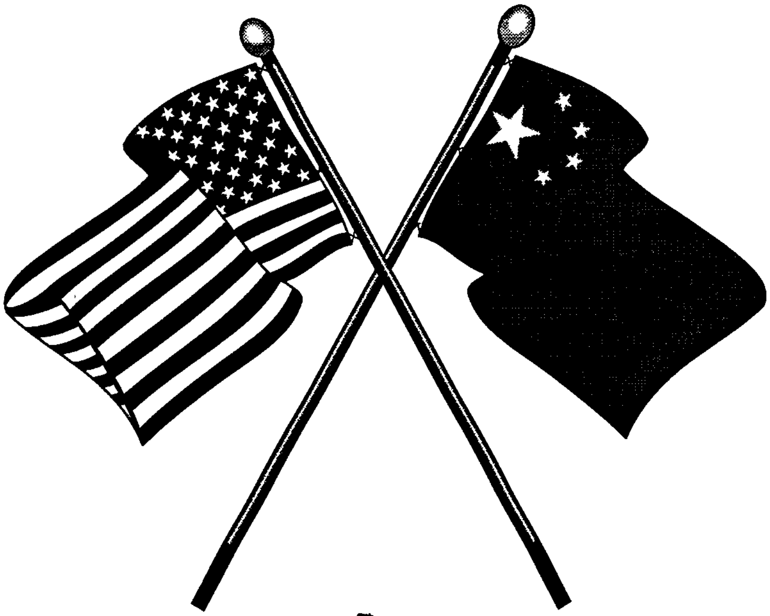
Annual Report

Joint United States and People's Republic of China Clean Coal Activities

April 1994 - December 1995



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Jointly prepared by:
Assistant Secretary of Fossil Energy
Office of Clean Coal Technology
U.S. Department of Energy
and
Department of Industrial Technology
State Sciences and Technology Commission
People's Republic of China

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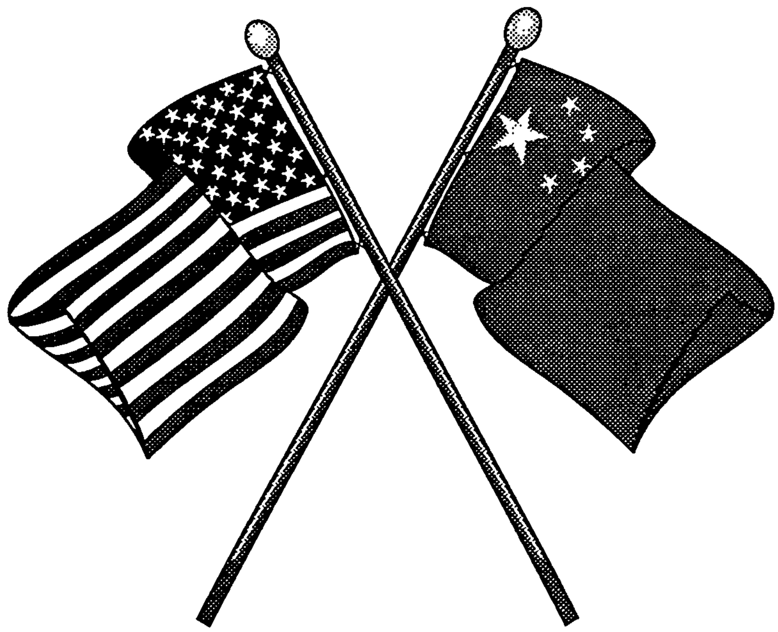

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June 1996

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I. INTRODUCTION

The United States Department of Energy (U.S. DOE) and the Ministry of Coal Industry of the People's Republic of China (China) signed a protocol in the field of fossil energy research and development in April 1985. An annex to this agreement, Annex IX, was signed in April 1994 for cooperation between the U.S. DOE and China's State Science and Technology Commission (SSTC) in the area of clean coal utilization.

Article III of Annex IX requires the United States and China jointly to prepare an annual report describing the work performed and results achieved. This report, in compliance with Article III, is a description of the activities conducted under Annex IX during the period from April 1994 through December 1995. The report also contains the plans for future activities for the next 12 months, or through December 1996.

The United States and China signed Annex IX to address the common problems of power plant and other emissions resulting from the use of coal and the need to provide for a cleaner future environment. Both nations will derive benefits from cooperating to resolve these problems. As China seeks to commercialize clean coal technology, the United States can assist China by providing experience gained through the U.S. DOE Clean Coal Technology Program.

The Clean Coal Technology Program is a U.S. government and industry collaborative technology development effort to demonstrate a new generation of innovative coal utilization processes in a series of large-scale "showcase" facilities built across the country. The program takes the most promising advanced coal-based technologies and moves them into the commercial marketplace through demonstration. These demonstrations are on a scale large enough to generate all the data, from design, construction, and operation, that are necessary for the private sector to judge commercial potential and make informed, confident decisions on commercial readiness. The projects in the program demonstrate technologies to be applied to the U.S. coal resource base and encompass advanced electric power generation systems, high-performance environmental control devices, coal processing for clean fuels, and industrial applications.

The innovative clean coal technologies demonstrated offer tremendous potential as part of the solution to many complex problems that face the United States -- and the world -- in a rapidly changing arena dominated by energy, economic, and environmental issues. These issues include air quality, acid rain, global climate change, power production, energy security, technology awareness, and international competitiveness.

Research, development, and demonstration (RD&D) activities being conducted in China are similar to many RD&D activities pursued by the United States for the reduction of pollutants and efficient use of coal. China is conducting feasibility studies for determining the application of some of these technologies to its energy-related problems.

Coal is currently the primary fuel in China and will remain so well into the next century. China is projected to have the largest growth rate for electric power generating capacity in the world, and the country faces increasing problems of polluting emissions from power plants. Low power plant efficiency and poor availability present an excellent opportunity for the development and application of clean coal technologies. China's energy sector growth strategy is based on coal as the dominant fuel for the 21st century, as well as the development of future coal-based facilities that operate more efficiently and produce less pollution than conventional coal technologies. Much of the technology being developed under the U.S. Clean Coal Technology Program will be important to successful implementation of a clean coal strategy for China.

The need to utilize resources more efficiently and cleanly has created a market for clean coal technologies (CCT) that will continue to grow in proportion to China's population and economic growth in the future. The technologies of interest in the near-term (prior to 2000) will include new approaches to coal cleaning and more efficient conventional power generating systems with low-cost SO_2 and NO_x emission reduction systems. These technologies include supercritical boilers, large (greater than 150 megawatts, or MWe) circulating fluid-bed boilers, low-NO_x burners, dry sorbent injection, and advanced coal-cleaning systems requiring low water use. New technologies, with utilization planned for after the year 2000, are high-efficiency integrated gasification combined-cycle (IGCC) power plants and pressurized fluid-bed combustion (PFBC) power systems.

Economic policies are being developed in China to encourage reforms that support sustained growth through more attractive conditions to invest capital. It is projected that the planned growth in power generation capacity of 12-15 gigawatts (GWe) per year will require capital to be supplied from foreign sources.

II. WHY CHINA IS INTERESTED IN CLEAN COAL TECHNOLOGY

China fully recognizes the need for sustainable energy development and is investigating the use of clean coal technologies for the control and reduction of air and water pollution, reduction and conversion of solid waste, and efficient use of resources. China's plan for sustainable development, Agenda 21, seeks to promote research, development, and diffusion of technologies, such as clean coal technologies that offer higher efficiency in the production of clean power from coal.[1] However, the ability to import clean coal technologies is currently constrained by the restrictions on foreign exchange, energy pricing policies, and lack of experience with environmental management.

The most populated country in the world, with a population of more than 1.2 billion, China is experiencing a short-fall in electricity supply and difficulties in meeting the total energy requirements of its growing population and economy. China's projected electric power needs will require the continuous addition of approximately 1,000 MWe per month of new power generating capacity to meet the predicted economic and population growth for the next 20 years. This overwhelming need for new power generating capacity precipitates a need for additional fuel supply and transportation and expansion of the electric transmission and distribution infrastructure.

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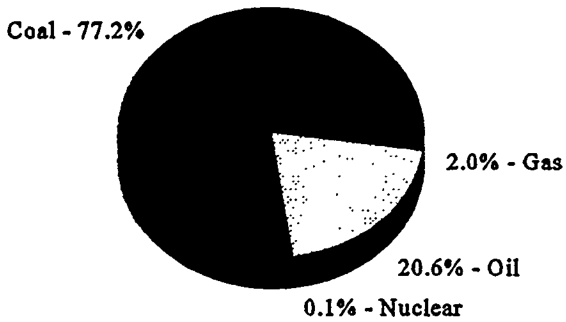
1 *China's Agenda 21 -- White Paper on China's Population, Environment, and Development in the 21st Century* (China Environmental Science Press: Beijing). Agenda 21 was adopted at the 16th executive meeting of the State Council of the People's Republic of China on March 25, 1994.

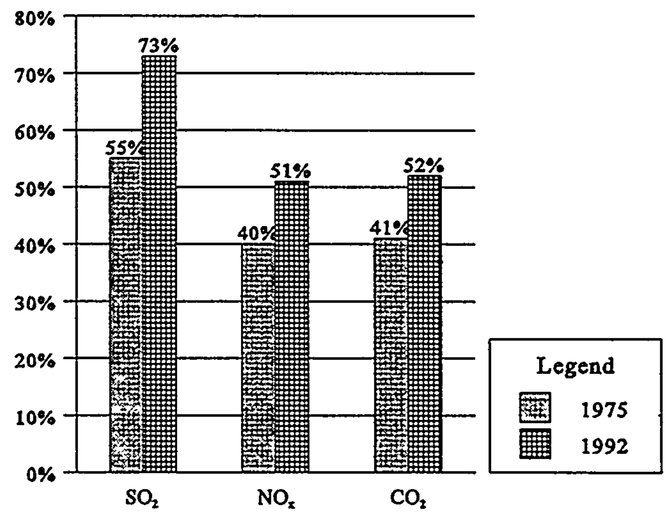
Figure 1. China's Energy Consumption, 1994 (Total Consumption = 31.2 x 10^{15} kilojoules)



Because coal is the most abundant natural resource available for energy supply in China, it is the source for over three-quarters of China's energy consumption (Figure 1), and China's coal consumption accounts for approximately one-fourth of the coal consumed in the world. China produced 1.2 billion tons of coal in 1994 and by 2000 China plans to produce 1.4 billion tons.[2] However, even with conservative projections, coal demand in China is likely to exceed 1.5 billion tons by 2000. The 100-million-ton disparity between projected coal production and coal demand will require a major effort by China to accelerate domestic energy development. Whether or not China can close the gap between coal supply and demand through increases in domestic production will depend upon the country's future development policies in energy and transportation sectors.

About 90 percent of China's coal reserves are in the midwestern and northern part of the country; however, the majority of the energy is consumed by the economically advanced southeastern coastal provinces. In 1993, coal was consumed primarily by industrial boilers (42 percent) and electric utility power plants (29 percent), with the remaining coal use (29 percent) in residential and commercial sector applications. China is the largest producer of chemicals from coal in the world.

Figure 2. China Share of Coal-Related Emissions in Asia



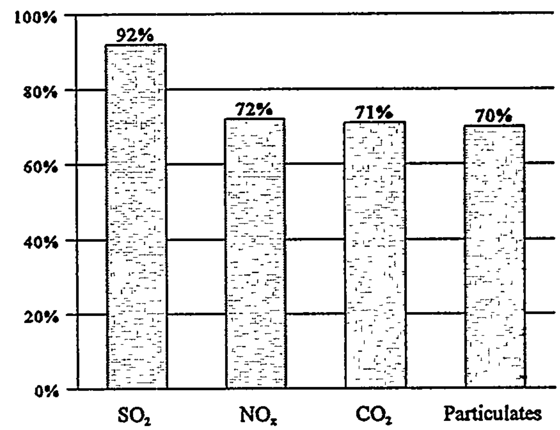
During the period between 1975 and 1992, the share of emissions in Asia that were contributed by China increased from 55 percent to 73 percent for SO_2, from 40 percent to 51 percent for NO_x, and from 41 percent to 52 percent for CO_2 (Figure 2). These trends are of increasing concern and are one of the reasons China developed Agenda 21, which includes plans to direct efforts towards reducing the problems of greenhouse gas and acid rain. Currently total SO_2 emissions in China are

[2] Tons referred to in this report are metric tons, with 1 metric ton equal to 1,000 kilograms.

exceeding 16 million tons per year. China has set a goal that, by the year 2000, emissions are not to exceed 1994 levels.

Only a small portion of coal mined in China is cleaned or upgraded, resulting in large quantities of emissions leading to serious atmospheric and water pollution. Coal consumption contributes 92 percent of SO_2 emissions, 72 percent of the NO_x emissions, 71 percent of the CO_2 emissions, and 70 percent of the particulate emissions in China (Figure 3).

Figure 3. Coal-Related Emissions in China



China is a large developing country of massive energy production and consumption (coal mainly). In 1992, coal consumption was 815.7 million tons (standard coal, with a calorific value of 29,307.6 kilojoules per kilogram) and accounted for 74.9 percent of the total primary energy consumption. Fossil fuels dominate China's electric power industry. In 1993, fossil-fuel-based power generation constituted 75.6 percent of the total installed capacity and 82 percent of electricity generation. The majority of China's fossil-fuel power plants are coal-fired and 255 million tons of standard coal were used in 1993 to produce power; power generation represented approximately 30 percent of China's total coal consumption. Total installed electric generating capacity by the end of 1995 was approximately 200 GWe. The structure of energy resources, in which coal has the major role for power production, is not expected to change significantly in the next 30-50 years. According to projections of electric industry development, the total installed capacities of power generating units will reach 300 GWe in 2000, 540 GWe in 2010, and 800 GWe in 2020, and coal-fired power plants will constitute 77.8 percent, 75.3 percent, and 70.6 percent of total capacity in the respective years. Coal-fired power will remain dominant in the first half of the next century and possibly even longer.

At present, coal-fired power generation technology in China is relatively backward, and in 1993 the nationwide average efficiency (based on power supplied) of coal-fired power plants was only 29.5 percent. The total emissions from coal-fired power plants having a capacity of more than 6 MWe accounted for one-third of China's total SO_2 emissions and over half of China's total NO_x and dust emissions. Projections for the 21st century show that China's electric power industry has an unprecedented opportunity for further development and also faces a great challenge as environmental impacts become a key factor restricting the development of the electric industry. Therefore, developing and promoting clean coal technology having higher efficiency and lower emissions are essential for the coordinated and sustained development of population, economy, society, resources, and environment. Clean coal technology represents the future direction of China's energy industry.

IGCC, a new coal-based power generation technology for improving efficiency and reducing emissions, is approaching maturity. IGCC is in the transitional stage from industrial demonstration to full-scale commercialization in Europe and the United States. Presently available IGCC technology has already achieved 40-43 percent efficiency (based on power supplied), and IGCC efficiency is expected to reach more than 50 percent in the next century through further improvement of coal gasification, hot gas cleanup, and high-temperature gas turbines. Excellent IGCC performance in reducing environmental impacts from power production was verified by several demonstration plants in the United States and Europe; thus, IGCC is a very promising clean coal technology for power generation.

To develop higher efficiency and clean coal-based power generation technology for the 21st century, the Ministry of Electric Power has included IGCC in its mid- and long-term plan and strives to build a large-scale (200-400 MWe) advanced IGCC demonstration power plant (with efficiency more than 42 percent and excellent environmental performance). This demonstration will serve as a foundation for commercial application of the IGCC technology in China for the 21st century. China has placed a priority on building an IGCC demonstration plant under Agenda 21. This demonstration plant is to be based on imported technology that can serve as the foundation for large-scale application and diffusion of IGCC technology in China.

Establishment of an IGCC data base will provide information to support research and equipment development and provide the foundation for future installations in China. A high-level group of Chinese experts was established to define the demonstration project. The group is composed of representatives of the State Science and Technology Commission, State Planning Commission, State Economic and Trade Commission, Ministry of Electric Power, Ministry of Machinery Industry, and Ministry of Coal Industry.

III. U.S. ACTIVITIES CONDUCTED UNDER ANNEX IX

Sustaining economic growth drives the development of China's energy infrastructure and capacity. Energy, which is largely produced from fossil fuels, is a key to achieving sustained growth. Although China is concerned that pollution affects the health and quality of life and may have global impacts, environmental pollution relating to coal-based power production has not yet been adequately controlled. In the past, China has been constrained in the adoption and wide application of clean coal technologies for pollution control due to high capital demands and the higher priority of meeting the energy growth needs. China plans to use high-efficiency clean coal technologies that can improve operating performance, reduce polluting emissions, and reduce operating costs over the life cycle of the power plant.

As part of its objective for achieving sustainable economic and energy growth in an environmentally acceptable manner, China plans to proceed with the development of an IGCC demonstration project identified in Agenda 21. To support this objective, China requested as an initial activity for the U.S./China cooperative program during the period of April 1994 through December 1995 to examine IGCC as compared to supercritical pulverized-coal-fired power plants, atmospheric fluidized-bed combustion (AFBC) and pressurized fluidized-bed combustion (PFBC) power systems. This activity included ascertaining the competitive status of IGCC in China through the performance of a comparative assessment of the economic and technical feasibility of using IGCC for electric power production in 200-MWe and 400-MWe steam-producing power plants. During the development of the U.S. budget for fiscal year 1995, U.S. DOE sought funding for providing some financial assistance for an IGCC demonstration project in China to promote the clean and efficient use of coal to produce power. This request for funding was not supported by the U.S. Congress. The Secretary of Energy notified the Ministry of Electric Power of this decision during the Presidential Trade Mission to China in February 1995.

A Chinese delegation was sent to the United States in July 1994. The delegation attended a week-long IGCC seminar at Tulane University and participated in meetings with representatives from the U.S. DOE and industry, including Destec, Texaco, Foster Wheeler, ABB Combustion Engineering, General Electric, and Westinghouse. U.S. industry site visits and plant tours were included in the activities of the delegation. These visits included Tampa Electric's Polk Power Station in Lakeland, Florida, site of the Texaco-based U.S. DOE IGCC demonstration project; Westinghouse Gas Turbine Works in Pensacola, Florida; General Electric Gas Turbine Works in Charlotte, North Carolina; and PSI Energy's Wabash River Generating Station in West Terre Haute, Indiana, site of the Destec-based U.S. DOE IGCC demonstration project. A site visit was also made to the Bakersfield combined-cycle oil field, and the delegation met with representatives from Burns and Roe Enterprises and Bechtel who provided presentations on the status of IGCC technology in the United States and prefeasibility study approaches to IGCC power plant engineering and design. Visits were also made to the U.S. DOE Pittsburgh Energy Technology Center and Morgantown Energy Technology Center where the delegation received presentations and tours showing "in-house" IGCC and advanced combustion technology research and development.

After the U.S. visit, the Chinese delegation requested, through Annex IX, U.S. assistance to support a technical and economic assessment of the competitiveness of IGCC compared to other advanced power-producing technologies at the 200-MWe and 400-MWe nominal power output basis. The assessment considered specific attributes of IGCC and advanced power generation technologies selected for analysis by the SSTC. The study included an assessment of the availability and costs of the equipment being considered for use in the IGCC project. Estimates of the associated costs of equipment and power plant support systems were provided for total plant completion and operation as required on the basis of U.S. and/or Chinese supply and delivery to the selected plant site in China. The analysis was based on site conditions in Table 1 and Chinese coal represented in Table 2.

SSTC requested that the United States perform the following tasks in support of the Chinese IGCC prefeasibility study:

- Discuss the IGCC program with Chinese engineers and advise on the best way to select the parameters of the systems.
- Introduce the procedure for acquiring project funding as used in the United States and other Western countries.
- Introduce the experiences and problems during the construction of the existing IGCC plants.
- Recommend the best forms of technology transfer and equipment manufacturing cooperation that may be used in IGCC projects.
- Forecast the market potential and commercial prospects of IGCC in China.
- Define equipment for the IGCC plant based upon U.S. and Chinese manufacture and supply.

Table 1. Design Data for Chinese IGCC Prefeasibility Study

Design coal	Datong (see Table 2)
Plant capacity, MWe	200 and 400
Air emissions, ppm	
NO_x	20
SO_2	U.S. EPA* standards
Desulfurization, %	95-98
Net thermal efficiency (LHV), %	41-43
Meteorological data (conditions at site)	
Ambient temperature, °C	12
Yearly average temperature in July, °C	25.73
Rainfall, yearly average, mm	590
Humidity, yearly average, %	58
Average relative humidity in August, %	78.7
Average relative humidity in January & February, %	42.29
Temperature of circulating water, °C	
Makeup water temperature	15
Design water temperature	20
Water temperature in summer	33
Yearly average water temperature	24
Topographic conditions and site elevation	
Topography at site	Even
Site elevation (above Yellow Sea), m	42-45
Earthquake intensity and frozen soil depth	
Earthquake intensity, degree	8
Ground horizontal acceleration, cm	2.5-7.6
Frozen soil depth at site, m	0.8

*United States Environmental Protection Agency

Table 2. Datong (China) Design Coal Properties for IGCC Prefeasibility Study

Total moisture, % (AR)	8.84
Proximate analysis, % (AD)	
Moisture	3.6
Volatile matter	29.9
Fixed carbon	55.1
Ash	9.98
Total sulfur, % (AD)	1.0
Fluorine, % (AD)	0.011
Chlorine, % (AD)	0.003
Calorific value, (kj/kg) (AR)	HHV 28.64
	LHV 26.71
Ultimate analysis, % (AD)	
Carbon	73.72
Hydrogen	4.56
Nitrogen	1.03
Combustible sulfur	0.61
Oxygen	9.34
Ash	10.74
Ash analysis, %	
SO_2	49.5
Al_2O_3	15.1
FeO	19.46
TiO_2	0.4
CaO	6.7
MgO	1.6
Na_2O	0.4
K_2O	0.5
P_2O_5	0.7
Mn_3O_4	trace amounts
SO_3	6.3
Ash fusion temperature, °C	
Deformation	1135
Sphere	1175
Hemisphere	1210
Flow	1260

AR = As received
AD = As determined

- Analyze potential sources of financing including the possibility of financing from the World Bank (e.g., Global Environment Facility) and U.S. banks (e.g., EXIM Bank) or from companies and manufacturers based on mode and quantity of offer, interest, return rate, etc.
- Investigate the manufacturing options and transfer of gas turbine technology between the United States and China.
- Analyze the effect, efficiency, and capital costs of the IGCC power plant during high efficiency quench, hot gas cleanup, and integrated air separation.
- Prepare performance and cost trade-off analysis.

The analysis of technical and economic trade-offs of options considered for a Chinese IGCC project optimized technology availability. The trade-off analysis included the following factors:

- Base plant with full heat recovery versus quench
- Gross and net power output
- Net thermal efficiency trade-off
- Reliability of critical equipment and burners
- Equipment list, including items that must be purchased outside of Chinese
- Investment, operating, and maintenance costs

The analytical effort was organized into five tasks:

- Task I - Power Generation Technology Comparisons
- Task II - IGCC Technologies under Consideration
- Task III - Sources of Financing for IGCC
- Task IV - Status of Hot Gas Cleanup Technology Development in the United States
- Task V - IGCC Equipment Considerations

The following sections provide task summaries and results of the work conducted by U.S. DOE.

Task I - Power Generation Technology Comparisons

The study investigated the economics of four technologies that were preselected by China for consideration in the trade-off analysis based upon the technologies' commercial availability and competitiveness. The four technologies that China presented are as follows:

- Supercritical pulverized-coal fired-power boilers
- Atmospheric fluidized-bed combustion
- Pressurized fluidized-bed combustion
- Integrated gasification combined-cycle system

<u>Technology Descriptions</u>

Supercritical Pulverized-Coal-Fired Boilers. Supercritical pulverized-coal-fired power plants are operating in Europe, Japan, Korea, the United States, and other economies. These plants operate at much higher temperatures and pressures than conventional power plants. Supercritical boilers operate at pressures that can range from 24 to 38 mega Pascales (MPa) (conventional systems operate at 16-19 MPa), representing the upper limits of the supercritical steam pressure on a temperature-enthalpy diagram. A simple flow diagram for a supercritical plant is shown in Figure 4. Depending on the specific configuration of the plant, modern power plants using supercritical boilers can achieve overall plant thermal efficiency, based on coal's higher heating value (HHV), in the range of 40-43 percent compared to the efficiency of a conventional coal-fired power plant of 38-40 percent. Depending on the systems selected, 98 percent SO_2 and over 90 percent NO_x emissions reduction can be achieved using advanced systems that produce some solid waste.

Atmospheric Fluidized-Bed Combustion. In an atmospheric fluidized-bed combustion (AFBC) plant, the pulverized-coal-fired steam generator and the flue gas desulfurization unit of a conventional power plant are replaced by a fluidized-bed combustion steam generator. The system operates at atmospheric pressure. As much as 90 percent of the sulfur released from the coal during combustion can be removed in the fluidized bed. The normal operating temperature for a fluidized-bed combustor is 760-871 °C, which is below the threshold where NO_x is formed. Hundreds of fluid-bed boilers are in operation throughout the world. Many are located in China. However, only a few of the units in operation in the world are of a scale of 100 MWe or larger (none are in China). Recently, technology venders have offered units up to 400 MWe.

Coal, air, and a solid sorbent, such as limestone, are introduced into the lower portion of the combustor where initial combustion occurs. As coal particles decrease in size due to combustion and breakage, they are carried higher in the combustor to an area where additional air is introduced. As the coal particles continue to be reduced in size, the coal, along with some of the sorbent, is carried out of the combustor, collected in a particle separator, and recycled to the lower portion of the combustor. The sorbent in the bed removes sulfur during the combustion process, eliminating the need for scrubbers. A simple flow diagram for this system is shown in Figure 5.

Steam is generated in tubes placed along the combustor's walls and superheated in tube bundles placed in the solids-circulating stream in the flue gas stream. The steam is then used to produce power in a conventional steam cycle. Depending on the design configuration, an AFBC-based cogeneration plant can achieve efficiencies in the range of 37-40 percent. This technology operates at lower temperatures than conventional boilers, thus reducing NO_x production by as much as 80-90 percent. Because sorbents are injected into the fluidized-bed to achieve the reduction of SO_2, disposal of the solid waste produced is required.

Pressurized Fluidized-Bed Combustion. Pressurized fluidized-bed combustion (PFBC) uniquely joins two power generating systems: the fluidized-bed combustor and the gas turbine. There are four PFBC units in operation, one each in the United States, Spain, Sweden, and Japan, all at the 70-MWe scale. The pressure in a PFBC unit is approximately 12 bars; an AFBC unit is slightly above atmospheric pressure. Pressurized operation allows the use of the combustion gases from the fluid bed to produce electricity in a gas turbine, which improves the efficiency of the system.

Crushed coal and sorbent, for sulfur removal, are injected along with air through the bottom portion of the boiler. When the air velocity inside the boiler reaches a certain level, the particles of coal and sorbent assume a random-type motion and appear to float or "fluidize." The fluidized motion ensures

Figure 4. Flow Diagram for Supercritical Pulverized-Coal-Fired Boiler System

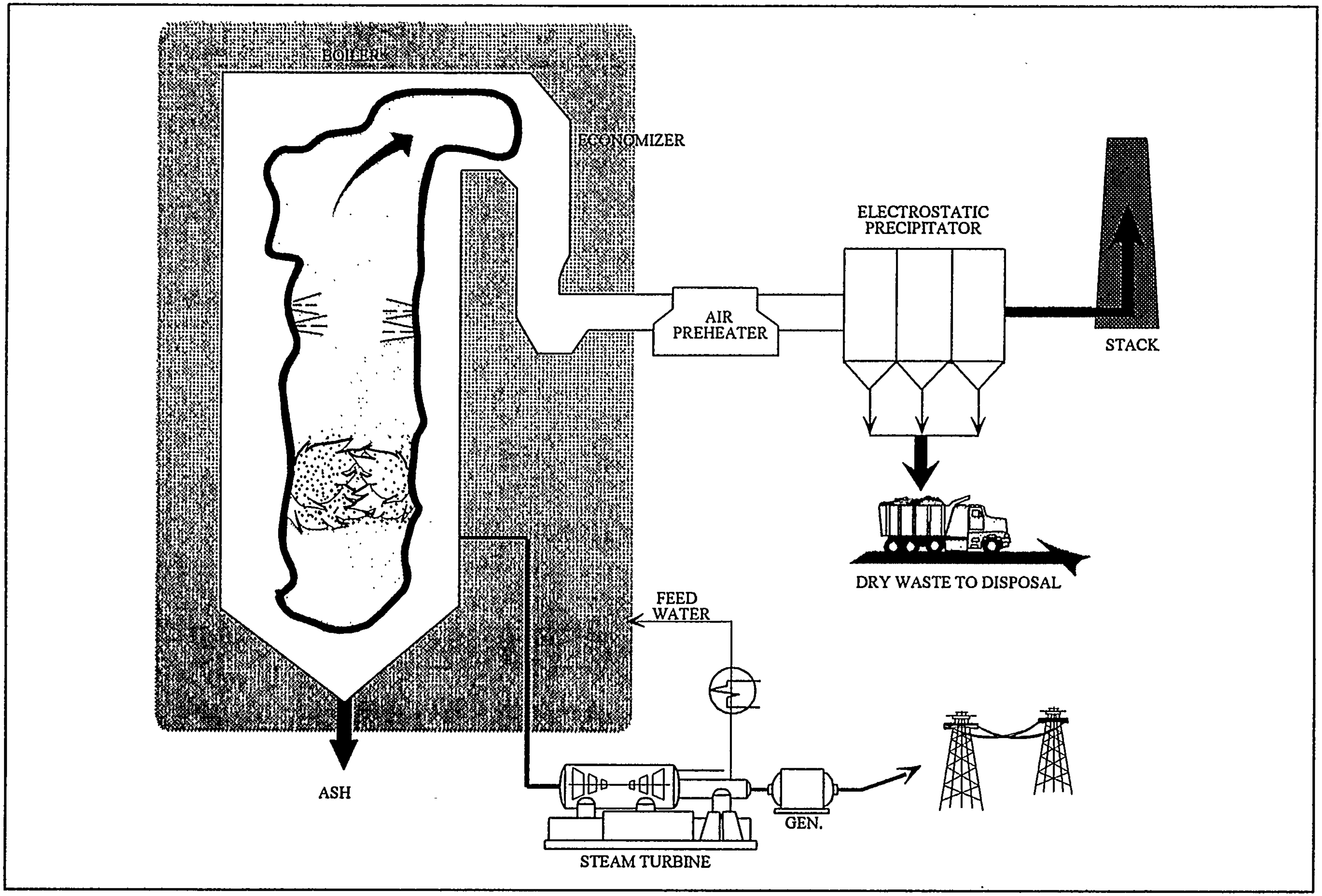
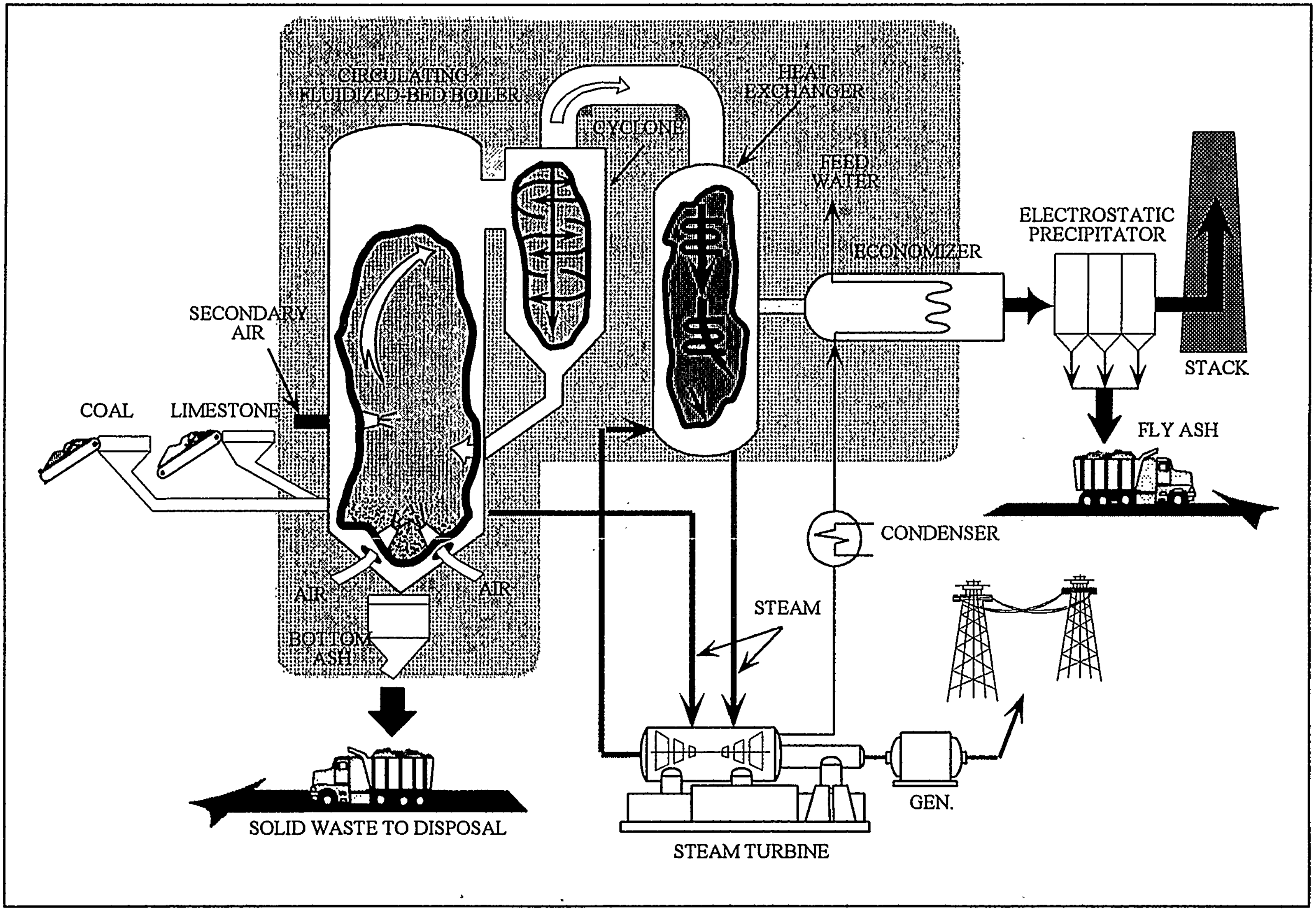


Figure 5. Flow Diagram for Atmospheric Fluidized-Bed Combustion System



thorough mixing of the particles. During the combustion process, the sulfur in the coal is released and chemically attaches to the sorbent. Combustion temperature is approximately 871 °C, or about half that encountered in a conventional boiler. The sulfur-laden sorbent is removed with the coal ash.

Smaller ash particles, or fly ash, are carried from the top of the bed by hot gases produced during the combustion process. The gases pass through dust collectors where the fly ash is removed. This separation procedure minimizes the potential of erosion and corrosion damage to the gas turbine downstream. The gas turbine drives both an air compressor (which provides combustion air for the fluidized bed) and a generator to produce electric power. Gases exhausting from the gas turbine are used to preheat feedwater for the steam turbine cycle. The preheated feedwater is then sent through the tubes submerged in the fluidized-bed boiler. The tubes extract heat from the combustion process in the boiler and convert the feedwater to steam. The steam is used to turn a steam turbine generator that produces the bulk of the plant's electric power. Solid waste from a PFBC system is increased over a conventional pulverized-coal-fired boiler due to the addition of the sorbent. The flow diagram for the PFBC system is shown in Figure 6.

Up to 95 percent SO_2 emission reduction is possible using PFBC technology, and up to 90 percent NO_x emission reduction can be achieved. PFBC technology has an overall thermal efficiency in the range of 40-42 percent based on the higher heating value of the feed coal.

Integrated Gasification Combined Cycle. The integrated gasification combined-cycle (IGCC) system is entering the global market as the cleanest and most efficient coal-based power generation technology. The IGCC system uses a coal gasifier in place of the pulverized-coal-fired boiler coupled with a combined-cycle system that provides high system efficiencies and ultra-low pollution levels. In an IGCC plant, coal is converted to a synthetic gas that is cleaned of impurities (including particulates, SO_2, CNS, COS, and NH_3) and used to produce electric power in a gas turbine. Waste heat from the process is used to produce steam which is used in a steam turbine to generate additional electricity. The Brayton-cycle gas turbine operating in combination with the traditional Rakine-cycle steam turbine make up the combined cycle. Integrating gasifier technology with a combined cycle offers high system efficiencies, low costs, and ultra-low pollution levels. The IGCC system is shown in a simplified flow diagram in Figure 7.

Up to 99 percent of the sulfur in the coal can be recovered as a by-product of the gasification process, and the IGCC system can be designed to reduce NO_x emissions by up to 90 percent. Solid waste from the IGCC technology is a benign material (slag) which has value as a by-product that can be used for roadbed construction and maintenance. IGCC technology can achieve overall thermal efficiencies in the range of 40-43 percent based on the higher heating value of coal, and with new advances in high-temperature turbine development, efficiencies of up to 50 percent are possible.

Total Life-Cycle Cost Model

During the performance of support activities for China's IGCC prefeasibility study, it was established that the predictions of the cost of electricity based on investment, capital, operating costs, and maintenance costs were insufficient. More reliable predictions of the cost of electricity in the mid-

Figure 6. Flow Diagram for Pressurized Fluidized-Bed Combustion System

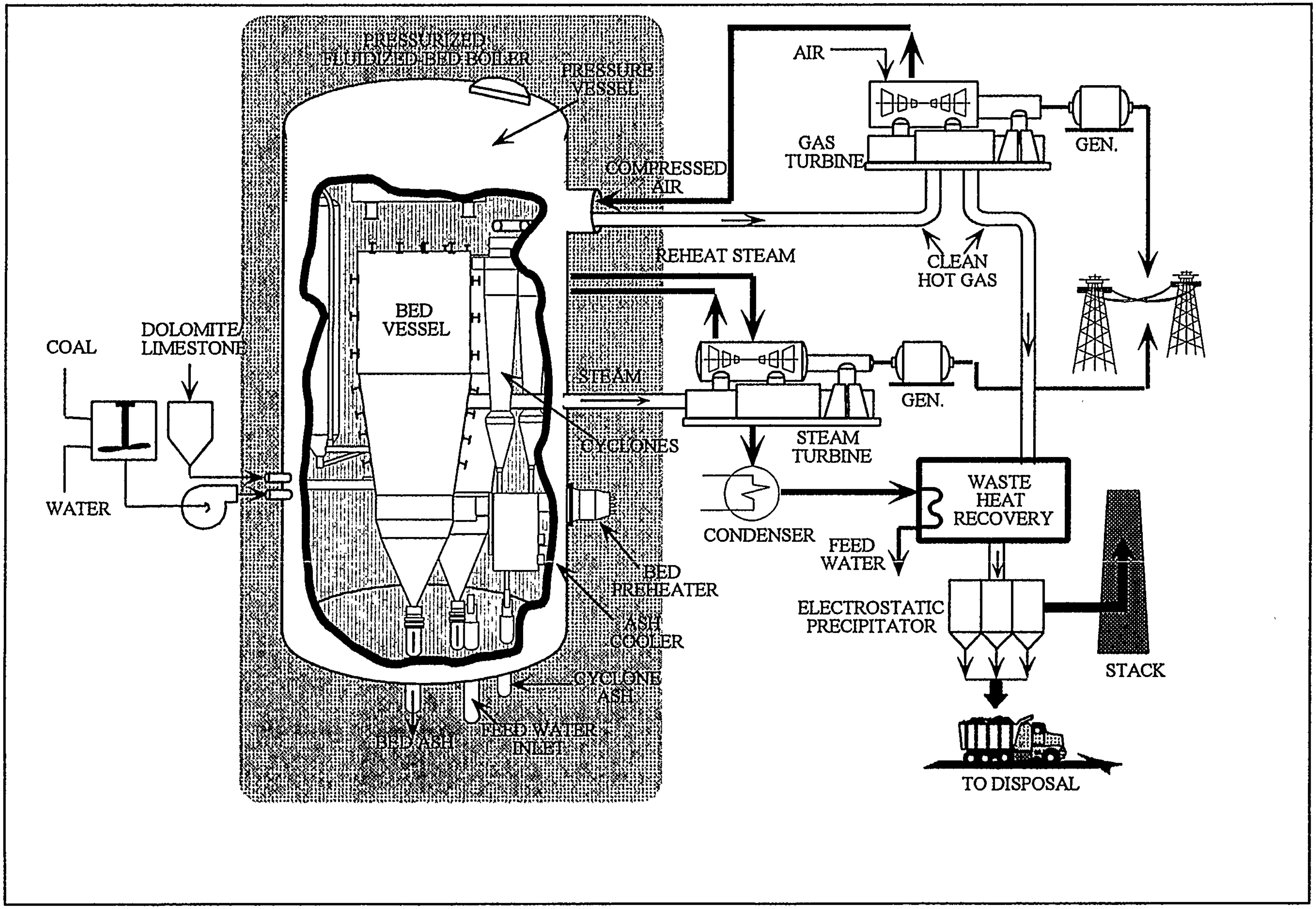
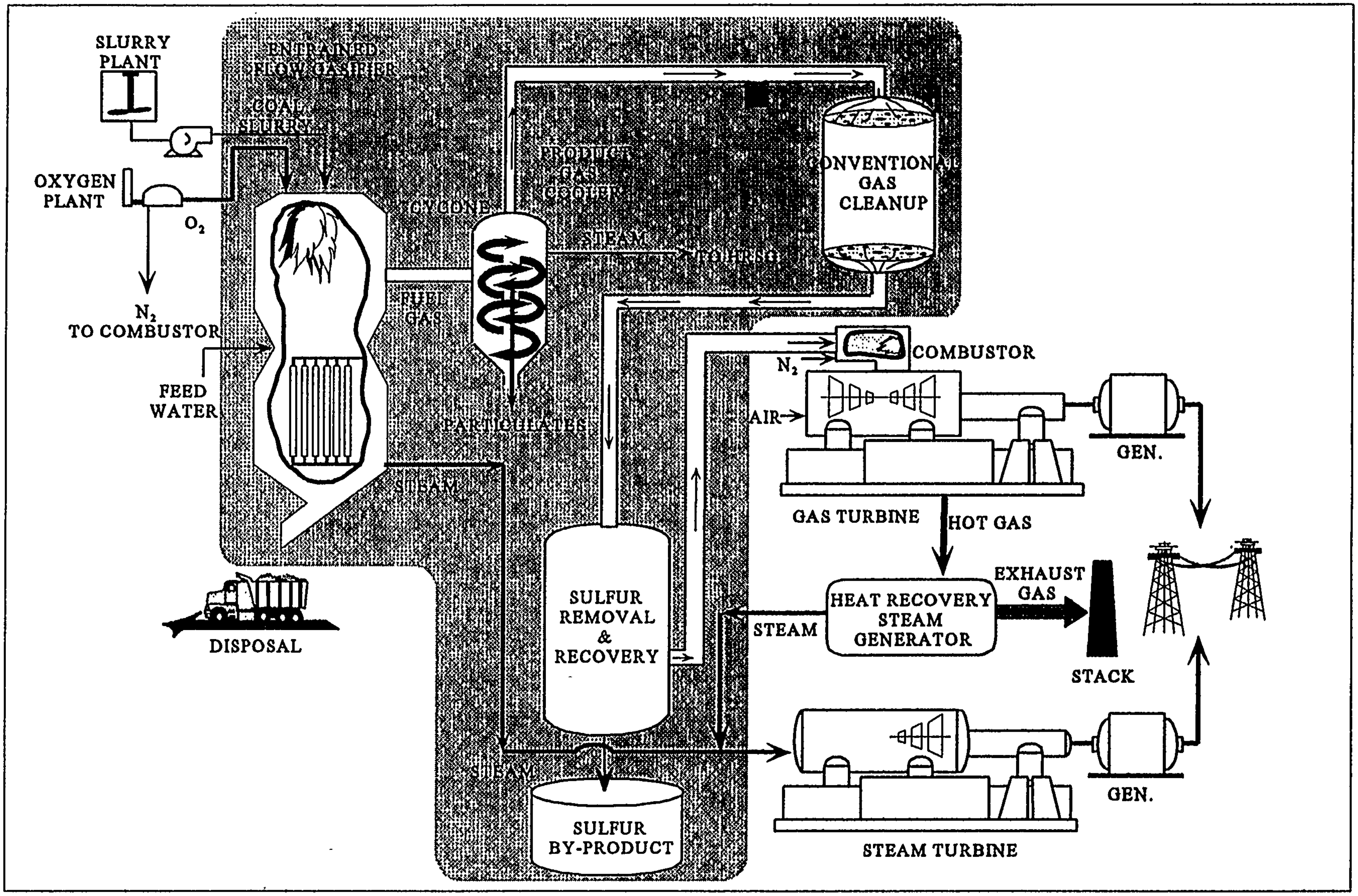


Figure 7. Flow Diagram for IGCC System



and long-term can be made based on total life-cycle costs (TLCC). A TLCC analysis considers all cost elements, including environmental costs, to arrive at the total cost of alternatives.

A need existed to provide China with the means to screen various technology concepts for the project. The screening method chosen was a TLCC model which was developed specifically for this purpose. The model is not meant to provide detailed design costs, but to provide a means for comparing various power plant technologies on a common basis. While the model uses the concept of total life-cycle costs, including estimated costs for environmental costs, the model also breaks out the various capital and operating cost components and includes interest during construction and various nonprocess plant costs.

The TLCC model was used to determine the economics of IGCC and competing advanced combustion technologies. Some of the cost information is based upon the 1989 and 1993 Electric Power Research Institute (EPRI) *Technical Assessment Guide* (TAG).[3] Where possible, the model employed current vendor-supplied cost estimates resulting from the construction costs associated with the U.S. Clean Coal Technology Program projects.

The TAG and other algorithms were used to generate capital and operating costs. The initial analysis of the capital costs and annual operating costs was computed for the IGCC and other advanced combustion technologies that were deemed to have reached commercial electric utility scale. The 1997 costs for the China-based technology analysis were derived using the TLCC model and are based upon information supplied by the SSTC during meetings with the U.S. DOE delegation during the information-gathering trip to China in December 1994. The following section summarizes the TLCC model features and methodology used in producing the results of the economic assessment of IGCC and other advanced power generation technologies for application in China.

Model Features. The TLCC analysis involves normalizing cost estimates with respect to performance standards and financial assumptions and preparing a profile of all costs over the service life of the power station. These costs when "levelized" present a value in terms of a utility electricity rate (e.g., mills per kilowatt-hour).[4] Comparison of cost and the pricing of the electricity for a utility shows whether or not a valid project exists.

Cost components include both internal and external costs. Internal costs are direct costs associated with the purchase and operation of the power station and include initial capital costs, operating costs, and maintenance costs. External costs result from societal and/or environmental impacts that are external to the marketplace and can include air quality impacts due to emissions, infrastructure costs, and other impacts. The cost stream is summed (current dollars) or discounted (constant dollars) to some base year to yield an overall, comparable total life-cycle cost of each power station technology.

The TLCC analysis can indicate whether or not paying a relatively high initial capital cost for advanced technology with low operating and/or environmental costs is advantageous over paying a

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[3] Electric Power Research Institute, *Technical Assessment Guide (TAG), Volume 1: Electricity Supply,* G. Ramachandran, 1993 (Revision 7).

[4] Levelizing refers to the use of present worth calculations to convert a series of varying quantities to a financially equivalent constant quantity over a specific time interval.

lower initial cost for conventional technology with a higher operating and/or environmental cost. While minimizing life-cycle cost is an important consideration, it may not always be a preferred method for some utilities which may prefer minimizing capital costs. Such consideration does not always result in technology penetration in a marketplace such as the utility sector. Depending on the regulatory climate, a utility may prefer to weight heavily initial capital costs while giving limited consideration to other costs such as societal costs. Policy makers considering external costs, such as those resulting from environmental impacts, may reach significantly different conclusions about which technologies are most advantageous to society. The TLCC model for power stations was developed to facilitate consideration of all perspectives.

The TLCC model for power stations was developed to provide a tool for comparing various technologies. The TLCC model is a parametric model (i.e., with scalable factors) which has been designed to be "user friendly," easily expandable, and modifiable as new data become available. The model is designed to operate on an IBM-compatible personal computer using Microsoft Windows® (version 3.1 or later) and Microsoft Excel® for Windows (version 6.0 or later). The modifiable data are contained in embedded data sheets within the TLCC model. A systems approach was used in developing the TLCC model for electric power stations; the model consists of the following key components:

- Technology
- Economic
- Environmental
- Location
- Fuel

The model presented has the following characteristics:

- Considers variations in technologies, types of fuel[5], and plant location
- Accounts for the time value of money
- Uses embedded data sets which can be easily modified
- Links all model modules

Model Structure. The TLCC model is structured in a linked spreadsheet environment. Each spreadsheet deals with a specific analytical element of life-cycle cost analysis. The various spreadsheets are linked to form an interactive model. The model is composed of the following modules or separate, linked spreadsheets:

- Input modules -- input data, technology, environmental data, location data, construction parameters, fuel library, environmental costs, economic assumptions

- Intermediate modules -- bases and assumptions, reference operating data, reference cost data, levelizing factors, carrying charge (current cost and constant cost)

- Output modules -- total power plant investment (capital cost), annual operating costs, cost of electricity, total life-cycle cost summary

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[5] The TLCC model currently covers coal and natural gas.

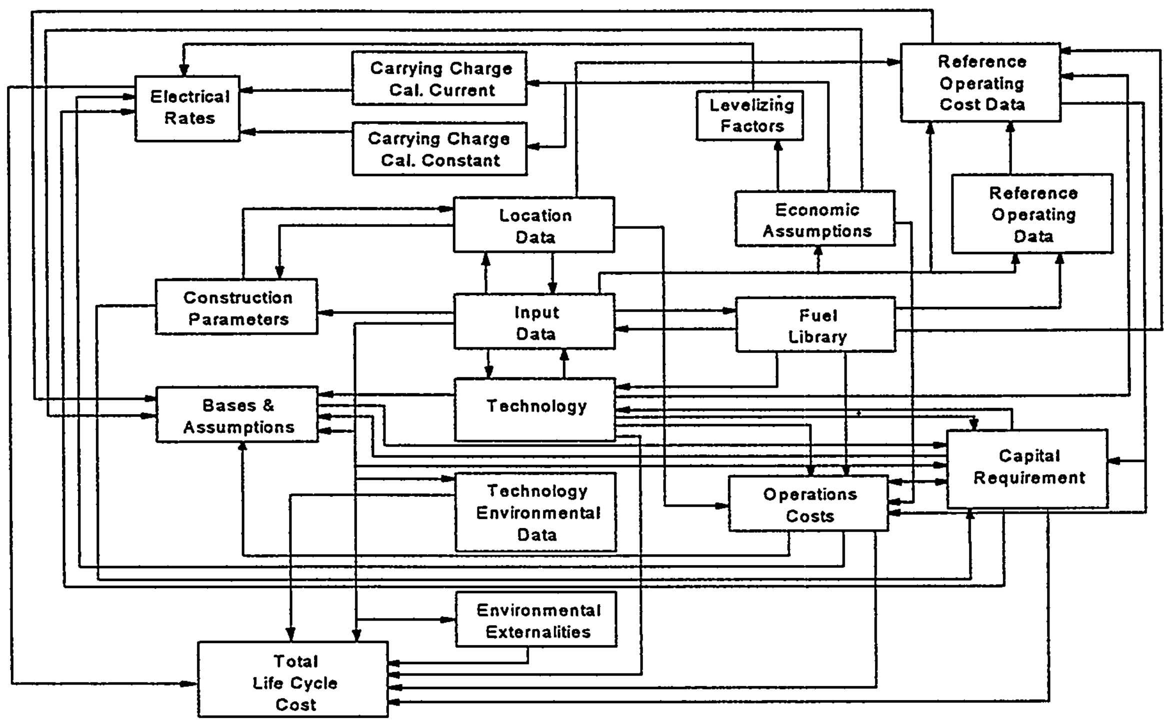

Figure 8. Total Life-Cycle Cost Model for Electric Power Stations

Figure 8 shows the model structure and the data flow paths among modules. The TLCC model utilizes Excel® workbooks. Each Excel® file is a workbook, and each workbook contains one or more sheets. Each sheet can be a worksheet, chart, Microsoft Visual Basic® module, or a macro sheet. By starting the TLCC model, all the modules are opened simultaneously.

The TLCC model draws upon data sets that are embedded in various modules in the form of lookup tables. Lookup tables contain a variety of economic, cost, performance, and environmental data indexed to correspond to a given power station configuration and/or economic standards. These embedded data sets were constructed for data that may require periodic update prompted by changes in economic assumptions, cost basis, and/or technology advances. The model accesses data based upon the inputs entered to represent a given analytical case or scenario.

The TLCC model offers an opportunity for policy analysis of various projects prior to detailed feasibility analysis. Project funding can be based on the best total life-cycle cost. The model can be expanded to include nuclear power stations and decommissioning cost. Using the TLCC model in combination with investment and risk analysis can provide decision makers with useful information, because it is only through consideration of total life-cycle costs that a realistic understanding of major investment decisions can be achieved.

Total Life-Cycle Cost Summary. The assessment of total life-cycle cost considers the costs associated with construction, operation, and maintenance of a utility-size power plant over the entire predicted life of the plant. In the TAG evaluation of the economics associated with new and existing power-producing technologies, the levelized costs of the capital and associated investment costs are considered over the project life. First year start-up costs are also included, and operating and maintenance costs are considered through the life of the power plant. The TLCC model calculates the associated costs for a 20-year plant life, which includes fuel cost predictions, and the model provides input options that allow for the productivity factors associated with the manufacture and supply of equipment from China as well as U.S.-based Gulf Coast fabrication locations.

The output of the TLCC model consists of capital cost, operating cost, cost of electricity, and total life-cycle cost, including the environmental factors. Table 3 shows the results of TLCC calculations for a 200-MWe power plant using the advanced Texaco gasifier and operating in China. The TLCC model output also presents the environmental costs associated with a particular technology. These costs are not normally compensated within the cost of electricity for a particular power plant.

Environmental costs represent costs associated with environmental impacts from pollutants and land and water use. These costs are generally borne by society. Therefore, the total life-cycle costs are the sum of capital, operating, and the environmental costs. Technologies that have the effect of reducing emissions and land and water use reduce the environmental or societal costs. However, when these costs are added to the other costs, revenues rarely compensate for these environmental costs, and thus the total life-cycle cost tends to be positive. The electrical rate charged on a 10-year levelized cost basis would have to be increased by 26 mills per kilowatt-hour to compensate for the environmental cost and have a neutral total life-cycle cost, i.e., $0 per kilowatt.

The principal module for determining capital requirements is divided into the following basic segments:

- Process plant cost
- General costs and contingency fees
- Construction financing cost
- Other direct and indirect costs

Process plant cost is assessed by developing parametric costs for the various sections of the power plant. The user can input process contingency costs as a percent of plant sector bases costs. The individual plant section costs include all direct field materials and labor and indirect costs. The plant size-related cost algorithms were derived from EPRI data that related cost to size.[6] These estimates and others result in the following quadratic regression equation:

$Y = a + bx + cx^2$
where
Y = cost (millions of dollars)
a, b, and c = constants
x = sizing parameter (e.g., tons/day, MWe)

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[6] Electric Power Research Institute, *Economic Assessment of the Impact of Plant Size on Coal Gasification Combined-Cycle Plants*, EPRI Report AP-3084, May 1983.

Table 3. TLCC Results

Plant size	200-MWe power plant
Technology	IGCC
Company	Any company
Primary fuel	Datong coal
Plant location	People's Republic of China
Capital requirements	1997 dollars
Project life	20 years

	Total Life Cycle ($1,000)	Average per Year ($1,000)	10-Year Levelized Cost	
			$ per kW	mills per kWh
Process plant cost	$182,712	$9,136	$914	24.77
General plant & contingencies				
General plant facilities	$34,382	$1,719	$172	4.66
Engineering fees	$3,654	$183	$18	0.50
Process contingency	$6,117	$306	$31	0.83
Project contingency	$21,709	$1,085	$109	2.94
Subtotal general plant & contingencies	$65,863	$3,293	$329	8.93
Total plant cost	$248,575	$12,429	$1,243	33.69
Interest costs				
Plant construction period				
Construction interest rate, adjustment for interest & inflation	$5,706	$5,706	$29	0.77
Subtotal interest cost	$5,706	$285	$29	0.77
Total plant investment	$254,281	$12,714	$1,271	34.47
Additional capital requirements				
Prepaid royalties				
Initial catalyst and chemical inventory	$2,180	$109	$11	0.30
Start-up costs	$7,197	$360	$36	0.98
Spare parts	$1,243	$62	$6	0.17
Working capital	$1,372	$69	$7	0.19
Land	$24,579	$1,229	$123	3.33
Subtotal start-up cost, land & prepaid	$36,571	$1,829	$183	4.96
Total capital requirement	$290,852	$14,543	$1,454	39.42
Operating cost				
Fuel	$128,055	$6,403	$640	5.75
Consumable materials	$24,535	$1,227	$123	1.10
Ash/sorbent disposal costs	$15,521	$776	$78	0.70
Plant labor	$34,085	$1,704	$170	1.53
Maintenance costs	$109,373	$5,469	$547	4.91
Insurance & local taxes	$107,901	$5,395	$540	4.84
Royalties	$12,000	$600	$60	0.54
Other operating costs	$5,987	$299	$30	0.27
Total operating costs	$437,457	$21,873	$2,187	19.63
By-product credits	($34,630)	($1,731)	($173)	(1.55)
Net operating costs	$402,828	$20,141	$2,014	18.07
Total operating & capital cost	$693,680	$34,684	$3,468	57.50
Environmental cost				
Carbon dioxide (CO_2)	$896,922	$44,846	$4,485	40.24
Nitrogen oxides (NO_x)	$62,989	$3,149	$315	2.83
Sulfur dioxide (SO_2)	$4,741	$237	$24	0.21
Particulates	$2,528	$126	$13	0.11
Volatile organic compounds (VOC)				
Carbon monoxide (CO)	$2,750	$137	$14	0.12
Methane (CH_4)	$267	$13	$1	0.01
Nitrous oxide (N_2O)				
Land and water				
Total environmental costs	$970,197	$48,510	$4,851	43.53
Revenue	($904,297)	($45,215)	($4,521)	(74.96)
Total life-cycle cost	$759,579	$37,979	$3,798	26.07

General costs and contingency fees include general plant facilities costs, engineering fees, process contingency fees, project contingency fees, and equipment shipping cost. The general plant facilities cost algorithm, which also uses a quadratic regression equation, relates these costs as a percentage of the process plant cost and total fuel throughput. General facilities costs are sensitive to both plant size (fuel throughput) and complexity (process facilities costs). The other costs either are input or result from calculations carried out in other modules. Construction financing cost captures interest and inflation during the construction of the plant.

Other direct and indirect costs are derived from calculations carried out in other modules and summarized in the capital requirements module. The summary of these calculations is displayed as total capital cost in constant dollars based on the year that the plant construction is initiated and as cost per energy unit (e.g., dollars per kilowatt).

Table 4 shows the various inputs used to calculate the operating cost for the 200-MWe IGCC power plant. Annual operating cost is presented in terms of constant dollars for the project initiation date (1997). In calculating net operating cost, total operating costs are offset by by-product credits.

Table 4. Operating Cost

Plant size	200-MWe power plant
Technology	IGCC-advanced
Company	Any company
Primary fuel	Datong coal
Plant location	People's Republic of China
Capital requirements	1997 dollars
Capacity factor	69%

	Annual Operating Costs		
	Quantity (tons/day)	Unit Price ($/ton)	Annual Cost ($1,000)
Fuel	895.6	$28.59	$6,403
Consumable materials			
Catalyst & chemicals	31.6	$111.26	$880
Water	8,676.2	$0.16	$347
Limestone		$17.25	
Dolomite		$22.25	
Ash/sorbent disposal costs	348.7	$8.90	$776
Plant labor			
Operational labor (includes benefits; 57 persons per shift at a rate of $1.63 per hour)			$806
Supervision & clerical			$898
Maintenance costs			$5,469
Insurance, local taxes & utility tax			$5,395
Royalties			$600
Other operating costs			$299
Total operating costs			$21,873
By-product credits			
Sulfur	77.8	$89.01	$1,731
Fertilizer		$116.82	
Sulfuric acid		$76.60	
Tars		$178.01	
Methanol		$166.89	
Total by-product credits			$1,731
Net operating costs			$20,141

Operating costs include the various elements associated with directly operating the power plant, such as follows:

- Fuel
- Consumable materials
  - Catalyst and chemicals
  - Water
  - Limestone
  - Dolomite
- Ash and sorbent disposal costs
- Plant labor
  - Operating labor including benefits
  - Supervision and clerical costs
  - Maintenance costs
- Insurance, local taxes, and utility tax[7] (if any)
- Royalties
- Other operating costs

The operating and maintenance costs are based on work sponsored by the U.S. DOE and are shown explicitly within the model in the cost-of-electricity section.

By-product credits reflect potential sale of by-products from the power plant output. Salable by-products include sulfur, fertilizer, sulfuric acid, tars, and methanol. These by-products can be increased as necessary. The sum of both the total operating cost and total by-product credits results in a net operating cost expressed in constant dollars.

Table 5 shows the cost of electricity for the power plant. The approach to determining the cost of electricity is based upon the methodology developed by EPRI for the TAG. The cost of electricity is stated in terms of the tenth-year levelized cost. The EPRI TAG approach is the general approach used by the U.S. utility industry to compare the cost of electricity over a 10-year period, i.e., large capital costs and other factors, such as depreciation, are spread over the life of the power station and then presented in a constant dollar format through the use of levelization.[8] Insurance and local taxes are accounted for explicitly in the operating cost rather than being included in the capital charges, as is the case in the EPRI TAG methodology.

The TLCC model was used to calculate the various cost elements for a number of power plant technologies. Table 6 shows the cost elements for IGCC, PFBC, AFBC, pulverized coal supercritical combustion (PC supercritical), and pulverized coal subcritical combustion using a spray dry flue gas desulfurization system (PC/FGD -- spray dry). The table is useful when used for comparison, because the absolute values differ from a finalized, detailed cost analysis. The capital cost elements for the

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7 In some instances, the utility may be required to pay a separate utility tax based on power production. This is the case for Chinese utilities.

8 A life of 10 years is used for analytical purposes. In reality, the life of a fossil-fuel-fired utility power plant is 25-30 years or more.

Table 5. Cost of Electricity

Plant size	200-MWe power plant	
Technology	IGCC	
Company	Any company	
Primary fuel	Datong coal	
Plant location	People's Republic of China	
Capital requirements	1997 dollars	
	Current $	**Constant $**
Levelizing factors		
Capital carrying charge, 10th year	0.232	0.163
Fuel cost, 10th year	1.845	1.077
Operating & maintenance cost, 10th year	1.845	1.077
Cost of electricity, levelized (mills/kWh)		
Capital carrying charges	56.3	39.4
Fuel cost	9.8	5.7
Operating & maintenance cost	21.1	12.3
Total cost of electricity (mills/kWh)	**87.2**	**57.5**

five technologies for both a 200-MWe and 400-MWe power plant built and operated in China are shown. These cost elements include process plant cost; general plant and contingency costs; construction interest; and start-up, land, and prepaid other costs. Table 6 shows a positive total life-cycle cost for each of the concepts investigated, i.e., the revenue stream will not fully compensate for all costs including the environmental costs. However, the system that has the lowest total life-cycle cost is the most "totally economical" system considering all factors. Thus the IGCC system has both the lowest total capital cost and lowest total life-cycle cost among the candidate systems screened.

Figure 9 shows the graphical output that the TLCC model provides as a summary of the calculations. Each of the bars of the chart show the value of each of the major components of the TLCC analysis. The negative bars represent revenues received for both by-products and electricity sold by the utility. This figure also shows a summary of the various numerical values for the costs computed by the model.

Task II - IGCC Technologies under Consideration

The comparison of the following IGCC technologies being considered by the SSTC for China project are included in the study:

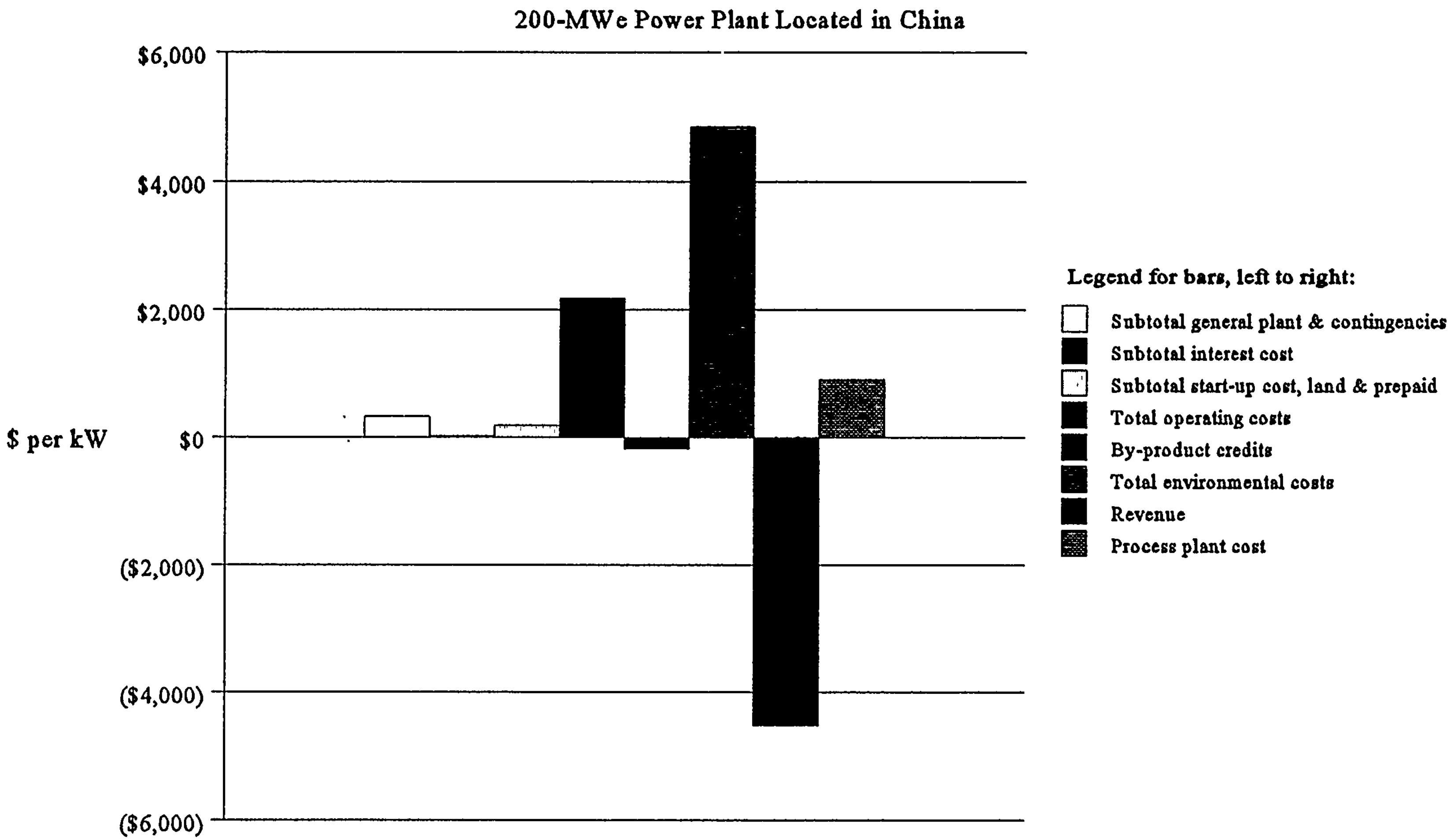
- Destec -- slurry-feed entrained flow gasifier
- Shell -- dry-feed entrained flow gasifier
- Prenflo -- dry-feed entrained flow gasifier
- Texaco -- slurry-feed entrained flow gasifier

Table 6. Comparison of Costs

200-MWe Power Plant								
Technology	Process Plant Cost ($ per kW)	General Plant and Contingencies ($ per kW)	Construction Interest ($ per kW)	Other Direct and Indirect Costs ($ per kW)	Total Capital ($ per kW)	Operating Cost ($ per kW)	TLCC ($ per kW)	Cost of Electricity* (mills per kWh)
IGCC	$914	$329	$29	$183	$1,454	$2,187	$3,798	57.50
PFBC	$1,047	$310	$31	$138	$1,526	$3,617	$5,402	73.83
AFBC	$1,047	$88	$31	$267	$1,632	$3,788	$6,684	78.25
PC supercritical	$1,084	$338	$33	$115	$1,569	$2,989	$4,740	69.37
PC/FGD (spray dry)	$1,116	$366	$34	$137	$1,652	$3,155	$4,988	73.09
400-MWe Power Plant								
Technology	Process Plant Cost ($ per kW)	General Plant and Contingencies ($ per kW)	Construction Interest ($ per kW)	Other Direct and Indirect Costs ($ per kW)	Total Capital ($ per kW)	Operating Cost ($ per kW)	TLCC ($ per kW)	Cost of Electricity* (Mills per kWh)
IGCC	$811	$246	$24	$131	$1,212	$2,577	$1,520	54.43
PFBC	$908	$197	$25	$171	$1,301	$5,249	$4,921	77.77
AFBC	$916	$214	$26	$104	$1,259	$4,862	$3,990	82.37
PC supercritical	$938	$234	$27	$88	$1,287	$3,998	$3,115	70.77
PC/FGD (spray dry)	$1,021	$271	$30	$102	$1,423	$4,189	$3,442	76.17

* Excluding the environmental costs

Figure 9. Total Life-Cycle Cost -- Texaco Advanced IGCC
(1997 dollars)



Total life-cycle cost	$3,798 per kW
Total capital requirement	$1,454 per kW
Total operating cost	$2,187 per kW
Cost of electricity	57.5 mills/kWh (constant $)

Destec Gasification Process

The Destec gasification process was originally developed by the Dow Chemical Company during the 1970s in order to diversify its fuel needs to include lignite and other coals. The technology was in operation at the Dow Chemical Louisiana Division from 1987 through 1995 at a scale of 160-MWe. This project has provided the design base for the U.S. clean coal project at the Wabash River Generating Station in West Terre Haute, Indiana, which employs the Destec technology to produce 262 MWe. This project began start-up in the fall of 1995.

The Destec gasification process is a pressurized two-stage (coal feed to bottom and top of reactor) entrained flow, slagging gasifier. Briefly, in the Destec process, coal is ground with water to form a slurry and then pumped into a gasification vessel where oxygen is added to form a hot gas through partial combustion. Most of the noncarbon material in the coal melts and flows out of the bottom of the vessel forming slag -- a black, glassy, nonleaching, sand-like material. The hot, raw gas is then cooled in a heat exchanger to generate high-pressure steam. Particulates, sulfur, and other impurities are removed from the gas before combustion to make it acceptable fuel for the gas turbine. The Destec technology has successfully gasified bituminous coal, subbituminous coal, and lignite feedstock.

Shell Gasification Process

The Shell gasification process was originally developed in the 1950s for the production of synthesis gas from liquid and gaseous hydrocarbons. Since commercialization in 1956, over 150 Shell units have been built in 80 different plants. Experienced gained from oil gasification led to work on coal gasification in 1972. Based upon experience with a 6-ton-per-day pilot plant, a 150-ton-per-day plant was operated at Deutsche Shell's Harburg refinery near Hamburg, Germany. From this experience, a 250-ton-per-day plant was built at Shell Deer Park manufacturing complex near Houston, Texas. Some 18 different feedstocks, including lignite, petroleum coke, and high-sulfur bituminous coal, were successfully gasified. Demkolec BV, a subsidiary of the Dutch Electricity Generating Board (N.V. Sep), has built a 250-MWe IGCC plant at Buggenum in the Netherlands; this facility, which uses the Shell technology, started its operating program in early 1994.

The Shell technology is a single-stage pressurized entrained flow gasifier to which dry pulverized coal is fed via a lock hopper system along with steam and oxygen to the gasifier. The raw gas produced in the gasifier is quenched with a cool recycled product gas; then particulates and other impurities are removed prior to combustion in the gas turbine. The coal ash melts in the gasifier and is removed as slag, an inert solid.

Prenflo Gasification Process

The Prenflo gasification process is a pressurized dry feed, entrained flow technology developed by Krupp Koppers, a licensor of the Kopper-Totzek coal gasification process. The Prenflo process is similar to the Shell process and was derived from the demonstration at Shell's Harburg refinery. The Prenflo technology is being used in a 335-MWe unit IGCC in Puertollano, Spain, with start up planned for 1996. This project is owned by a consortium of European utilities and equipment suppliers.

Texaco Gasification Process

The Texaco gasification process was developed in the late-1940s to produce hydrogen and carbon monoxide for chemical and refinery applications. The technology was originally developed for processing natural gas and heavy oil feedstocks. In the 1970s, it was modified for solid feeds, such as coal and petroleum coke.

Texaco gasification technology was demonstrated in the 120-MWe Cool Water Project in southern California. This was the world's first commercial application of IGCC technology. During the 5 years (1984-1989) of operation, the plant won numerous environmental awards and was considered the world's cleanest coal-fueled power plant.

Over 100 Texaco gasification plants have been licensed worldwide, including the United States, Europe, and Asia. Currently 21 licenses have been issued in China for a variety of feedstocks. In 1992, the Texaco gasification was selected for a 250-MWe IGCC power plant being built by Tampa Electric in Tampa, Florida. This project is expected to begin operation in late-1996.

Texaco gasifiers have proven records of performance, having accumulated more than 200,000 operating hours handling over 5 million tons of various coals with wide ranges of sulfur content and ash fusion temperature.

The Texaco gasifier is a single-stage down-flow pressurized entrained gasifier. Coal is slurried with water and injected into the top of the gasifier along with oxygen and converted into hot, raw gas which is cooled in heat exchangers and cleaned of impurities before being combusted in a gas turbine. Any ash in the feedstock is melted in the process and, when cooled, formed into as slag.

Cost Comparison of IGCC Technologies

Rather than initiating another comparison of the capital and operating costs of the different gasification technologies, previously developed information was collected and presented. The primary sources of cost comparisons for IGCC technologies are the many studies issued by EPRI. Table 7 presents a summary of the costs for the different IGCC technologies and references the source reports. Within the range of the accuracy of the estimates, all of the technologies represent similar capital and operating costs. The differentiating factors in the selection of technologies will be based on specific applications (e.g., coal type, product mix, scale, and site-specific conditions), prior experience, and the business terms of the offering.

Task III - Sources of Financing for IGCC

Host Government Commitment and Commercial Financing

Strong support from the Chinese government will be essential to secure financing for an IGCC demonstration project in China. China is expected to contribute a portion of the cost required to finance an IGCC project in conjunction with multilateral, bilateral, or private financial institutions.

Table 7. IGCC Study -- Summary and Cost-of-Electricity Calculation

(All costs in December 1994 dollars)

Gasification Technology	**Shell**			**Prenflo**		**Destec**	**Texaco**		
Data source Report Gas turbine technology Level of integration Coal	EPRI (TAG) TR-102275-V1 GE Frame 7F Conventional Illinois 6	EPRI (TAG) TR-102275-V1 GE Frame 7F High Illinois 6	EPRI (TAG) TR-102275-V1 GE Frame 7F High Pittsburgh 8	Sargent & Lundy TR-101609 Siemens 84.4 High Pittsburgh 8	Sargent & Lundy TR-101609 Siemens 84.4 High Pittsburgh 8	Fluor TR-10319 GE Frame 7F Conventional Illinois 6	Fluor TR-102156 UT TP&M High Pittsburgh 8	Fluor Technical Paper UT TP&M High Pittsburgh 8	Fluor Technical Paper UT TP&M High Pittsburgh 8
Coal cost, $ per billion joules	1	1	1	1	1	1	1	1	1
Net plant capacity, MWe	500	500	500	440	430	508	502	474	494
Thermal efficiency, LHV	40	41	43	43	44	40	42	37	38
Capital cost factors									
Total contingency, % of total plant cost	12	12	12	12	12	12	12	12	12
Construction years	3	3	3	3	3	3	3	3	3
Total plant cost calculation, $/kW									
Air separation	157	142	140	231	213	146	154		
Fuel gas plant	406	403	380	559	535	463	461		
Combined cycle	460	457	453	494	508	472	414		
Balance of plant	186	184	173	75	70	100	264		
Total field cost	**1,209**	**1,186**	**1,146**	**1,359**	**1,326**	**1,181**	**1,293**	**0**	**0**
Engineering	121	119	115	129	127	146	129		
Total contingency	160	157	151	179	174	159	171		
Total plant cost	**1,490**	**1,462**	**1,412**	**1,667**	**1,627**	**1,486**	**1,593**	**1,461**	**1,416**
Total capital requirement calculation, $/kW									
Total plant cost	1,490	1,462	1,412	1,667	1,627	1,486	1,593	1,461	1,416
Total cash expended (mixed yr $)	1,432	1,404	1,357	1,602	1,564	1,428	1,530	1,404	1,360
AFUDC	156	153	148	175	171	156	167	153	149
Total plant investment	**1,588**	**1,557**	**1,505**	**1,777**	**1,735**	**1,584**	**1,697**	**1,557**	**1,509**
Owner's costs	80	78	78	87	85	80	84	82	80
Total capital requirement	**1,668**	**1,635**	**1,583**	**1,864**	**1,820**	**1,664**	**1,781**	**1,639**	**1,589**
Operators per shift	20	20	20	20	20	14	24	20	20
Fixed O&M, $/kW-yr	46	45	44	53	52	39	46	42	40
Variable O&M, mills/kWh	1	1	1	1	1	1	1	1	1
Economic bases/parameters									
Carrying charge (constant $)	0	0	0	0	0	0	0	0	0
Coal real escalation per year, %	0	0	0	0	0	0	0	0	0
Coal levelization factor (constant $)	1	1	1	1	1	1	1	1	1
Capacity factor, %	85	85	85	85	85	85	85	85	85
Cost-of-electricity calculation, mills/kWh									
Capital charge	23	23	22	26	25	23	25	23	22
O&M	6	6	6	8	7	5	6	6	6
Fuel	12	12	13	13	13	12	13	15	15
Levelized cost-of-electricity	**42**	**41**	**42**	**48**	**46**	**41**	**45**	**45**	**43**

NOTE: Numbers may not appear to add due to rounding.

The actual amount will be determined by the government's ability and willingness to provide funds from internal resources or by guaranteeing loans for financing an equivalent conventional power facility plus a portion of the differential increased cost of IGCC. Equity participation by vendors, project developers, or other overseas investors will be encouraged.

Based on first-time costs and risks associated with a new technology such as IGCC, public financing is the most viable approach to securing funds to showcase the project. Public sources follow a broader set of criteria (benefits) in considering funding requests. These include the development priority of the host country, the potential for technology transfer, and the achievement of environmental goals. Commercial financing, in contrast, focuses more narrowly on the creditworthiness of the borrower in the case of general credits, or revenue stream of the project in the case of project financing, and is more sensitive to the issue of risk. Commercial financing may be possible if the technology supplier/vendor is willing to accept the technical risks associated with the project as well as contribute equity to the project. Table 8 summarizes financing options.

Projects in China face economic and legal constraints that contribute to difficulties when developing business ventures involving overseas investors. To solve these difficulties,the Chinese government has been taking measures, such as simplifying procedures for approving projects, enforcing tax laws and contract laws, and supervising the enforcement of intellectual property protection. In 1994 China took an important step for improving currency convertability by eliminating the dual exchange rate system.

U.S. EXIM Bank

The U.S. EXIM Bank is very active in providing financial support for the export of U.S.-based technologies, manufactured goods, and services to China. The EXIM Bank provides short-term, near-term, and long-term insurance, loans, and loan guarantees for U.S. exports to China. Over $3 billion have been invested in U.S. exports since inception of the EXIM Bank's programs in China in 1981.

For fiscal year 1994, China was the largest market in Asia for the EXIM Bank, with $1.3 billion in loan guarantees and insurance authorizations issued in support of U.S. exports. These commitments have supported transactions representing U.S. exports to various sectors, including energy, telecommunications, manufacturing, transportation, and petrochemicals. The EXIM Bank's largest commitments and exposure are with financial institutions in China, including the Bank of the People's Republic of China, Construction Bank of China,and the People's Republic of China International Trust and Investment Corporation. The EXIM Bank is also developing relationships with several of China's independent trust and investment corporations that have not been given China's full faith and credit backing.

In February 1995, an expression of interest was issued by the EXIM Bank for a $150-million loan to support the commercial demonstration of IGCC technology in China. This expression of interest is the first step to obtaining a bank loan. The loan will be placed at terms competitive with any other country's export credit and provides additional benefits for environmental technology (for which IGCC qualifies) of lower basis points on interest rates and coverage of a percentage of "on-the-ground" costs of the project.

Table 8. Finance Options

	Public Financing		Commercial Financing	
	Multilateral	**Bilateral Assistance**	**General Credit**	**Project Finance**
Form of finance	Grants, concessional loans, guarantees	Grants, concessional loans, guarantees	Commercial loans, equity, export credits, guarantees, export insurance	Commercial loans, equity, export credits, guarantees, export insurance
Key requirements	Host government development priority; environmental, social & economic benefits	Host government development priority; meets donor government goals, such as export promotion/sovereign guarantee	Bankable project, sovereign guarantee from host government	Cash flow of project, favorable risk/reward structure, limited risk and high return on equity
Technology	Proven & experimental	Proven & experimental	Proven	Proven
Ownership	Public/private	Public/private	Public or private	Private (Build-own-operate, build-own-transfer structure)
Risk	Accept risk	Accept risk	Risk adverse	Highly risk adverse
Sources of finance	GEF, World Bank, Asian Development Bank	U.S. DOE, U.S. EPA, Japan Green Aid Plan	U.S. EXIM, commercial banks, private investors, investment funds	U.S. EXIM, IFC, commercial banks, private investors, investment funds

Gobal Environment Facility Funding

Coal gasification is a technology that is eligible for funding through the Global Environment Facility (GEF). The maximum amount of funding that can be obtained through this facility has been $25 million; however, this maximum is expected to be increased to $50 mllion. The actual amount that can be obtained will depend on the priority that the Chinese government places on the project and the cost-effectiveness of the technology in terms of CO_2 reduction. The GEF favors projects with a CO_2 reduction cost of less than $25 of GEF assistance per ton of CO_2 reduced. China has identified IGCC as a candidate technology for GEF CO_2 abatement program initiatives directed toward the reduction of global warming gas emissions.

Task IV - Status of Hot Gas Cleanup Technology Development in the United States

Commercialization of IGCC systems depends upon reducing capital and operating costs. This is achieved through the development of more projects and advances in the component technology. One advance having an important impact is a gas turbine that utilizes higher inlet temperature, and thus is more efficient. Another technology advance that could improve the economics of IGCC is high-temperature (427-538 °C) gas cleanup encompassing particulate removal and desulfurization. The advantage of high-temperature cleanup is that the overall thermal efficiency of the IGCC system could increase by about 1-2 percent over the current conventional cleanup systems.

Two different approaches to high-temperature gas cleanup technologies will be demonstrated under the U.S. DOE Clean Coal Technology Program in the Tampa Electric and the Piñon Pine IGCC projects. These projects are scheduled to start up in late-1996. Based upon the performance of the technology in these projects, a determination will be made of commercial viability.

A report was provided to China by the U.S. DOE Morgantown Energy Technology Center on the status of the development of hot gas cleanup technology in the United States; the report identifies the operating parameters that have to be proven at the Tampa Electric IGCC demonstration project prior to commercial acceptance.

Task V - IGCC Equipment Considerations

The EPRI TAG was initially used to develop equipment lists for the 200-MWe and 400-MWe IGCC cases. These equipment lists were supplemented with additional information available from U.S.-based equipment vendors and Chinese sources. It was estimated that over $150 million of exported equipment may need to be imported for a China-based IGCC project.

IV. CHINESE ACTIVITIES TO DEVELOP AN IGCC PROJECT

Presented below are summaries of 1994 and 1995 activities and summaries of the technological feasibility study and engineering prefeasibility study completed in 1994.

Summary of Activities Conducted

- On April 12, 1994, China SSTC and the U.S. DOE signed Annex IX for Cooperation in the Area of Clean Coal Technology Utilization to the Protocol in the Field of Fossil Energy Research and Development.

- On April 26, 1994, a preparatory meeting of a steering group for the IGCC demonstration project was held by the SSTC to discuss the establishment of an expert group, a project office, and a working plan.

- On May 12, 1994, the steering group for the IGCC demonstration project held the first meeting. The group determined the objectives and tasks of the first IGCC demonstration power plant project with a capacity of 200-400 MWe, a net efficiency of more than 42 percent, excellent environmental performance, and which is planned to be built by the year 2000. An organizational structure for the project was set up with the steering group composed of representatives of three commissions (State Science and Technology Commission, State Planning Commission, and State Economic and Trade Commission) and three ministries (Ministry of Electric Power, Ministry of Machinery Industry, and Ministry of Coal Industry). A project office and expert group were formally established. According to the working plan drafted, the prefeasibility study was scheduled for completion in 1994. The Thermal Power Research Institute of the Ministry of Electric Power was selected to be the leader for the project and responsible for this work.

- From April 30 through May 8, 1994, a U.S. DOE delegation of three people visited China and discussed issues relating to cooperation on the demonstration project. Chinese representatives introduced the project's objectives, organization, contents of the prefeasibility study, working schedule, procedure of approval for engineering projects involving electric power, relevant laws and policies, and so on. The U.S. representatives presented the development of IGCC technology in the United States and the available options, legal requirements, and restrictions in the United States for supporting funding of China's IGCC project. The responsibilities and obligations of both sides were discussed and a memorandum was signed.

- From June 2 through June 6, 1994, the first meeting of the expert group was held in Beijing and a research group to address the prefeasibility study was established. Experts from 11 different Chinese organizations (institutes, universities, companies) were invited to participate in this project.

- From July 18 through August 6, 1994, China's delegation of IGCC experts visited the United States where they took part in a seminar of Sino-U.S. IGCC technology held by Tulane University and toured more than 10 companies and institutes associated with coal gasification, gas turbine manufacturing, engineering design, energy research, and IGCC demonstration power plants. During this study tour, the delegation acquired knowledge of IGCC technology in the United States and the prospects for its future development. The delegation also held in-depth discussions with U.S. experts concerning technical and economic issues.

- From June through November 1994, experts of the research group performed and finished the technological feasibility study and the engineering prefeasibility study of the IGCC demonstration project. During July 13-17, members of the expert group and the research group discussed the framework for an initial report and selected the following major subjects for inclusion:

  - Comparison of various clean coal power generation technologies
  - Selection of coal and site for the demonstration project
  - Comparison of options for IGCC thermal system and selection of equipment
  - Preliminary analysis of the economic benefit of the IGCC demonstration project
  - Considerations for key and heavy equipment to be manufactured in China

  From August through November, based on results of the U.S. study tour and the technical information provided by foreign companies, the research group did a more in-depth study, enriched the contents of the initial report, and finished two other reports:

  - Technological feasibility study report for China's IGCC demonstration project
  - Engineering prefeasibility study report for China's IGCC demonstration project

- From November 29 through December 5, 1994, a technical seminar attended by Chinese and U.S. officials and experts was held in Beijing and addressed the prefeasibility study for China's IGCC demonstration project. Chinese representatives presented the results of an analysis and verification of developing IGCC power generation technology in China and an analysis of the preliminary plan for the IGCC demonstration plant. In addition, the engineering prefeasibility study of the project was presented. U.S. representatives demonstrated a computer model that was used to determine power plant economics, such as investment, capital cost, cost of electricity; the model was run with the data for a Chinese IGCC project. U.S. representatives also explained that in the budget process for fiscal year 1995 the U.S. Congress did not approve the $50-million funding proposed by the U.S. DOE for the Chinese IGCC project.

- During 1995, China's SSTC and Ministry of Electric Power (MEP) managed and coordinated a national-levl review of the prefeasibility study of an IGCC demonstration project. The Electric Power Design Institute of North China continued discussions with Texaco on U.S./China cooperation and technology development. Activities also included preparations for the engineering prefeasibility study of an IGCC demonstration plant. Also during the year the U.S. DOE and Texaco representatives traveled to China and discussed issues relating to cooperation on the IGCC demonstration plant with staff of the SSTC and MEP.

Essentials of the Technological Feasibility Study

In late-1994, the research group completed a study of the technological feasibility of an IGCC demonstration project in China. Results of the study are summarized in this section.

Electric power production is one of the basic industries of China's national economy, and the current coal-based power generation technology available in China cannot meet the demand of the next century's development. Environmental impact will be a key factor in restricting development of the electric power industry, so promoting the use of clean coal power generation technology having higher efficiency and lower emissions is especially important for China.

Three main coal-fired power generation technologies -- pulverized-coal-fired steam cycle system, pressurized fluidized-bed combustion combined cycle, and integrated coal gasification combined cycle -- were analyzed and compared for their maturity, performance, difficulties, economics, and other characteristics. It was concluded that all of the coal-fired power generation technologies could be applied suitably at different periods and in specific situations; but IGCC technology is the most attractive option in the 21st century because it integrates so many advantages, such as higher efficiency, cleanness, recovery of wastes, multiproduct generation, and water savings. There is good potential to improve IGCC technology's net efficiency and to reduce manufacturing costs. This technology can also meet the demands of a coordinated and sustained development of China's resources, economy, and environment in the 21st century. Therefore, developing IGCC is considered to be of major significance for China's electric power industry, and thus, priority has been placed on building an IGCC demonstration plant and promoting deployment of IGCC technology.

China has a good team of experts who have followed and studied IGCC technology, including coal gasification, syngas cleanup, and combined-cycle power systems, and who have practical experience with power plant operation and maintenance. Moreover, China has a large number of experienced power plant design engineers, as well as capabilities in manufacturing the major IGCC equipment components (e.g., gasifier, steam turbine, and portions of heat recovery steam generator, and air separation equipment, etc.). This expertise will benefit China in the design, construction, and operation of the IGCC demonstration plant.

The desired capacity of the IGCC demonstration plant was determined to be 200 MWe or 400 MWe, based on consideration of factors such as conforming to the demand of the electric network, practicality, prospects for future development, and technical and economic performance.

Because entrained flow gasification is the most proven technology for single unit, large capacity (greater than 2,000-ton-per-day) applications, it has become the technology of choice for large IGCC demonstration power plants. The entrained flow gasifier was chosen after more than 10 gasifiers based on three technologies (fixed bed, fluidized bed, and entrained flow bed) were analyzed and compared. The major candidates are the Texaco and Destec entrained flow gasifiers, which are oxygen blown and slurry fed, and the Prenflo and Shell gasifiers, which are oxygen blown and dry pulverized-coal fed.

An integrated air separation system can be used to increase IGCC plant efficiency. However, this system may have some difficulties in plant operation. Therefore, it will be appropriate to select independent or semi-independent air separation systems for China's first demonstration plant.

Hot gas cleanup technology is being researched intensively abroad but is still being tested and remains in the demonstration stage. China's first IGCC demonstration plant is expected to adopt the mature, lower temperature cleanup technology for its syngas cleanup system. However, an interface for performing higher temperature cleanup testing should be included in the IGCC plant design.

For the demonstration plant with a capacity of 200 MWe or 400 MWe, the most applicable types of gas turbines are as follows: 9FA, 6FA, 9E by the United States; V94.3 by Germany; GT13E2 by Switzerland; and 701F by Japan. In order to make plant efficiency higher, the corresponding heat recovery steam generator and steam turbine should be designed with a two-pressure or three-pressure reheat system which has been proven.

How much of the sensible heat in the syngas that is recovered has a direct effect on overall efficiency, investment, and complexity of the IGCC plant. Therefore, the optimum efficiency achievable using IGCC must be pursued with a comprehensive technical and economic assessment to be finalized when the system is designed. It is important to consider heat recovery and efficiency trade-offs, rather than just maximizing efficiency performance.

The IGCC plant to be built in China would be designed to demonstrate the new technology and show its commercial value. System matching and selection of equipment and process configuration should favor advanced, proven, and reliable technology. A balance between plant investment and efficiency also needs to be considered in order to achieve the most optimal economic benefit.

After a preliminary screening, nine different options were selected and analyzed carefully. Of these, five options based on Texaco, Destec, Prenflo, and Shell technologies were determined to be worthy of further analysis based on considerations for technical sophistication, economics, and maturity. Plant efficiency for these five options is between 41 and 45 percent.

A site near Beijing was selected for the first IGCC demonstration power plant to enable institutes and companies of the whole nation to work together easily. This location would be conducive to international cooperation. Preliminary investigation of two sites in the Liang Xiang area of Beijing showed that the geological condition, transportation, water resources, and other factors could meet the requirements of the plant. After screening available coals from North China, coal from the Mei Yu Kou Mine in Datong was selected as the design coal and coal from the Yan Bei Mine as the testing coal. These two coals have good properties for gasification. However, because these coals have low sulfur content, the full capabilities of IGCC will not be utilized.

According to available data and the investment estimated by foreign companies, the IGCC plant to be built in China with part of its equipment manufactured domestically would have a cost of around $950-1,100 per kilowatt, based on Texaco or Destec gasification technology, and $1,275-1,500 per kilowatt, based on Prenflo or Shell gasification technology.

To build this demonstration plant, funds would be raised from several sources with risks shared among investors. Financing support by foreign governments and international organizations, investments from companies abroad, and loans having favorable terms should be pursued.

To accelerate the development of IGCC technology and the relevant manufacturing industries in China, international cooperation should be fully utilized and cooperative activities carried out for developing IGCC technology. Key technologies and equipment would need to be imported, with the remaining equipment and materials manufactured in China. In some cases, a foreign company may supply equipment, portions of which should be manufactured in China under subcontract (including some design and software imported). This type of joint effort would decrease the cost of power plant construction and reduce the cost of future plants through increased domestic manufacturing when economically feasible.

Engineering Prefeasibility Study

The U.S. DOE input to the engineering prefeasibility study for China's IGCC demonstration project was completed in late-1994. The work emphasized conditions for building the plant, comparison and selection of technology and systems, and investment and economic analysis.

Choosing a site for the IGCC demonstration plant was performed by considering the plans of the electric power industry, the distribution of power plants in a network, and the importance of demonstration. The Electric Power Design Institute of North China drafted a report for the engineering prefeasibility study which contains results of the overall investigation and comparisons regarding the site's natural conditions, water resources, ash yard, communication, transportation, environmental protection, and other characteristics.

The selected site, about 1 square kilometer in area, is located in a southwest suburb of Beijing, 30 kilometers away from the city center. The distance between the connecting railway station and the site is 1 kilometer. It is also convenient for highway transportation. The water for the plant is available from deep wells; the ash yard is nearby. The preliminary analysis indicates that geological conditions of the site and the ash yard conform to the engineering project standards.

Following the normal procedures of an engineering project, concerned departments of the local government issued a letter of intent approving the site, land usage of the ash yard, and water usage, and a permit to build the demonstration plant was authorized by the local bureau of environmental protection.

Comparison and selection of the technology and configuration for the IGCC demonstration project are based on state-of-the-art technologies available worldwide. The report presents the results of an analysis of the characteristics of different technologies and systems from the United States, Europe, and other countries and a comparison of parameters of various components. Furthermore, the report contains a discussion of the application and prospects of high-temperature cleanup and desulfurization. All this information provides a scientific basis for the selected technology and system for the next stage of the feasibility study.

The IGCC technology is progressing toward maturity and has obvious advantages over conventional coal-fired power generation. Thus, a significant part of the prefeasibility study was an analysis of investment and economic benefits of an IGCC plant, comparing these benefits with those of a conventional coal-fired plant. Future market and development potential also must be considered.

The Electric Power Design Institute of North China, which is experienced in designing power plants, has finished a cost estimation and a benefit assessment for the IGCC demonstration project after conducting technical exchanges and cooperation with foreign companies and analyzing the application and diffusion of IGCC in China.

V. FUTURE WORK

Activities planned for 1996 and beyond are summarized below.

IGCC Activities

The U.S. DOE has received funds from EPA to conduct the following activities in conjunction with U.S. industry and China to support the development of IGCC in China:

- Task 1 - Engineering Study to Quantify the Investment -- Cost/Fuel Efficiency Trade-Offs of Different Configurations. The deliverable of this task will be a report quantifying the cost/efficiency trade-offs of various configuration options, with a recommendation for the most cost-effective option. Plans include U.S. industry funding for this task.

- Task 2 - Study to Identify Potential Equipment Manufacturing Capabilities for IGCC Components within China as the Basis for U.S. Competitiveness. The deliverable of this task will be a report identifying the capabilities of the Chinese to fabricate/manufacture specific IGCC equipment and set a benchmark for U.S. manufacturers to focus their ability on to compete on a cost-effective basis. Plans include U.S. industry funding for this task.

- Task 3 - Identification of Financing Sources and Requirements for Chinese-Based IGCC Projects. The deliverable for this task will be a financial plan identifying sources of funds to be used for an IGCC project and requirements and restrictions associated with project funding. Plans include U.S. industry funding.

- Task 4 - Environmental Benefits Quantification Study. The deliverable for this task will be the results of a trade-off analysis of increased IGCC capital and operating costs as offset by the reduction of the cost of environmental impacts of current power generation technology practices in China.

- Task 5 - Workshops and Training. A workshop and training program will be conducted in the United States for Chinese representatives. IGCC projects will start operation in the United States in 1995. The delegation will visit these facilities for technology workshops and will participate in a training program with U.S. industry.

- Task 6 - Joint Expert Working Group Report for IGCC. Meetings of the Expert Working Group for IGCC were held in 1995 to determine the potential benefits of IGCC for China. A team of experts in IGCC was identified; it includes both U.S. and Chinese individuals representing the different interest groups associated with IGCC technology development and commercialization. The participants of the Expert Working Group include governmental, industrial, and academic representatives renown in the field of IGCC. This effort will be led by President Zhou Guangzhao of the Chinese Academy of Science (CAS). CAS will provide the final report to China's State Council, including the commissions and ministries, as well as relevant environmental agencies. Simultaneously, the U.S. DOE will provide the final report to the relevant U.S. government departments and institutions.

The Expert Working Group had its first meeting in Beijing during the November 29 to December 6, 1995, time frame. Ten topical areas were addressed, reflecting five points of discussion for the Chinese and five points of discussion for the U.S. participants. These ten areas will form the basis for the structure of the group's report.

Chinese experts will develop the following five themes:

- Outlooks and prospects for the demand of energy and electrical power in China based on current economic development and improvement
- Current technical status on coal utilization in China and the exploration of clean coal technology applications
- The current status in China of coal-fired power generation and environmental pollution
- Gasification as a clean coal technology; experience of coal gasification accumulated in China's chemical industry that can be transferred to power generation
- IGCC as an efficient clean coal technology for power generation in China and an estimation of its potential market in China

U.S. experts will contribute material addressing the following five areas:

- Overview of U.S. clean coal technology with special emphasis on the experience and trend of U.S. IGCC technology
- Strategy and goal for global commercialization of U.S. IGCC technology
- Short-term demand and long-term projection of market potential in China for U.S. IGCC technology
- The potential impact and benefits of U.S. IGCC technology in China on global environment
- U.S. utility perspective of IGCC technology for the generation of electric power and steam

U.S./China Energy and Environmental Technology Center

The concept of the U.S./China Energy and Environmental Technology Center was developed during the July 1994 U.S./China IGCC Seminar at Tulane University. Subsequently, Tsinghua University, under the direction of SSTC, submitted proposals to Tulane University. In August 1994, Tulane University submitted an unsolicited proposal to U.S. DOE; this action was the basis for a proposal submitted to the U.S. EPA for funding under the Environmental Technology Initiative Program. In September 1995, EPA awarded U.S. DOE funding to establish the center for the following purposes:

- Identification of opportunities for trade and export of technology and services
- Education and training

- Assistance in policy development
- Development of joint research and development efforts

Several rounds of meetings have been held between the main parties: SSTC, Tsinghua University, U.S. DOE, and Tulane University. Cost-sharing contributions agreed upon were 70 percent U.S. and 30 percent China. The U.S. funds are provided by government agencies, such as EPA and U.S. DOE, as well as universities and industry.

Several projects, including a binational electronic information system that would serve as a "one-stop shopping center," are under development. A U.S. mission to China for coal technologies is being planned for June 1996 in conjunction with the center.

Joint R&D Activities

SSTC under Annex IX has provided proposals to undertake projects with the U.S. DOE in the following areas:

- Fluidized-bed combustion
- Mild gasification
- Coal upgrade with minimal water use
- SO_2 removal and control
- Production of liquid fuels and chemicals from coal

These proposed activities are currently being evaluated for joint participation by the U.S. DOE and other U.S. participants.

VI. CONCLUSION

During the period ending December 1995, the joint U.S. DOE/SSTC team has made substantial progress in developing the tools necessary for China to demonstrate the technical and financial suitability of a China-based IGCC power plant. This joint activity has resulted in a number of mutual benefits, including the development of the TLCC model for screening of candidate power plant technologies for implementation in China and an understanding of the costs involved in building an IGCC project in China. These activities have also resulted in developing a strong multifunctional U.S./China team capable of addressing complex bilateral energy issues.

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