I. EXECUTIVE SUMMARY

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Abstracts

Integrated Coal Gasification Combined Cycle (IGCC) is the most clean, most efficient and most mature technology among currently available clean coal power generation technologies. It is also an affordable advanced technology for China. In order to secure the safety and diversity of energy supply, industrialized nations continually invest personnel and material resources to develop and improve IGCC technology and cost in order for them to be competitive with the low natural gas prices and combined-cycle power systems. This competitive advantage of natural gas with the combined-cycle does not exist in China. IGCC is a unique advanced clean coal technology, specifically developed for nations with abundant coal which must be utilized with high efficiency and low pollution characteristics. It is a much more environmentally friendly technology than any of the other coal-based power generation technologies and contributes to the reduction of global emissions and improvement of air quality. Construction and operation of a commercial-sized IGCC demonstration plant in China will provide the know-how and first-hand information for future broader applications in the 21st century.

Realizing the strategic goals of economic development, reform and opening, China's 21st Century Agenda, 9th Five-Years Plan, and energy development, China has established a three commissions and three ministeries leading group and an IGCC expert group to accelerate the IGCC demonstration project based on the large available Chinese coal reserves. Pre-feasibility study and engineering study for the 200 – 400 MW IGCC demonstration power plant have been completed. The object is to construct an IGCC demonstration power plant mainly by introducing foreign advanced technology to China in the year 2000.

Introduction

This US – PRC Expert's Report on Integrated Gasification Combined – Cycle Technology (IGCC) presents, by means of a series of papers, each of them authored by one or more of the IGCC experts, the history, present-day situation, and probable future development of the Chinese economy and, more particularly, of the Chinese energy and electric power generation industries.

The rapid development of the Chinese economy and the reasons for it, the present situation of the electric generation industry in terms of fuels, efficiency, capacity, environmental impact, rate of growth and probable future developments are examined in detail. Also, the clean coal technology advances that have been recently made in the US and the advantages to be had by China if these technologies are included in China's electric generation industry, as well as the large potential market for advanced technologies presented by the anticipated rapid expansion of China's electric generation industry is discussed.

This report illustrates that there may now be a confluence between China's requirements and a desire in the US to propagate the clean coal technologies throughout the world. This confluence of interests and motives between China and the US has all of the elements of a classical **"win – win"** situation.

(1) Coal is China's Major Energy Resource

Coal constitutes 90 percent of total fossil energy resources in China, where oil and natural gas resources are relatively small. In order to meet the demands for energy as the national economy experiences rapid growth, the proportion of coal in primary energy production will remain at or near its present level of 70 percent for the next 30-50 years. A large part of the balance of about 30 percent is provided by hydropower.

Energy production in China has grown rapidly. Between1949 and 1993, the annual production of raw coal increased from 32 million tons (Mt) to 1,149.7 Mt; that of crude oil from 120 thousand tons (Kt) to 145.2 Mt; and natural gas grew from 7 million cubic meters to 16.95 billion cubic meters. Total production of primary energy reached 1,112.63 million tons of coal equivalent (Mtce) – ranked the third in the world. The average annual growth rate of overall energy production is 9.1 percent.

(2) Chinese Coal Resources, Production, and Application

Coal resources in China amount to about one trillion tons, of which 30 percent are proven reserves. Eighty percent of China's coal lies in the north and northwest. All ranks of coal exist in China, from lignite at the low end to high-rank anthracite. According to recent statistics, lignite constitutes 13 percent of the total, subbituminous and bituminous 75 percent, and anthracite 12 percent.

Coal has been extensively used in every sector of China's economy. In the power industry sector, 76 percent of the total power output was generated by coal, and this accounted for 30 percent of the total annual coal production. In the other industry sectors, coal provided about 75 percent of energy used as fuel and power and this totaled another 33 percent of annual coal production. Coal was the source of 60 percent of the raw materials for the chemical fertilizer industry sector. Coal constituted 80 percent of the fuel consumed in the domestic household sector, which amounted to 20 percent of China's annual coal production. Another 8 percent of the annual coal production was used in the metallurgical industry sector, mainly for coking purposes and for power supply.

(3) China's Electric Power Generation is Based on Coal

Coal is the most plentiful of China's verified primary energy reserves. It accounts for about 75 percent of the fuel for thermal electric power generation.

The Chinese electricity industry has made great progress since economic reformation and open. In 1980, the installed capacity was only 65,870 MW, and annual power generation was only 300.6 billion kWh. By year-end 1995, the total installed capacity had risen to 210,000 MW (162,900 MW thermal) and annual power generation was 1000 billion kWh (780 billion kWh from coal). New capacity installation will be at the rate of about 16,000 MW per year during the "ninth 5 years plan" between 1996 and 2000. By the end of the year 2000, the installed capacity is expected to reach 300,000 MW (227,900 MW thermal) and annual generation is expected to be 1,400 billion kWh (1,130 billion kWh thermal). This means that at the end of the year 2000, China will have increased its power capacity and annual production to four times those of 1980.

China's average coal-fired power generation efficiency is currently about 30 percent LHV. This equates to an average coal consumption rate of 410 g/kWh. During the "ninth 5 years plan," new units will be over 300 MW in size and will utilize high-efficiency technologies. This will improve

the average efficiency and coal consumption rates to 32 percent LHV and 380 g/kWh, respectively, by the end of the year 2000. The average efficiency and coal consumption rates are expected to be 34 percent LHV and 360 g/kWh, respectively, at the end of the year 2010.

Based on the above estimates, coal-fired power generation consumed about 325 million tons of standard coal for the year 1995 and this will increase to about 430 million tons in the year 2000. At the end of year 2000, the annual SO_2 emissions from the electric power industry alone will be about 6.25 million tons if no desulfurization is done. SO_2 emission from coal-fired power generation plants is very serious, and will have serious effects on today's population and on their descendants.

(4) China Recognizes the Need for Clean Coal Technologies

Coal is China's primary source of energy, and is expected remain so over the next 30 to 50 years. The burning of coal has already caused serious environmental problems. In order to progress further, China has adopted the development and implementation of clean coal technologies as an important national policy to ensure that protection of the environment will parallel progress in energy development.

Chinese coal is relatively high in ash content, and its sulfur content increases with the depth of the mine. The environmental impacts resulting from utilization of coal are serious, in part because of the huge levels of coal output and consumption.

Only about 23 percent of all Chinese coal is washed and, for power generation, only 11.28 percent is washed. In addition to the problems created for the users, unwashed coal wastes the energy required for transportation. High ash content in coal always causes reduced coal utilization efficiency.

Particulates removal at coal-fired power plants is the most successful of the efforts that have been directed to control of environmental pollution. But there is almost no control of SO_2. In 1994, particulates amounted to 14.14 million tons and SO_2, 18.25 million tons. Shenyang, Xi'an and Beijing are listed 2nd, 7th and 8th, respectively, in a UN report on cities of the world with the highest airborne SO_2. In the year 2000, China's total annual SO_2 emissions may reach 30 million tons without adoption of any SO_2 control technology such as IGCC power plants. Rapid national economic growth and quick energy and electric power growth are good and desirable, but not at the expense of air and water pollution, and destruction of the value of land.

China's coal utilization efficiency is still low compared with advanced countries. Industrial furnaces are 10 percent lower and industrial boilers are 15-20 percent lower. The national average thermal efficiency of coal-fired power plants is 30 percent LHV and the specific coal consumption rate is 30 percent higher than in developed countries. Under the current China 5 Years Plan, the improvement of total thermal efficiencies for the electric power industry means the reduction of airborne emissions. Therefore, 33,000 MW of low-efficiency, smaller units will be retired and replaced by high-efficiency, larger coal-fired units; 40,000 MW of existing, old coal-fired units will be refurbished; and 60,000 MW of new coal-fired power plants will be constructed.

IGCC technology has proven its ability to solve most of China's power generation problems at costs that are comparable with those of conventional, PC-fired power plants, and it has great promise for continuing reductions in first-cost relative to other technologies. Adoption of IGCC for new facilities and for repowering of facilities that are appropriate candidates for it would result in efficiencies that are today as good or better than the best-performing conventional technologies, environmental performance that is vastly superior to conventional technology and very good potential for continuing reductions in specific cost.

(5) China Should Develop and Deploy IGCC Technology to Maintain Progress in Economics and Environmental Improvement.

China has considerable experience with coal gasification, and presently has large number of gasifiers producing feedstock streams for chemical and fertilizer manufacturing plants. There are also numerous combined-cycle units generating electricity in coastal areas. But these two technologies have never yet been combined in China to produce an IGCC unit.

Of the world's emerging coal-firing technologies applicable to the commercial-scale generation of electric power, IGCC is the most mature, efficient, the most environmentally sound and cost-competitive.

In terms of maturity, there are at least 5 IGCC units between 250 and 300 MW either under construction or operating in the US and Europe in 1996.

Current IGCC plant efficiency is at least 10 percent better than all coal-fired, conventional power plants currently under construction. Fifty percent thermal efficiency will be reached with IGCC utilizing the "H" class gas turbine technology after the year 2000.

IGCC units typically prevent all of the particulates, 99 percent of the sulfur and 90 percent of the NO_x from reaching the environment. The pollution-control features are integral parts of the operating unit and are included in the overall efficiency numbers. With their inherent efficiency, IGCC units contribute correspondingly less CO_2 to the atmosphere.

The investment cost for IGCC has been comparable with current, and lower than projected, near-term, conventional PC power plant costs, and the IGCC technology has great potential for further reductions in first cost, making it even more attractive as an alternative for power generation. With its technological advantages, e.g., maturity, efficiency, and environmental cleanliness, and its cost, which is the same or less than that of current conventional PC-fired technology, it makes good sense for China to begin the introduction of new IGCC power plants and IGCC repowering of existing facilities into its electric generation system at the earliest possible date. A good first step would be the construction and operation of a single, commercial-scale, IGCC demonstration plant as soon as it can be done.

(6) Global Environmental Protection Is The Subject for Today, Not For Tomorrow.

At present, China is experiencing unprecedented expansion of its economy and requires massive additions to its electric generating capacity to sustain this growth. Over 30 GW of the existing generating capacity is so old, inefficient and/or in such poor condition that it demands near-term replacement.

The very rapid movement in China to expand the use of coal for power production presents a real concern about local and global environmental impacts. If new information on global warming confirms the importance of controlling CO_2 emissions, this impact could be even more dramatic. Chinese power plants do not have even the most rudimentary pollution control devices for controlling SO_2, NO_x, or particulates, all of which are common in most developed countries. Therefore, whatever China does in the future concerning coal burning power plants will have a global impact.

China's energy consumption, dominated by coal, has resulted in serious air pollution, including urban particulates, acid rain area expansion and large CO_2 emissions. In northern China, particulate concentrations are 4-6 times higher than the maximum permissable level declared by the World Health Organization. In one-fourth of the cities in north China the SO_2 emissions are three times the national standard. China is the third largest CO_2 emission country in the world as a result of coal combustion for energy. With the increase of energy consumption, particularly the

increase of coal utilization, pollution from energy will further increase in the future. A series of policies and regulations have been promulgated to alleviate this condition including strategies to use clean coal technologies. Of these technologies, IGCC is the least polluting.

(7) The US is Leading the World in Clean Coal Technologies.

The United States clearly is leading the world in terms of Clean Coal Technologies. During the 1970s, the U.S. was faced with 2 oil embargoes which led to rapidly advancing motor fuel costs and a feeling of national unrest when the extent of America's dependence upon middle-eastern oil became widely known. Today, largely as a result of these experiences, many of the options in terms of gasification technologies available in the world are American, e.g., Texaco, Destec, KRW, etc.

The U.S., like China, has relatively large reserves of coal, and a significant industry is built upon coal. So persistant is the desire to utilize coal in the U.S. that, even today in an era of near economic parity between coal and other fuel forms in the U.S., e.g., natural gas, power plants employing IGCC are being built and operated at the commercial scale.

The combined-cycle portion of the IGCC is based upon the gas turbine. The U.S. has been the clear leader in development of gas turbine technology for many years. Commercial aviation blossomed early in the U.S. From the mid-1950s, turbine-powered aircraft became the mainstay of America's large commercial air fleet. The development of industrial turbines has benefitted directly from this wide aviation experience, to the point where now, industrial turbines are able to employ ever higher firing temperatures, resulting in ever-increasing efficiencies. Several significant manufacturers of industrial turbines — used in IGCC facilities — are in the U.S., among them GE and Westinghouse.

In the mid-1980s, the U.S. government, in response to environmental concerns, kicked-off the Clean Coal Technology (CCT) demonstration program to be funded to several billions of dollars over several years, and to be administered by the U.S. Department of Energy. The CCT program provided financial support for innovative applications of technology aimed at utilizing coal more efficiently. Now nearing its conclusion, the CCT program can boast many commercial-scale power plants to its credit, among them Tampa Electric's Polk Power Station, the Wabash River project, Piñon Pine, and others.

The U.S. Department of Energy, in addition to its own in-house efforts, continues to fund private

research into energy-related matters through cooperative agreements, fellowships, etc.

(8) Commercialization of the IGCC Technology Is One of the US Significant Contribution to World Energy and Environmental Improvements.

In addition to its abundant coal, the US also has large quantities of natural gas and oil, which tends to make these materials relatively less expensive compared to coal than is the case in China. In spite of this, the U.S. has moved ahead in the development and commercialization of coal conversion technologies, most notably IGCC technologies. The cost of IGCC per kilowatt-hour of capacity is rapidly dropping as more units are built and placed into operation but, in the U.S. today it is unquestionably less expensive to build and operate a natural-gas fired, combined-cycle generating plant than to build and operate an IGCC. This is because of the large amount of additional equipment required to control the NO_x, SO_2, dust ash, etc., generated by the processing of coal into clean energy.

There are few places in the world in which the ratio of costs between the available fuels is less favorable to coal than in the U.S., yet it continues to be the world leader in commercializing the clean coal technologies, such as IGCC.

Perhaps uniquely, the U.S. has a memory of the oil embargoes of the 1970s, and the national vulnerability represented by its reliance on OPEC to continue to provide over one-half of the U.Ss' daily crude oil requirements. Further, the U.S. coal industry directly and indirectly employs many Americans and pays a lot of taxes. Also, the U.S. has so much coal available that it simply cannot be bypassed in favor of other fuels.

The U.S. is home to the sponsors of several gasification technologies, such as Texaco, Destec, KRW, etc., and these companies aggressively market these systems on a commercial basis. These efforts have not been without success since, quite apart from the DOE's Clean Coal Technology, sales have been made, both in the U.S. and elsewhere.

(9) Fast growth rates of the Chinese electric power industry provide a vast potential market for applying US IGCC technology.

The installed generation capacity in China was 210 GW in 1995, over 70 percent of it thermal and the balance hydro power. Most of the thermal generation now consists of conventional steam power plants burning coal. It is expected that nearly 25 GW in generation capacity must be added

each year in order to reach the projected 290 GW in generation capacity around year 2000. The vast majority of the new thermal generation will be coal-fired and all coal-fired power plants to be installed will be conventional steam power plants with or without FGD under China's "Ninth 5-Year Plan". IGCC power plants will be the best choice for China based on predicted power growth rates after year 2000, if an IGCC demonstration plant can be built now.

It appears evident that the market potential for IGCC in China is substantial – particularly in the longer term (15 to 20 year horizon). The realization of this potential will depend on the availability of project financing. China and the US have taken some significant steps in collaborative efforts to initiate IGCC planning for China's power systems. However, because of project financing requirements, it appears necessary to bring into the discussion and planning process multilateral financial organizations such as the Asian Development Bank and the World Bank.

IGCC technology can be applied in China in different ways. One of the primary uses would be for the addition of totally new capacity which would begin to establish a foundation of highly efficient and environmentally clean baseload generating capacity. Another use for IGCC technology would to repower existing generating units into highly efficient and environmentally sound facilities with lower investment and extended plant life.

Progressive generation (PROGEN) refers to the ability to build a gas turbine simple-cycle power plant in small increments and change from a peaking to a mid-range combined-cycle to a base-loaded, coal-fired IGCC power plant. Because of the rapid economic growth in the Southeast China coastal areas, many simple-cycle and recently converted to combined-cycle plants can be converted into IGCC power plants for coal burning.

Most coal-fired power plants can be designed for co-generation (COGEN) operation. The IGCC power plant can be operated as a COGEN, tri-generation (TRIGEN) or poly-generation (POLYGEN) plant. The coal gasification TRIGEN plant of the Shanghai Wujing Coking and Chemical Factory is in operation to produce chemicals (methanol, acetic anhydride, and cellulose acetate), town gas, and electrical power.

(10) Construction of a US IGCC Technology Demonstration Power Plant in China will Exhibit the Economic and Social Benefits to China.

China is likely to add more than 10 GW in coal-fired generation per year both short- and long-

term. Additions of IGCC technology should start around the year 2000. Initially, current GT/CC technology should be utilized, but as operating experience on natural gas demonstrates the economies of scale to be gained from increased CC output, the transition to IGCC plants utilizing that technology should begin. The proper combustion of coal-gas in the next generation GT/CC technology is already being explored and will be completed well before the technology is applied in an IGCC plant.

Long-range IGCC penetration is likely to be strongly supported by economics. Plant costs with the next generation of IGCC technology are expected to be the same or lower than a conventional coal-steam power plant with FGD. The LHV efficiency will be about 50 percent compared to around 38 percent for the coal-steam plant, resulting in about 25 percent lower coal consumption due to the efficiency difference alone. Operations and Maintenance (O&M) costs are expected to be similar for the two options. The economics should always favor the IGCC option.

Other important IGCC features are reliability and operational characteristics, which are normally not fully accepted until a proper demonstration program has been conducted. Therefore, China must install and operate a full-scale IGCC demonstration facility as soon as feasible. As much as possible should be learned from existing commercial IGCC plants to shorten the learning curve vis-á-vis the IGCC technology. The current family of IGCC facilities incorporates different gasifier technologies and fuels. Careful monitoring of the status of these facilities should allow China to get maximum performance from their first IGCC facility. The first IGCC in China will also be an important step in the learning process for other interested countries.

Another important issue, not only for China, but for other countries as well, is the acceptance of the IGCC technology by the electric power industry. A steam boiler operator will not automatically accept the introduction of a gasifier plant as part of his operational responsibilities. Education and instruction in IGCC operation and maintenance during the full-scale demonstration phase will be an important step toward general acceptance by China's regional electric power systems.

As acceptance increases, a general shift in domestic manufacturing capability to provide suitable GTs, HRSGs and STs will be necessary. This is another factor in the pace of adoption of IGCC technology in China. Initially, a relatively high portion of foreign-sourced components may be acceptable, but optimum penetration of IGCC will require that a significant portion of the plant equipment be manufactured domestically.

II. INTRODUCTION

Background

The United States (US) Department of Energy (DOE) and the Ministry of Coal Industry (MCI) of the People's Republic of China (PRC) 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 US DOE and PRC State Science and Technology Commission (SSTC) in the area of clean coal technology (CCT) utilization.

The United States and China signed Annex IX to address the common problems of power plants and emissions resulting from the use of coal. 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 DOE CCT program.

The need to utilize the coal resources of China more efficiently and cleanly has created a market for CCT which will continue to grow in proportion to PRC economic growth in the future. The technologies of interest in the near-term (prior to 2000) will include approaches to more efficient conventional power generating systems with low-cost SO_2 and NO_x emission reduction systems. New technologies, with utilization planned for after the year 2000, are high efficiency integrated gasification combined-cycle (IGCC) power plants and others. IGCC, a new coal-based power generation technology for improving efficiency and reducing emission, is reaching maturity. IGCC is in full-scale commercialization in Europe and the United States. Presently available IGCC technology has already achieved better efficiency than conventional power generating systems, and IGCC efficiency is expected to reach 50 percent in the next century through further improvement of coal gasification and high-temperature gas turbines.

To develop higher efficiency and clean coal-based power generation technology for the 21st century, the PRC Ministry of Electric Power (MEP) has included IGCC in its mid- and long-term plan and strives to build a large-scale (200-400 MW) advanced IGCC demonstration power plant. 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.

Objective of the IGCC Experts Report

Establishment of an IGCC data base will provide information to support research and equipment development and provide the foundation for future installations in China. An IGCC leading committee composed of high-level Chinese official representatives of the SSTC, State Planning Commission (SPC), State Economic and Trade Commission (SETC), MEP, Ministry of Machinery Industry (MMI), and MCI was established to define the demonstration project.

According to the estimated economic growth rate, the demand for energy in China will increase at a rapid rate in the near future. Coal will maintain a prominent position in the energy supply for a long time to come. The means to solve the problem of burning coal with high efficiency and lower pollution is of vital importance, for it not only affects the rational utilization of energy in China but also helps protect the global environment. Preliminary engineering feasibility studies already are complete

The intention is that preparation of this report for high level decision makers by the US and PRC recognized experts in IGCC may greatly accelerate the development of the IGCC demonstration project in China. The potential market for IGCC in China and the competitiveness of IGCC with other clean coal options for China will also be analyzed in the report. Such information will be useful not only to the Chinese Government but also to the US vendors and companies. The report will be used by US technology developers and equipment vendors in assessing the potential of IGCC in China as related to equipment and systems procurement and supply.

The goal of this report is to analyze the energy supply structure of China, energy and environmental protection demand, and potential market in China in order to make a justified and reasonable assessment on the feasibility of transfer of US CCT to China. The IGCC Expert Report has been developed and written by the joint US/PRC IGCC experts and will be presented to the SPC by the President of the Chinese Academy of Sciences (CAS) to ensure the consideration of the importance of IGCC for PRC power production.

The objective of this report is to answer questions posed by the PRC regarding the commercial acceptability and acceptance of IGCC technology for the production of power in China. The report will focus on the following considerations:

1. What is the current degree of maturity, reliability, flexibility and suitability for IGCC for different kinds of coals?

2. What is the difference between the first demonstration costs, and owning and operating an IGCC plant after commercialization?

3. Why is IGCC not widely used since the U.S. successful demonstrations?

4. Why is sulfur content of coal a key criteria for the selection of IGCC when China has vast reserves of low sulfur coal (<1%S)?

5. How is turbine life affected and what are the modifications required for gas turbines firing middle Btu value coal derived gas?

IGCC Expert Meeting

As part of the justification for China to continue to pursue the demonstration of IGCC technology at a large utility scale (250 MW - 600 MW), a team of experts in IGCC was identified which includes both US and PRC individuals representing the different interest groups associated with IGCC technology development and commercialization. The participants of the IGCC Expert Meeting include government, industry and academia representatives renown in the field of IGCC and its related technologies. The IGCC Experts Meeting was held in Beijing during the November 29 to December 6, 1995 where ten topical areas were discussed. The technical materials presented reflected the ten points approach both the US and PRC suggested as the input to the jointly prepared IGCC Experts Report.

The planned agenda included technical discussions regarding the status of IGCC technology development and the potential for its demonstration and use in China for the production of power. Discussion workshops were held to review the material presented, and to provide the various points of views, issues and content of the presentations, the use and commercial readiness of IGCC, and the barriers that are perceived associated with the use of IGCC for power production in China, as well as the advantages of IGCC selection and use in meeting PRC current and future electric power needs. The IGCC Expert Report format and outline were finalized and assignments agreed upon for the US and PRC members to provide specific technical input to the jointly-developed composite report.