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The United States of America
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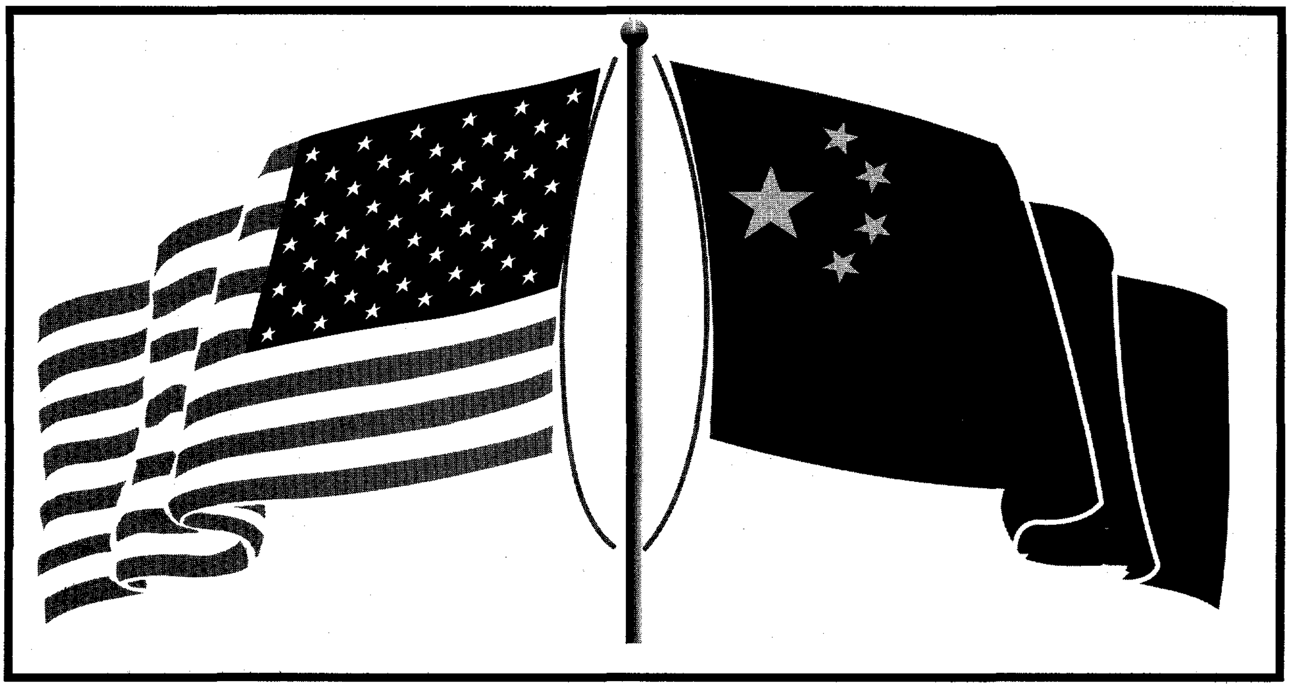
People's Republic of China
Experts Report on

Integrated Gasification Combined - Cycle Technology (IGCC)

December 1996



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Note of Appreciation

Those responsible for the final preparation and printing of this report wish to express their appreciation, and that of the entire team, to those whose vision initiated this effort and the many people in China, the United States and elsewhere who contributed to the process. Thanks to all who did the background work, who participated in the expert meetings, who contributed papers, and to those who wrote, arranged, drafted, edited and printed the report. Thanks for your efforts, the sharing of your knowledge and, most of all, for your belief in the benefits to China and to the world that will be derived through China's adoption of many of the ideas presented herein.

PREFACE

- **Opening Remarks From Professor Zhou Guangzhao, Member and President of CAS**
- **Opening Remarks From The Honorable J. Bennett Johnston, United States Senate**

CAS

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CHINESE ACADEMY OF SCIENCES

It is widely known that, with the implementation of the policy of reform and opening to the outside, China's national economy has achieved rapid development. As a basic industry in the national economy, electric power is a significant criterion in evaluating the nation's progress. With its annual growth rate of 15 GW/a, China's electric power industry has now leaped to second place in the world in terms of installed capacity.

China is a nation with coal as its main energy source. Therefore, coal-fired power plants will remain dominant in the long run. Thus, enhancing plant thermal efficiency and reducing polluting emissions will be crucial measures, contributing not only to the sustained development of the national economy but also to improvement of the world environment. Ever since the 1992 UN Conference on Environment and Development in Brazil, the Chinese government, sticking staunchly to its commitment, has stipulated with ratification, by the State Council, of China's Agenda 21, in which strategies for efficient control over air pollution and for the development of clean coal technology have been formally put forward.

Integrated Gasification Combined Cycle (IGCC), a new technology developed since the 1970's, has drawn world-wide attention for its high efficiency, lower pollution and low water requirement characteristics.

In May 1994, the Chinese government established an IGCC demonstration leading group, consisting of six government agencies: State Science and Technology Commission, State Planning Commission, State Economic and Trade Commission, the Ministry of Electric Power, the Ministry of Machinery Industry, and the Ministry of Coal Industry, which soon developed a collaboration with the Department of Energy of the United States. In order to carry out the IGCC technology as early as possible, the Chinese Academy of Sciences, together with Tulane University, USA, made a suggestion to organize concerned specialists from both countries to give an objective evaluation of the IGCC technology, thus pushing forward the development of the technology in China. The suggestion received support from PRC SSTC and the US DOE, and has been listed as a project in the Annex IX of the Sino-US fossil Energy Cooperative Agreement.

Assessing the IGCC technology by the Chinese and American specialists from different perspectives, this report points out that China is a developing country with limited economic strength but a very wide market. As a result, more attention should be paid to assimilating the imported technology, so as to reduce construction cost of the new IGCC power station by making efficient use of the existing domestic technology and construction capacity, and at the same time, providing market information for oversees enterprises who wish to extend the IGCC technology in China.

We sincerely hope that the publication of this report will provide a pragmatic analytical basis for the Chinese and American governments, related enterprises, and all those concerned with developing the IGCC technology in China.

G. Zhou

Professor Zhou Guangzhao
Member and President of the Chinese Academy of Sciences

J. BENNETT JOHNSTON
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November 20, 1996

The United States and the People's Republic of China share the need for more efficient and environmentally friendly power production technologies to help meet increasing energy demands. The Integrated Gasification Combined Cycle (IGCC) technology is a promising example--it is the cleanest and most efficient means of producing power and other products from coal. China's Agenda 21 plan identified IGCC technology as a top priority for sustainable development. The U.S. has been developing IGCC technology for the past twenty years and has become the world leader in advancing and commercializing the technology. This joint effort between the United States and China to analyze the advantages and potential for IGCC should serve as a model for future cooperative efforts to find solutions to our common environmental and energy production problems.

It gives me great pleasure, therefore, to introduce the attached report. Because of the high degree of technical and financial risk associated with the use of new technologies for production of energy, the research, development and demonstration path to commercial acceptance of new power production technology is long and arduous. The demonstrated performance of IGCC in the U.S., and its potential for helping to meet the future energy needs of China, is exciting and merits the attention and resources reflected in this joint effort. This report will be critically valuable in the assessment of IGCC's potential role in mitigating climate change resulting from CO2 emissions and will also provide insight into options for the best utilization of China's vast coal reserves. Such options might include the production, using IGCC, of chemicals, automotive, residential and industrial fuels, as well as many other coal-derived products.

The joint effort that produced this report is the result of the growing recognition that the U.S. and China have common interests and purposes in the broad area of energy and environmental technology. I trust that the project will provide a useful framework for future cooperative efforts.

J. Bennett Johnston
United States Senator

ABSTRACT

A report written by the leading U.S. and Chinese experts in Integrated Gasification Combined Cycle (IGCC) power plants, intended for high level decision makers, may greatly accelerate the development of an IGCC demonstration project in the People's Republic of China (PRC). The potential market for IGCC systems in China and the competitiveness of IGCC technology with other clean coal options for China have been analyzed in the report. Such information will be usefil not only to the Chinese Government but also to U.S. vendors and companies. The goal of this report is to analyze the energy supply structure of China, China's energy and environmental protection demand, and the potential market in China in order to make a justified and reasonable assessment on feasibility of the transfer of U.S. Clean Coal Technologies to China. The Expert Report was developed and written by the joint US/PRC IGCC experts and will be presented to the State Planning Commission (SPC) by the President of the CAS to ensure consideration of the importance of IGCC for future PRC power production.

US-PRC IGCC EXPERT REPORT

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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.

III. CHINESE FIVE IGCC EXPERTS DISCUSSION

1. **Current Status and Prospects of China's Energy and Electricity Industry**

   Professor Zhou Fengqi

2. **Coal and Clean Coal Technologies in China**

   Professor Chen Jiaren

3. **Perspective on IGCC in the Chinese Electric Power Industry**

   Senior Engineer Huo Hongxian, and Dr. Xiao Yunhan

4. **The Application of Coal Gasification Processes in China**

   Professor Fang Dewei and Professor Yu Zunhong

5. **IGCC — An Advanced Power Generation System with High Efficiency, Low Pollution, and Low Water Consumption for China**

   Academician Cai Ruixian and Professor Lin Rumou

1. Current Status and Prospects of China's Energy and Electricity Industry

Professor Zhou Fengqi, Director
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Chinese Academy of Sciences
Beijing, China

Energy Resources and Energy Production

China has rich coal and hydropower resources.

Proved resources of coal in China amount to about 1 trillion tons, which accounts for more than 90 percent of the available conventional energy. Of this, 75 percent is bituminous, 12 percent is anthracite, and the balance, 13 percent, is lignite. 80 percent of Chinese coal lies in north and northwest China.

China has 379 gigawatts (GW) of exploitable hydropower resources, which ranks the first in the world, and most of this is in southwest, northwest and central China.

According to major reviews completed in 1993, China has 94 billion tons of total oil resources, and total natural gas resources of 38 trillion (T) cubic meters. Exploration for oil and gas in China is still at the beginning stage. Proven reserves are only a small part of the total, most of which are concentrated in the eastern region north of the Yangtze River.

The major biomass resources of China include three parts: Crop stalk which can be used as fuel; Firewood from the logical felling of different kinds of trees; human and animal manure and organic waste water. At present, the annual consumption of biomass resources is about 300 million tons of standard coal equivalent (Mtce).

In summary, China has abundant energy resources of comprehensive types, but it is unevenly distributed, and because of the large population, available energy per capita is small, and its use should be frugal.

Energy production in China has developed rapidly,. During the period from 1949 to 1993, the output of raw coal increased from 32 million tons (Mt) to 1,149.7 Mt; that of crude oil increased from 120 thousand tons (Kt) to 145.2 Mt; natural gas grew from 7 million cubic meters to

16.95 billion (G) cubic meters; and electricity rose from 4.3 trillion watt-hours (TWh) to 839.5 TWh, of which hydropower rose from 0.7 TWh to 151.8 TWh. The total output of primary energy reached 1,112.63 Mtce, ranking the third in the world.

Chinese energy production for different years is shown in table 1. According to the data in the table, we can calculate the annual average growth rate of energy production, to be 9.1 percent.

The Current Status and Characteristics of Energy Consumption

Table 2 shows China's total energy consumption, by type, for some selected years.

The table indicates that, from 1949, along with the increase of energy consumption, the primary energy consumption structure changed significantly, which changed from coal alone to a multi-energy structure comprising coal, oil, gas, hydropower, and etc. But we can predict that it is difficult to change the coal-dominated energy structure within a short period of time.

Table 3 shows the primary energy consumption and mix by sector in China. The table shows that industry is the major energy consumer. Since the 1980s, the fraction of energy consumption by industrial production hasn't decreased. On the contrary, it has continuously increased. Energy consumption by industrial production accounts for 70 percent in 1992. Within the industrial sector, energy consumption of chemistry, metallurgy and building material accounts for 45.8 percent.

Energy produced in China mainly supplies domestic consumption. Coal exports in 1993 were less than 2 percent of this year's output. Where China once exported great quantities of crude oil, it became a net oil importer in 1993.

Table 4 shows China's energy imports and exports from 1980 to 1993. The proportion of coal converted into secondary energy is small. In 1992, 1140 Mt of coal was consumed in China altogether, of which 43 percent was converted into secondary energy including 29.3 percent for electricity. The remaining 57 percent was used in industrial boilers, kilns, and residential cooking and heating. The huge amount of direct coal combustion led to serious air pollution.

People make use of biomass as their major residential energy in rural areas. 70 percent of residential energy in rural areas of China was derived from biomass in 1992, but during the 12 year period from 1980-1992, the annual growth rate of commercial energy was larger than 10 percent on average. Commercial energy consumption exceeded that of biomass in 1992.

Future Energy Demand Forecast of China

The method for energy demand forecast: LEAP (Long-Range Energy Alternatives Planning) model is used to help the energy demand forecast. 1990 is taken as the base year, and 2000, 2010, and 2020 are the planned target years. Six major sectors with 17 subsectors and 11 kinds of end use energy types are taken into consideration.

Assumptions for the Planned Indicators

Economic development: It is projected that the GDP growth rate from 1990 to 2000 will average 9 percent per annum; from 2000 to 2010, 7.5 percent; and 6 percent per year for 2010 to 2020. The economic growth rate of the first, second and third industry and sectors are shown in table 5.

Population: It is projected that the annual average population growth rate will be 12.5 percent, 7.2 percent, and 4.2 percent during the periods of 1990-2000, 2000-2010, and 2010-2020, respectively. According to the projection, the population will be 1.294, 1.39 and 1.45 billion, respectively. Table 6 shows the details.

Energy conservation rate: It is assumed that the nationwide annual average energy conservation rate will be 4.49 percent, 4.42 percent, and 3.35 percent during the periods of 1990-2000, 2000-2010, and 2010-2020, respectively.

Results of the Energy Demand Forecast

According to the end energy consumption and the assumptions outlined above, the LEAP model is used for energy demand forecasts of the target years. The results are presented in table 7. Table 8 shows the increase rate of China's end energy demand of China in target years. Tables 9 through 12 present the end use energy demand of China in target years by sector. From the results of energy demand forecasts we can conclude:

(1) The share of coal in end use will decrease from 33 percent in 1990 to about 20 percent in 2020;

(2) Electricity demand will rapidly increase. The share of electricity in end use will rise from 17.7

percent in 1990 to 35.5 percent in 2020;

(3) The demand for oil and gas will also increase considerably. The share of oil and gas will increase from 13 percent in 1990 to 22.4 percent in 2020.

Forecast for Future Electricity Production of China

The total installed capacity of electric power of China was 137.89 GW in 1990, of which hydro power was 36.05 GW, accounting for 26.1 percent; Electricity generation reached 621.62 TWh, of which hydro power amounted to 126.47 TWh, accounting for 20.34 percent.

In 1990, the fuel consumption for thermal power stations was 202.18 Mtce, of which, 94.4 percent came from coal, and only 5.65 percent came from fuel oil and gas. The average energy consumption for electricity generation was 392 gram standard coal equivalent/kilowatt-hour (gce/kWh), while generation gross efficiency was 31.4 percent. The average unit consumption for thermal power stations was 427 gce/kWh at the consumer's end, and electricity supply net efficiency was 28.8 percent. The main reasons for high unit consumption are: most of the existing thermal power plants are fueled by coal, while most of these coal-fired plants utilize technologies and equipment typical of the 1950s and 1960s. Only a few of these plants utilize modern, highly efficient technologies. At the end of 1990, the Chinese generating plants of greater than 125 MW capacity that operated at higher pressures and efficiencies constituted only 47 percent of the total installed thermal generating capacity. At present, operating small capacity units of medium and low pressure account for 26 percent of the installed thermal power capacity. The larger Chinese thermal power generation plants are less efficient than those in more advanced countries by an average of 10 percent and normally cannot reach their nominal design output in terms of electricity production. Generally, auxiliary equipment efficiency also is lower and thus the internal electricity consumption is higher, at 8.22 percent in 1990, than more advanced plants by 30-50 percent.

According to experts' forecasts, tables 13 and 14 present the development trend of China's electric power industry. What should be indicated is that this forecast is based on a low rate of increase. During the 30 years' period of 1990-2020, the annual average rate of increase in installed capacity for thermal power generation will be 5.55 percent, while during the 1990s, it will be 8 percent.

Forecast for Primary Energy Supply

According to the forecast results of end use energy demand, and considering the consumption arising from energy production, transportation and distribution, the primary energy demand can be derived. After considering domestic output and import, we can get the scenarios for primary energy supply, which are shown in table 15.

Table 15 shows that the primary commercial energy demand in 2000, 2010, and 2020 will be about 1.5, 2.0, and 2.5 billion tons of standard coal equivalent (Gtce) respectively; Coal demand will be 1.5, 2.0, and 2.5 Gt respectively; Crude oil demand will be 0.2, 0.28, and 0.35 Gt; and Natural gas demand will be 30, 60, and 120 billion (G) cubic meters. The share of coal in primary energy will decrease by 10 percent during the 30 year period, and the share of natural gas, hydro power, and nuclear power will increase gradually.

Challenges in China Energy Development

China's modernization faces huge pressure in terms of population, available resources and the environment. Energy is closely related to the three restricting factors.

At first, population is too high. As of February 1995, China's population had reached 1.2 billion. More than half of the population's education level was limited to primary school or even lower. Excess population and low educational levels are the long term and most important restricting factor in resolving China's energy problems. At present, China's primary energy consumption has ranked second in the world, but the per-capita figure is very low. The per-capita commercial energy consumption was 1,024 kilograms of standard coal equivalent (kgce) in 1994, which was only 50 percent of the world average. Household per-capita electricity consumption was 73 kWh, only equivalent to 2.2 percent of the American figure. Moreover, up to now, there are still 100 million people in China who have no access to electricity

Second, per-capita energy resources are insufficient. China has an abundance of many kinds of energy resources, but, on a per-capita basis, this is relatively insufficient. The total coal resources amount to 4,000 Gt in the 1,500 meter depth range, but under the current technological and economic conditions, the recoverable reserves only amount to 114.5 Gt. The per-capita figure is only equivalent to half of the world average. According to data from "1995 World Energy Statistic Review," which was completed by British Petroleum Corporation, by the end of 1994 the undeveloped demonstrated reserves of petroleum amounted to 3.3 Gt, making the per-capita amount only 2.75 tons, equivalent to only 11 percent of the world average. Relatively insufficient per-capita energy resources, especially petroleum, is an important restricting factor for society and economic development of China.

Third, the ecological environment is deteriorating. The major energy and environment problems of China are atmospheric pollution in the cities, caused by great quantities of coal combustion and ecological damage caused by over consumption of biomass in rural areas.

China is one of few countries in which coal plays so large a role in the energy mix. It is also the largest coal consumer in the world. China's coal consumption in 1994 amounted to 26.6 percent of the world's coal consumption. Nationwide (not including town and village enterprises), SO_2 emissions amounted to 18.25 Mt and total suspended particulates (TSP) emissions amounted to 14.14 Mt. Compared to 1990, this represents increases of 12.2 percent and 6.8 percent respectively. Of this, it was estimated that 90 percent and 70 percent, respectively, was due to coal combustion. Because the controls on SO_2 emissions lack strength at present, it is estimated by experts that acid rain happens in one third area of China's national land area. The economic damages which are caused by SO_2 and acid rain pollution from 1 ton of coal combustion in some cities reaches 50-70 yuan RMB.

Additionally, as greenhouse gas emissions from China have been ranked third in the world, it is also necessary to adopt some measures for controlling the rapid increase of CO_2 emissions.

Energy Policies for Sustainable Development

Integrated Energy Planning and Management

To establish an energy supply system and consumption model which can adapt to economic development and environmental requirements, it is necessary to undertake integrated planning for energy, environment and economic development, which can be used as the proof of planning, policy, measures and management. It is advantageous to comprehensively analyze, study and solve the cross-problems in the fields of energy, the environment and the economy, to coordinate correlations, so as to realize the comprehensive coordination and balance among energy, the environment and economic development.

The goal of integrated energy planning and management is to establish a set of methods for integrated planning in the areas of energy, the environment and the economy which can be appropriate to China's situation and the requirements of the socialist market economic mechanism, disseminate and apply it to different levels of energy management departments. National and local energy, the environment, and economic integrated planning and corresponding implementation scenarios will be developed before 2000.

Before the end of this century, China's strategies and policies can be summarized as follows: Equal focusing given to energy exploitation and conservation, and give priority to energy conservation; improvement of energy mix and distribution; As for energy industrial development, taking electric power as the center, taking coal as the base, energetically developing hydro power, positively exploiting petroleum and natural gas, moderately developing nuclear power, suiting measures to localities, developing new energy and renewable energy, depending on scientific and technological improvement, raising energy efficiency, reasonably using energy resources, and reducing environmental pollution.

Raising Energy Efficiency and Energy Conservation

Along with the rapid economic development and population increase, the contradiction that the energy supply is unable to meet the demand will exist in a long term, the gap between high quality energy supply and demand will enlarge day by day, so Chinese economic development pattern should change from extensive operation to intensive operation, and begin to focus on efficiency. On the other hand, energy conservation is also an economic and efficient measure for preventing pollution, and limiting the production of so-called greenhouse gases.

Currently, energy consumption per unit production value in China is equivalent to 3-4 times that of developed countries, the energy consumption per unit production of major products is higher than that in developed countries by 40 percent on average. China's average energy utilization rate is only about 30 percent, compared with more than 40 percent in developed industrial countries. Therefore, China has great direct energy conservation potential.

Not all of the industrial structure of China is reasonable. The percentage of the service industry which has low energy consumption is small, while the share with intensive energy consumption is large, which accounts for 51.8 percent, there is only a small number of enterprises of moderate scale. Along with the adjustment and optimization of industrial structure, product structure and energy mix, energy distribution will become sound. The potential for indirect energy conservation is larger than that for direct energy conservation. The objective for energy saving is that the energy conservation rate should be higher than 4 percent before the year 2000. The energy consumption elasticity coefficient should be less than 0.5, i.e., more than half of an energy demand increase will be met by energy conservation. To achieve the targets mentioned above, it is necessary to include the work of energy conservation in national economic and society development planning, institute and implement an "Energy Conservation Law," gradually cancel the unreasonable financial subsidy for energy, and further rationalize energy pricing.

Dissemination of Clean Coal Technology

Deployment of clean coal technology is a component of the strategy for accelerating the change of the coal-dominated energy system to a sustainable model with no environmental damage. The Chinese government is planning to prepare a clean coal technology development plan, and put it into national economic and society development planning. Meanwhile, China will promote clean coal utilization by instituting a series of policies, laws, regulations and economic strategies.

Study cleaning, separation and desulfurization technologies f or high sulfur coal, dry separation technologies, increase the percentage of raw coal to be washed. Increase the production of residential and industrial briquettes, increase the share of quality coal for power plants, study and develop biomass briquetting which has high efficiency and little pollution, develop or introduce large scale circulating fluidized bed (CFB) combustion technologies, develop or introduce coal/water slurry combustion technologies, develop or introduce coal gasification and integrated (coal) gasification combined-cycle (IGCC) electricity generation technologies, study and develop high efficiency combustion, and technologies to utilize peat, anthracite and lignite.

The aim will be to raise the share of coal which is converted into clean secondary energy such as electricity, heat and coal gas etc., and reduce the end use of coal which is directly or separately burned.

Develop and introduce advanced and high efficiency flue gas clean technologies, focused upon development of technologies and equipment for flue gas dust removal, desulfurization, denitration and waste reuse which are suitable to China's national situation.

Development and Utilization of New Energy and Renewable Energy

Renewable energy doesn't produce, or produces little pollution. Therefore, renewable energy is the base of the future sustainable energy mix.

China has rich renewable energy resources, and there is great potential for further development and utilization. By the year 1993, the exploited hydro power was only 11.8 percent of the total, the exploited wind power is 0.002 percent, and the exploited geothermal power is 0.01 percent. Solar energy and biomass energy resources utilization also have a good prospects.

To increase the use of renewable energy and make it able to compete with fossil fuel, it is necessary to increase investment and policy support, develop technologies, and reduce cost. The target is that the total utilization of renewable energy should amount to 298 Mtce and 390 Mtce by the years 2000 and 2010, respectively.

Table 1. Energy Production in China 1949-1993

Year	Total (Mtce)	Coal (Mt)	Oil (Mt)	Natural Gas (Gm^3)	Electricity Generation (TWh)	
					Total	Hydropower
1949	23.71	32.0	0.12	0.007	4.3	0.7
1952	48.71	66.0	0.44	0.008	7.3	1.3
1957	98.61	131.0	1.46	0.07	19.3	4.8
1962	171.85	220.0	5.75	1.21	45.8	9.0
1965	188.24	232.0	11.31	1.10	67.6	10.4
1970	309.90	354.0	30.65	2.87	115.9	20.5
1975	487.54	482.0	77.06	8.85	195.8	47.6
1980	637.35	620.0	105.95	14.27	300.6	58.2
1985	855.46	872.0	124.90	12.93	410.7	92.4
1990	1039.22	1080.0	138.31	15.30	621.2	126.7
1993	1112.63	1149.7	145.20	16.95	839.5	151.8

Source: China Statistic Yearbook 1994

Table 2. Primary Energy Consumption Mix in China 1953-1993

Year	Total (Mtce)	Energy Consumption Mix (%)			
		Coal	Oil	Natural Gas	Hydropower
1953	54.11	94.33	3.81	0.02	1.84
1957	96.11	92.32	4.59	0.08	3.01
1962	165.40	89.23	6.61	0.93	3.23
1965	189.01	86.45	10.27	0.63	2.65
1970	292.91	80.89	14.67	0.92	3.52
1975	454.25	71.85	21.07	2.51	4.57
1980	602.75	72.15	20.76	3.10	3.99
1985	770.20	75.92	17.02	2.23	4.83
1990	987.03	76.20	16.60	2.10	5.10
1993	1117.68	72.80	19.60	2.00	5.60

Source: China Statistic Yearbook 1994

Table 3. Primary Energy Consumption by Sector and Mix

	1980		1990		1992	
	Mtce	%	Mtce	%	Mtce	%
Total End Energy Consumption	602.75	100	987.03	100	1,091.70	100
1. Production Sectors	480.55	79.7	794.30	80.47	891.73	81.68
A. Agriculture	46.92	7.8	48.52	4.92	50.20	4.60
B. Industry	389.86	64.7	675.78	68.47	762.79	69.87
a. Heavy Industry	322.14	53.4	538.60	54.57	606.28	55.53
b. Light Industry	67.72	11.2	137.19	13.90	156.51	14.34
C. Construction	9.57	1.6	12.13	1.23	13.92	1.28
D. Transportation & Communication	29.02	4.8	45.41	4.60	50.58	4.63
E. Commercial	5.18	0.9	12.47	1.26	14.24	1.30
2. Non-Production Sectors	12.05	2.0	34.73	3.52	43.61	4.00
3. Household	110.15	18.3	158.00	16.01	156.36	14.32

Source: China Statistic Yearbook 1994, 1991

Table 4. Energy Export and Import in China 1980-1993

Unit: Mt

		1980	1985	1990	1991	1992	1993
Crude Oil	Export	13.31	30.03	23.99	22.60	21.51	19.43
	Import	0.37		2.92	5.97	11.36	15.65
Oil Products	Export	4.20	6.21	6.33	6.82	5.98	4.56
	Import	0.46	0.90	3.94	5.91	7.78	17.54
Coal	Export	6.32	7.77	17.29	20.10	20.19	19.81
	Import	1.99	2.31	2.00	1.37	2.00	

Source: China Energy Annual Review 1994

Table 5. China Economic Development Scenarios by Sector

Unit: Output: 100 million yuan; Share: %; Growth rate: %

	1990		2000			2010			2020		
	Output	Share	Output	Share	Growth Rate	Output	Share	Growth Rate	Output	Share	Growth Rate
Nationwide	17,676	100	41,846	100	9	86,246	100	7.5	154,453	100	6
The first industry	5,024	28.4	7,700	18.4	4.36	10,522	12.2	3.17	13,437	8.70	2.48
The second industry	7,829	44.3	18,878	45.16	9.2	37,394	43.36	7.07	63,324	41.0	5.41
The third industry	4,818	27.3	15,170	36.3	12.15	38,385	44.44	9.73	77,711	50.3	7.31
Agriculture	5,024	28.4	7,700	18.4	4.6	10,522	12.20	3.17	13,437	8.70	2.48
Industry	6,981	39.5	16,679	39.90	9.10	32,859	38.10	7.0	55,140	35.70	5.3
Construction	848	4.80	2,199	5.26	10.00	4,534	5.26	7.5	8,124	5.26	6.0
Transportatio n	956	5.41	2,480	5.93	10.00	5,114	5.93	7.5	9,174	5.94	6.0
Commercial	944	5.34	2,958	7.07	12.10	7,596	8.81	10	15,560	10.10	7.4
Non-material	2,918	16.5	9,732	23.30	12.80	25,678	2,9.80	10	52,977	34.30	7.5

Table 6. China Population Increase Scenarios

Unit: Population: 100 million; Share: %; Growth rate: %

	1990		2000			2010			2020		
	Population	Share	Population	Share	Growth Rate	Population	Share	Growth Rate	Population	Share	Growth Rate
Nationwide	11.43	100.0	12.94	100.0	12.5	13.90	100.0	7.2	14.5	100.0	4.2
City	3.02	26.4	4.06	31.4		5.20	37.4		6.5	44.8	
Rural	8.41	73.6	8.88	68.6		8.70	62.6		8.0	55.2	
Persons/ Household	4.20		3.86			3.61			3.37		

Table 7. Forecast Results: Final Energy Demand and Mix

		1990		2000		2010		2020	
Type	Unit	Demand	Share (%)	Demand	Share (%)	Demand	Share (%)	Demand	Share (%)
Coal	Mt	530.98	33.04	632.76	27.85	771.59	24.00	715.71	19.97
Crude Oil	Mt	3.87	0.48	2.32	0.20	2.81	0.19	3.09	0.17
Natural Gas	100 Mm^3	147.89	1.71	268.20	2.20	537.74	3.38	995.19	5.17
Electricity	100 GWh	5182.40	17.70	11232.50	24.92	19413.94	30.26	28246.88	35.30
Oil Products	Mt	88.11	11.29	157.16	14.25	229.67	15.95	299.84	17.23
Biomass	Mtce	264.97	23.08	264.40	16.29	254.32	12.01	220.76	8.62
Others	Mtce	145.74	12.70	231.64	14.28	300.72	14.20	346.51	13.53
Total	Mtce	1147.98	100.00	1622.63	100.00	2117.46	100.00	2560.36	100.00

Table 8. Annual Increase Rate of End-Energy Demand

Unit: %

	1990-2000	2000-2010	2010-2020
Coal	1.77	1.18	0.06
Crude Oil	-4.97	1.93	0.95
Natural Gas	6.13	7.20	6.35
Electricity	7.13	4.71	3.50
Oil Products	5.96	3.87	2.70
Biomass	-0.02	-0.38	-1.40
Others	4.74	2.64	1.43
Total	3.52	2.70	1.92

Table 9. End-Energy Consumption and Mix by Sector in China 1990

	Household		Agriculture		Industry		Transportation		Construction		Service		Total	
	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%
Coal	93.13	24.56	14.93	3.94	237.35	62.58	10.01	2.64	3.40	0.90	20.45	5.39	379.27	100
Crude Oil	0	0	0	0	4.75	86.00	0	0	0.77	14.00	0	0	5.53	100
Natural Gas	2.47	12.58	0	0	15.63	79.45	0	0	1.41	7.16	0.16	0.81	19.67	100
Electricity	18.87	9.29	16.68	8.21	152.33	74.98	2.09	1.03	2.26	1.11	10.92	5.38	203.15	100
Oil Products	4.26	3.28	11.83	9.12	59.78	46.11	49.36	38.07	1.96	1.51	2.47	1.91	129.65	100
Biomass	264.97	100	0	0	0	0	0	0	0	0	0	0	264.97	100
Others	32.51	22.31	0	0	111.69	76.64	0	0	0	0	1.54	1.06	145.74	100
Total	416.21	36.26	43.44	3.78	581.53	50.66	61.46	5.35	9.80	0.85	35.54	3.10	1147.98	100

Table 10. Forecast on End-Energy Consumption and Mix by Sector 2000

	Household		Agriculture		Industry		Transportation		Construction		Service		Total	
	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%
Coal	89.28	19.75	16.29	3.61	308.29	68.21	7.28	1.61	3.54	0.78	27.29	6.04	451.9	100
Crude Oil	0	0	0	0	3.32	100	0	0	0	0	0	0	3.32	100
Natural Gas	9.45	26.49	0	0	24.0	67.27	0	0	1.64	4.59	0.59	1.65	35.67	100
Electricity	50.45	12.48	20.68	5.11	288.62	71.38	5.71	1.41	5.07	1.25	33.83	8.37	404.37	100
Oil Products	9.40	4.07	14.42	6.24	98.53	42.61	99.69	43.11	3.04	1.31	6.18	2.67	231.25	100
Biomass	264.40	100	0	0	0	0	0	0	0	0	0	0	264.40	100
Others	64.89	28.01	0	0	162.50	70.15	0	0	0	0	4.25	1.83	231.64	100
Total	487.88	30.07	51.39	3.17	885.26	54.56	112.68	6.94	13.29	0.82	72.13	4.45	1622.63	100

Table 11. Forecast on End-Energy Consumption and Mix by Sector 2010

	Household		Agriculture		Industry		Transportation		Construction		Service		Total	
	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%
Coal	93.27	18.35	17.27	3.40	351.85	69.22	4.15	0.82	4.03	0.79	37.72	7.42	508.28	100
Crude Oil	0	0	0	0	4.02	100	0	0	0	0	0	0	4.02	100
Natural Gas	32.15	44.96	0	0	35.11	49.09	0	0	2.58	3.60	1.68	2.35	71.52	100
Electricity	90.55	14.13	25.41	3.97	421.36	65.77	11.69	1.82	8.84	1.38	82.81	12.93	640.66	100
Oil Products	13.91	4.12	19.80	5.86	117.78	34.85	172.87	51.15	3.75	1.11	9.83	2.91	337.94	100
Biomass	254.32	100	0	0	0	0	0	0	0	0	0	0	254.32	100
Others	87.09	28.96	0	0	203.99	67.84	0	0	0	0	9.63	3.20	300.72	100
Total	571.30	26.98	62.49	2.95	1134.11	53.56	188.71	8.91	19.19	0.91	141.67	6.69	2117.46	100

Table 12. Forecast on End-Energy Consumption and Mix by Sector 2020

	Household		Agriculture		Industry		Transportation		Construction		Service		Total	
	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%
Coal	99.82	19.53	18.07	3.53	336.91	65.90	0	0	4.13	0.81	52.31	10.23	511.22	100
Crude Oil	0	0	0	0	4.42	100	0	0	0	0	0	0	4.42	100
Natural Gas	84.38	63.75	0	0	40.48	30.58	0	0	3.85	2.91	3.66	2.76	132.36	100
Electricity	128.74	14.24	31.61	3.50	543.35	60.11	21.83	2.42	13.73	1.52	164.64	18.21	903.90	100
Oil Products	18.72	4.24	24.54	5.56	123.91	28.09	255.21	57.85	3.84	0.87	14.95	3.39	441.18	100
Biomass	220.76	100	0	0	0	0	0	0	0	0	0	0	220.76	100
Others	108.79	31.40	0	0	222.65	64.25	0	0	0	0	15.07	4.35	346.51	100
Total	661.21	25.83	74.22	2.90	1271.72	49.67	277.05	10.82	25.54	1.00	250.62	9.79	2560.36	100

Table 13. The Development Trend of Installed Capacity of China Electric Power Industry

Electricity Generation Mode	1990		2000		2010		2020	
	MW	%	MW	%	MW	%	MW	%
Thermal power	101820	73.86	220200	75.79	374650	76.39	514850	73.55
Hydro power	36040	26.14	66500	22.89	100000	20.39	138000	19.71
Nuclear energy	0	-	2700	0.93	10700	2.18	32000	4.57
Wind energy	10	-	1000	0.34	4000	0.82	10000	1.43
Geothermal energy	21	-	60	0.02	100	0.02	150	0.02
Solar energy	0.26	-	80	0.03	1000	0.20	5000	0.71
Total	137891	100.00	290540	100.00	490450	100.00	70000	100.00

Table 14. Forecast on Electricity Generation of China Electric Power Industry

Electricity Generation Mode	1990		2000		2010		2020	
	TWh	%	TWh	%	TWh	%	TWh	%
Thermal power	495.05	79.64	1044.53	78.48	1788.72	78.81	2447.56	75.51
Hydro power	126.47	20.34	266.36	20.01	400.54	17.65	552.75	17.05
Nuclear energy	-	-	17.56	1.32	69.59	3.07	208.11	6.42
Wind energy	-	-	2.00	0.15	7.99	0.35	19.98	0.62
Geothermal energy	0.1	0.02	0.23	0.02	0.38	002	0.56	0.02
Solar energy	-	-	0.20	0.02	2.50	0.10	12.49	0.38
Total	621.62	100.00	1330.88	100.00	2269.72	100.00	3241.45	100.00

Table 15. Primary Energy Supply (1990 – 2020)

		Unit	1990		2000		2010		2020	
			Supply amount	Share %	Supply amount	Share %	Supply amount	Share %	Supply amount	Share %
Commercial Energy		Mtce	1041.92	79.54	1505.45	84.79	2045.58	88.62	2544.86	91.61
Coal		100 Mt Mtce	10.83 773.58	74.25	15.00 1072.45	71.23	19.63 1401.84	68.53	22.77 1626.23	63.91
Petroleum	Output	100 Mt Mtce	1.38 197.69		1.65 235.79		2.00 285.80		2.21 314.38	
	Import	100 Mt Mtce	0 0		0.38 54.14		0.84 119.47		1.34 191.59	
	Supply	100 Mt Mtce	1.38 197.69	18.97	2.03 289.93	19.26	2.84 405.27	19.81	3.55 505.97	19.88
Natural gas	Output	100 Mm^3 Mtce	157.74 20.98		300.15 39.92		499.25 66.40		798.80 106.24	
	Import	100 Mm^3 Mtce	0 0		0 0		99.55 13.24		393.76 52.37	
	Supply	100 Mm^3 Mtce	157.74 20.98	2.01	300.15 39.92	2.65	598.80 79.64	3.89	1192.56 158.61	6.23
Hydro power		100 GWh Mtce	1266.00 49.63	4.76	2665.28 95.95	6.37	4007.88 132.26	6.47	5525.63 176.82	6.95
Nuclear Power		100 GWh Mtce	0 0		175.83 6.33	0.42	696.36 22.98	1.12	2080.31 66.57	2.61
Wind, geothermal & solar energy		100 GWh Mtce	1.02 0.04		24.17 0.87	0.06	108.79 3.59	0.18	330.31 10.57	0.42
Sum		Mtce	1041.92	100.00	1505.45	100.00	2045.58	100.00	2544.86	100.00
Non-commercial energy (biomass)		Mtce	268.07	20.46	270.09	15.21	262.57	11.38	233.01	8.39
Total		Mtce	1309.99	100.00	1775.54	100.00	2308.15	100.00	2777.87	100.00

2. Coal and Clean Coal Technologies in China

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Abstracts

Both the proved coal reserves and the consumption of coal in China are in the dominant positions in the national primary energy mix. Chinese coal reserves and mines are mainly concentrated in North and North-west China, Chinese coal is of many different ranks and is more difficult to wash It has high sulfur and ash content, and is widely used in all industries and trades. The situation and status of Chinese Clean Coal Technologies (CCCT) are mentioned, the main gap in CCT between China and advanced countries is the scale of available technology and the maturity of CCT. Some suggestions, such as choosing the most suitable CCT according the coal characteristics and the user, in R&D of China's CCT, to promoting international cooperation, and focus on the main coal consumers, the key technologies and the more mature technologies, etc., have been made.

Chinese coal

Proved Chinese Coal Reserves and its Distributions

At the end of 1992, the Chinese coal resources amounted to 986.3 Gt, (of which the proved reserves accounted for 30 percent) about 90 percent of total conventional energy resources in China.[1,2] The main periods of coal represented in China are Early Cambrian, Early Carboniferous, Late Carboniferous-Early Permian, Late Permian, Late Triassic, Early and middle Jurassic, Early Cretaceous and Tertiary. It is almost the same as with other parts of the world, from the Paleozoic Era, the Mesozoic Era to The Cenozoic Era. Because the weather and conditions were different, in south China most coal accumulations are from the Paleozoic Era, and partly from the Cenozoic Era. In north China most are from the Late Paleozoic Era and the Mesozoic Era. In north-east China and the Inner-Mongolia area the coal accumulations are from the Cenozoic Era. In China the coal resources that were formed in the Carboniferous, Permian and Jurassic periods are most important, and account for 96 percent of the total coal resources. In north China the coal resources of the Carboniferous and Permian periods are estimated to be 70 percent of the total of the Permo-Carboniferous coal in China. So it is clear that the main Chinese coal reserves are in the north part of China, and this area — especially the north-west area — is the main coal mining area in China, comparatively speaking. In the south part of China, especially in south-east, the coal reserves are very small.

In recent years, most Chinese coal has been Permo-Carboniferous coal. In the future it will mostly be the Early and middle Jurassic coal, so coal mining will move from north to north-west. According to newly published geological information[3], the prospective coal reserves at the end of 1990, at depths of less than 2000 m amount to 5,328.7 Gt, of which the north China Permo-Carboniferous and Early and Middle Jurassic coals are 28 percent and 63.1 percent respectively.

The above data show that there are abundant coal reserves widely distributed in China's south and north, but from the amount of reserves that are not well distributed, most are in the north or north-west part of China. Northwest China will become the main coal mining area in the future. Figure 1 shows the actual locations of the Chinese coal reserves.

Metamorphism causes the different ranks of coal, from lignite, sub-bituminous, bituminous, and anthracite coals to natural graphite.

The Characteristics of Chinese Coals and Their Geological Locations

The characteristics of coal depends upon the conditions of formation and the age of the coal being formed. The conditions include the raw materials which form the coal, and the environment in which it is formed, such as location, space, temperature, pressure. etc. The ash content mainly depends on the distance between the peat bog and the mainland. The sulfur content in coal mainly depends on the sea water influence acting on the peat, while the coal is forming.

Temperature plays a very important role in the metamorphism, which causes different ranked coals from lignite, sub-bituminous coal, bituminous coal, and anthracite to natural graphite. In China, from north to south, there are three huge metamorphic zones. In these zones, about twenty metamorphic centers exist and around each center there are rings of different ranked coal . Generally speaking, in China the coal becomes higher-ranking from north to south, and from central to east and west. In the coastal areas of the mainland such as in the east part of Shandong, Fujian and Guangdong, most coal reserves are lignite and anthracite, the latter formed by the effect of heat from active igneous rock in these areas. All ranks of coal exist in China, from low rank lignite to high rank anthracite, but in different amounts. According to recent statistics, in the expected reserves the lignite is 2.7 percent, subbituminous coal is 54.1 percent, bituminous is 26.8

percent and the anthracite is about 9.3 percent. Only 18.7 percent of Chinese coal reserves are less than 600 m in depth, so underground mining predominates. The open cast process could only be used in a few coal mines.

The coalification conditions made the ash content of Chinese coal relatively high. The average ash content in ROM (run of mine) coal is more than 25 percent, and most of them are high sulfur and hard-to-wash coals. The average sulfur content of Chinese coal in 1995 is 0.77 percent. Although most Chinese high-sulfur coal are produced in the south, but the sulfur levels in coals from the north are getting higher since the coal mines are developing deeper underground. The average sulfur content of some northern coal mines in different seams are listed in Table 1. From these data, it is clear that in the top seams the sulfur content is less than 1 percent, low sulfur coal, but in the bottom seams most of them are between 2-4 percent, high sulfur coal. The reality is that desulfurization process development for Chinese coal utilization will become more and more important in the future.

Table 1. the average sulfur content of some coal mines in different seams

Mine	J.Z.	S.G.J.	A.T.B	X.V.(X.Z.)	Z.L.	N.T.	Q.J.Y.(K.R.)
top seams	0.34%	0.26%	0.51%	0.55%	0.81%	0.66%	0.57%
bottom seams	3.09%	3.28%	2.57%	4.1%	2.79%	3.17%	1.67%

The Position of Coal in Energy Mix of China

Coal reserves constitute 90 percent of total fossil energy reserves in China. Oil and natural gas reserves are relatively small. In order to meet the demands for energy as the national economy experiences rapid growth, the proportion of coal in the energy mix will not change in the next 30-50 years. The proportion of coal in primary energy production will remain at the level of 70 percent. Table 2 lists data on the total energy output and the proportion of coal in the total energy mix (1949 to 1994). From the data, the coal was in the dominant position and it will remain so in the coming years as well.

Table 2. Primary Energy Output (PEO) and Percentage of Raw Coal

Year	Total PEO (Mtce)	Percentage of raw coal	Year	Total PEO (Mtce)	Percentage of raw coal
1949	23.74	96.3	1950	31.74	96.7
1955	72.95	95.9	1960	296.37	95.6
1965	188.24	88.0	1970	309.90	81.6
1975	487.54	70.6	1980	637.35	69.4
1985	855.46	72.8	1990	1039.22	74.2
1991	1048.44	74.2	1992	1072.56	74.3
1993	1112.63	73.8	1994	1120.20	77.3

The dominant role of coal in the energy mix is also reflected by the extensive use of coal in every sector of the national economy. In the power industry, the thermal power output is 80 percent, of which 75 percent is coal-fired. Coal consumption in power generation is 30 percent of annual coal output. In the other industry sectors, about 75 percent of energy used as fuel and power is from coal, representing 33 percent of the annual coal output. Sixty percent of the raw material of chemical fertilizer is from coal. About 80 percent of domestic fuel is coal, representing 20 percent of China's annual coal output. Coal used in the metallurgical industry is 8 percent of the annual coal output, mainly used in coking and power supply.

Because of the abundant coal reserves and huge coal output, the coal-based industries which use coal as fuel or raw material show higher reliability and stability. For example, in the chemical fertilizer industry, in the 1970s, China imported some large ammonia plants which use natural gas as feedstock. The lack of natural gas was the first problem these plants suffered; in recent years, the price of the natural gas has been getting higher and higher, so in order to remain economical, these plants have to change to the use of coal in the future. On the contrary, the coal-based ammonia plants are developing fast, as lots of Texaco gasifiers, which use coal slurry as feedstock, were built up and more coal gasifiers will be erected in China as well.

The Existing Problems in Chinese Coal Production and Utilization

Coal is one of the solid forms of fossil energy, and the ash content of Chinese coal is relatively higher, while its sulfur content becomes higher as the coal mines get deeper. In the production and utilization of coal, the impacts on environment are serious because of the huge coal output and coal consumption.

During the Coal Production

Land surface subsidence after coal mining and solid waste deposit, such as refuse; coal mine waste water, and gas released from coal mining cause severe environmental problems. As mentioned above, the coal reserves are deep underground, so 96 percent of the mines in China are underground mines. Statistically, surface subsidence has damaged 0.2 hectares (ha) of cultivable land for every million tons (Mt) of raw coal produced. Up to the end of 1990, the total cultivable land damaged reached 300,000 ha. This equates to an area equivalent to the share of arable land of 3,750,000 people. (The equivalent arable land for each person is 0.08 ha, or 1.2 mu (mu≈0.2 acre)). It is expected that by the year 2000 the amount of damaged land will reach 0.5 Mha. The refuse accumulated is 3.0 Gt, occupying 12 kha of cultivable land, and the annual increase will be 130 Mt. The spontaneous combustion of refuse would cause air pollution as well. Annual waste water from underground mining is 1.75 Gt, some of which is not yet well treated. The coal seam methane released during coal mining is 6.0 Gm^3 annually. Not only does it waste water and fuel gas, but it is also harmful to the environment.

Problems Arising from Coal Preparation and Utilization are as Follows:

a) Only about 23 percent of Chinese coal is washed, and of the coal used for power generation only 11.28 percent is washed. And since the mines are mainly located in North and West China, coal transportation will be toward the South and East, where problems will be created by the refuse from washing in additional to the energy expended in shipping the refuse in the unwashed coal High ash content in coal always causes reduced coal utilization efficiency.

b) The coal briquetting and coal seam methane utilization in China have been developed in recent years, but most coal seam methane is still not being used, as coal seam methane utilization technologies are not yet mature. More research & development work needs to be done.

c) Compared with advanced countries, the utilization efficiency of Chinese coal is still low. For example, the average thermal efficiency of industrial furnaces is 10 percent lower; industrial boilers, 15-20 percent lower; and the national average thermal efficiency of coal-fired power plants is only about 30 percent. Specific coal consumption is 30 percent higher than that in developed countries.

d) More attention has been paid to the control of environmental pollution caused by burning coal. Dust removal of coal-fired power plants is the most successful. The articulates removal efficiency reached 93.9 percent in 1990, when 90 percent of the power plants reached the TSP emission control standard. But there is almost no control of SO_x emissions. About 90 percent of the SO_2 is from burning coal, and about 70 percent of the particulates is from coal combustion. In 1992, this amounted to 14.72 Mt and 9.9 Mt respectively. Several years ago, a UN report listed 10 cities with the highest airborne SO_2. Three of the listed cities are in China: Shenyang, Xi'an and Beijing are listed in second, 7th and 8th position, respectively.

In summary, coal is China's primary source of energy, and this is not expected to change over the next 30 to 50 years. Burning coal and the production of coal have themselves already caused serious environmental problems. In order to pursue further development, China has taken the development and adoption of clean coal technologies as an important national policy to ensure parallel progress in the development of energy and protection of the environment.

The Clean Coal Technologies (CCT) in China

The clean coal technologies include many areas and run through the entire process from production and transportation, through preparation and coal utilization. In coal production, the environmental protection technologies include the utilization of refuse, mining waste water, and coal seam methane, and protection against land surface subsidence, and comprehensively deal with the effects of existing subsidence. In coal preparation, there are coal preparation process development, the treatment and utilization of by-products from coal preparation plants, such as the tailings coal slime and so on, coal drying, briquetting and grinding, coal slurry preparation and application technologies; In coal utilization, there are different combustion technologies, gas clean-up technologies, coal conversion technologies, such as gasification, pyrolysis (coking and mild gasification) and liquefaction, non-fuel specific utilization technology and so on. China is one of the few countries in the world using coal as its main energy resource, with the exception of South Africa and India, so the development of clean coal technologies has been pursued over past decades. Many relevant Ministries and local organizations have done their best to develop clean coal technologies. In China, the Research Institutes and Universities are doing numerous coal projects directed toward development of clean coal technology. There are large numbers of experienced experts and a lot of clean coal programs have been done, are in progress and will be done. Some of the results of research progress have been used in industry as well.

The Development and Current Status of Chinese CCT

Coal Preparation and Washing

The different coal washing processes, such as dry washing, wet washing and magnetic separation have been used in coal preparation for many years and continue to be used. Some coal washing processes have already been used in commercial-scale coal preparation plants. For instance, in 1994 China built up two coal preparation plants using the heavy medium process. The capacity of these plants were 8 Mt/a and 15 Mt/a. About 80 percent of the Chinese coal are classified as hard-washing coals, so the new, so-called flotation and heavy-medium processes are being used in coal preparation more often in recent years. The current status of Chinese coal preparation plants is shown in table 3.

Table 3. The comparison of different coal preparation processes

Year	Jigging process	flotation process	heavy medium process	the others
1978	-70%	14%	-14%	2%
1985	-59%	16%	23%	
1994	-58%	17%	24%	

Briquetting of coal fines prior to burning reduces the pollution from particulates and smoke by 60 percent to 90 percent as compared with direct burning, and saves 20 percent of the coal. In China, coal briquetting technology has been under development for long time and a lot of briquetting binders have been developed, including organic, inorganic and mixtures, etc. For some coals, no binder agglomerating process is feasible since there is some clay in the coal ash. These technologies have been used in both industrial and domestic briquette production for many years. Now the North-East Asia UN program has introduced Chinese briquetting technology and stoves to some other Asian countries. The mechanization of mining has increased the proportion of fines in raw coal. In most coal mines the fine coal rate is 70 percent. But in China most medium- and small-size boilers utilize layered burning, and most gasifiers are moving bed gasifiers, both of them using sized coal which aggravates the coal fines problem and further promotes the development of coal briquetting technology, leading to even more experiences in briquetting technology and briquette application.

In China many studies on coal slurry preparation and application were finished in recent years, and now there are 6 coal slurry plants and 2 additive plants in operation. Also, some coal slurry application demo-programs are on going. The Texaco coal gasification process, which uses coal slurry as feed stock have been put into operation for years in Lunan (Shandong Province) and Shanghai. Some fertilizer plants using the Texaco process will be put into operation in the near future.

Coal Combustion

In China, 80 percent of coal produced was used in direct combustion. The high efficiency pulverized coal boiler is used in large capacity (over 300 MW) power plants. Most medium and small size boilers utilize layered combustion. The efficiency of these type boilers is 60 to 70 percent. The bubbling fluidized bed boilers (BFBB), which are able to use low heating value coal and coal wastes, was developed in the early 1960s (before the cultural revolution). Now the BFBB is a series, with different capacities. In recent years, the circulating fluidized bed boilers (CFBB) are being developed very fast since the CFBB features higher thermal efficiency and higher in-bed desulfurization efficiency. Twenty more CFBB manufacturers produced more than 300 CFBB unit with different capacities (less than 130 t/h of steam). After a long period of research and development, the pilot power plant (15 MW) using pressurized fluidized bed combustion (PFBC) technology has been built in Jiawan, Jiangsu Province, by South-East China University, etc.

Coal Conversion Technologies

(1) Coal Gasification:

Coal gasification often is the first step for some clean coal technologies. Synthesis gas production for ammonia and methanol, raw gas production for indirect liquefaction via the modified Fischer-Tropsch synthesis (MFT), integrated coal gasification combined cycle (IGCC) and fuel cell (FC) for power production – all of these clean coal technologies require coal gasification to convert the coal to gas as the first step. Even the second generation pressurized fluidized bed combustion combined cycle (PFBC-CC) can be considered as a combination of coal gasification (mild gasification) and coal combustion. Although in China the moving bed gasifier is in the dominant position, many research projects of the advanced gasifier, such as pressurized slagging gasifier, ash agglomerating fluidized bed gasifier, molten bath gasifier with two chambers and single shift, vortex flow entrained bed gasifier, down flow entrained bed wet feeding gasifier (similar to the original version of Texaco), countercurrent-flow, entrained bed, dry-feeding gasifier (similar to Koppers-Totzek gasifier) etc., were tested in pilot scale facilities in the early

1960s, of which the ash agglomerating fluidized bed gasifier, the down flow slurry-feeding gasifier and the pressurized gasifier are the most successful.

Underground coal gasification with large-section, long-passageway, two-stage process got some good test results. It could be used in "worked-out" coal mines to recover the remaining coal. The back-run gas producer, widely used in China in recent years, cracks out the high molecular weight hydrocarbon pollutants such as coal tar, gas liquid, etc., making the gas plant itself cleaner.

(2) Coal Liquefaction:

There are two direct liquefaction processes with promise: two stage hydrogenation and co-processing. General speaking, the conversion rate of direct liquefaction is about 50 percent, i.e., one ton of product requires 4 tons of raw coal feed. China is planning to build a direct liquefaction demo-plant in the near future. Direct liquefaction is suitable for low-rank bituminous coal or lignite. The conversion rate is higher with coals of lower ash content.

The keys to indirect coal liquefaction are coal gasification efficiency and the Fischer-Tropsch (F-T) process catalyst. Newly-developed catalysts generate higher oil recover rates. Following a test run in a 100 t/a capacity pilot facility, the 2,000 t/a demo-plant is in a performance test run.

(3) Coal Carbonization:

In China, most town gas is produced in the coal coking chemical works using the conventional coal carbonization process, i.e., a coke oven. The main product is coke, with by-products benzene, tar, gas, etc., also produced. Many new processes have been developed in these plants for the preparation of high value products in recent years. For low-temperature carbonization – so-called "mild gasification" – there are two processes in China: one is the Multistage Rotary Furnace (MRF), which uses indirect heating; the other is fast pyrolysis using direct heating by mixing with the solid heat-carrier (char or ash). The demo-plants of both processes were built in Hailaer and Pingzhuang, Inner-Mongolia Autonomous Region several years ago. The low-temperature carbonization process can also be used in the second generation PFBC-CC and CFBC based tri-generation (heat, electricity, and gas) process as well. The main problem for these processes is economics. The keys are to find proper uses for the main product – char, and the marketing of the products.

(4) Gas and Flue Gas Clean-Up:

Conventional low-temperature or atmospheric temperature gas cleaning technologies have been extensively used in Chinese chemical plants and town-gas plants for many years and some of them have been modified. The advanced hot gas clean-up (HGCU) processes have been under development in recent years. Under the support of State Science and Technology Commission, SSTC, and United Nations Development Program (UNDP), coordinated with IGCC and PFBC-CC development, Chinese HGCU projects are going smoothly. It is clear that these projects are of importance to increase the efficiency of the PFBC-CC and the wet-feeding gasification (such as Texaco and Destec IGCC) processes.

The Main Gap in CCT Between China and Advanced Countries

China is the largest coal producing country in the world, and also the largest coal consumer in the world. The leaders, from central government to the local level, all devote much attention to CCT development. Especially in recent years, the central government started with environmental legislation, strengthening international cooperation extensively with the advanced countries to develop clean coal technologies. But China is still a developing country, and its economic maturity is limited, so there is some gap between China and the developed countries. The main gap of CCT is that, in China, some areas of CCT are just in the beginning stages (pilot test or small scale unit), such as the PFBC-CC, IGCC, CFBC, etc., while in the advanced countries commercial demo-plants already been in operation for years and, as a result, some technologies are now commercially available products. For example, the circulating fluidized bed boilers (CFBB): in China the largest boiler steam capacity is only 220 tons per hour (t/h), but in the advanced countries the largest capacity is 700 t/h; the pressurized fluidized bed combustion combined cycle power generation technology in China is in the test stage with a 15 MW unit, when in Sweden, ABB finished a long time operation test of the P200 Project (75 MW) and now has turned to demonstration of a 350 MW unit. In the integrated coal gasification combined cycle power generation, 250 MW demo-Plants have been in operation for years in The Netherlands (at Bugganum) and the United States (at Wabash River power station No. 1, in Indiana), but in China these are at the discussion stage for 200 or 400 MW demo-plant technical pre-feasibility studies. In coal gasification process development, in The Netherlands the Shell dry-feed gasifier with coal capacity of 2,000 to 3,000 tons per day (t/d) has been successfully operating for years, in China the imported largest Texaco slurry-feed gasifier is 500 t/d of coal feed only. Efficiency of the Texaco coal gasification system in the Lunan fertilizer plant is only 69 percent, but the Shell in Bugganum reached more than 83 percent. In coal liquefaction, the indirect coal liquefaction used in production over years the capacity is very large, while in China is in the scale of 2,000 tons per year (t/a). So, generally speaking, the main gaps of CCT between China and the advanced countries are: the scale of the CCT unit, the maturity of the technology, and the availability of the equipment. The gap exists and the reasons for it are the late start for environmental legislation in China and the required increase in investment for CCT development.

Some Views and Suggestions on Chinese CCT Development

China is a developing country with large reserves of coal and relatively less reserves of natural gas and crude oil. Objective reality decided that, in the coming decades in China coal will have to be used as the main resource of energy. The socialist political system, as an important member of the globe, decided that, while speeding up social development, China must pay more attention to the environment in which we live. Obviously, in the next several decades, the development of CCT should be considered as one of the important national policies, as well as focus on strengthen coal cleaning, developing coal briquettes and then development of the high efficiency, low pollution, low cost coal conversion technologies, that is, the high efficiency, economically practical clean coal technologies (CCT) with Chinese features.

The characteristics of coals in China are variable: ranks range from lignite to bituminous coal and anthracite, and properties such as ash content, ash properties, sulfur content, and the type of sulfur are quite different from one to another. But the clean coal technology itself always has some limitation during application, so to develop suitable CCT applications, the coal which will be used and the end use of the technology must be considered, that is "suit measures to local conditions." For example, if the coal has high ash content then the fluidized bed processes, such as the CFBC boiler or circulating fluidized bed gasifier (CFBG) are better; for advanced power production the PFBC-CC is the better choice; if the coal has low ash and high sulfur and the power station is located in an area lacking adequate water, then the IGCC will be the best choice; for coal liquefaction where the coal is high rank anthracite the indirect processes is a suitable way, and if the coal is low ash and low-ranked, then direct coal liquefaction would produce better efficiency; if the end use of the gas is for ammonia synthesis, then the entrained flow, high temperature, slagging gasifier would produce gas with very low methane, which is the ideal situation for ammonia synthesis

When the clean coal technologies get to be extensively used, the CCT development teams should share out the work and cooperate with one another, and also make the key points stand out. The

CCT development effort ought to focus on the major coal users, pay close attention to the key technologies, and make every effort to popularize the mature technologies. For some long-term strategic CCT projects such as direct liquefaction, and fuel cells, etc., some basic research work needs to be continued.

Some Views and Suggestions:

1. Because of the coal reserves and output, its dominant position in the energy sector will not change in the coming 30 to 50 years. The practical situation is that the Chinese coal has high ash content and its sulfur content will be rising as the coal mines deepen. For these reasons CCT development in China is of significance.

2. After several decades of effort toward CCT development, some areas of CCT have gotten extensive application in China. Some new clean coal technologies had a very good beginning, but now the gap in CCT development still exists between China and the more advanced countries, mainly because of the limited available scale and technical maturity of CCT.

3. The distribution of Chinese coal according to types and amount is not uniform. The industrialized east and southeast parts, which are home to the main coal consumers, have only a few coal mines producing mainly high rank coal; in the underdeveloped north and northwest parts, on the other hand, where the weather is very dry and water is scarce, large amounts of coal are produced. Certainly coal transportation has to be by long distance "from west to east" and "from north to south." In order to address this situation, strengthening coal preparation assets is necessary, and to use the coal near the mines would reduce coal transportation. It will be preferable to export the coal-derived products such as coke, gas, oils, tar, and electricity etc., instead of exporting coal from the coal mining area. For the selection of a preparation technology, water saving is the first consideration.

4. Because of the situation of Chinese coal with its variant types, performances and extensive use in many industries and trades, the Chinese CCT development needs to follow "suit measures to local conditions," i.e., to select the best technology according to the coal and the end use of the coal derived products.

5. It is suggested that in order to speed up the development of China's CCT, we should strengthen international cooperation. In some areas, we can import the best mature technology from the more advanced countries. To develop CCT we ought to share the work and cooperate with one another, emphasize focus on the main coal user, key technologies and mature technologies.

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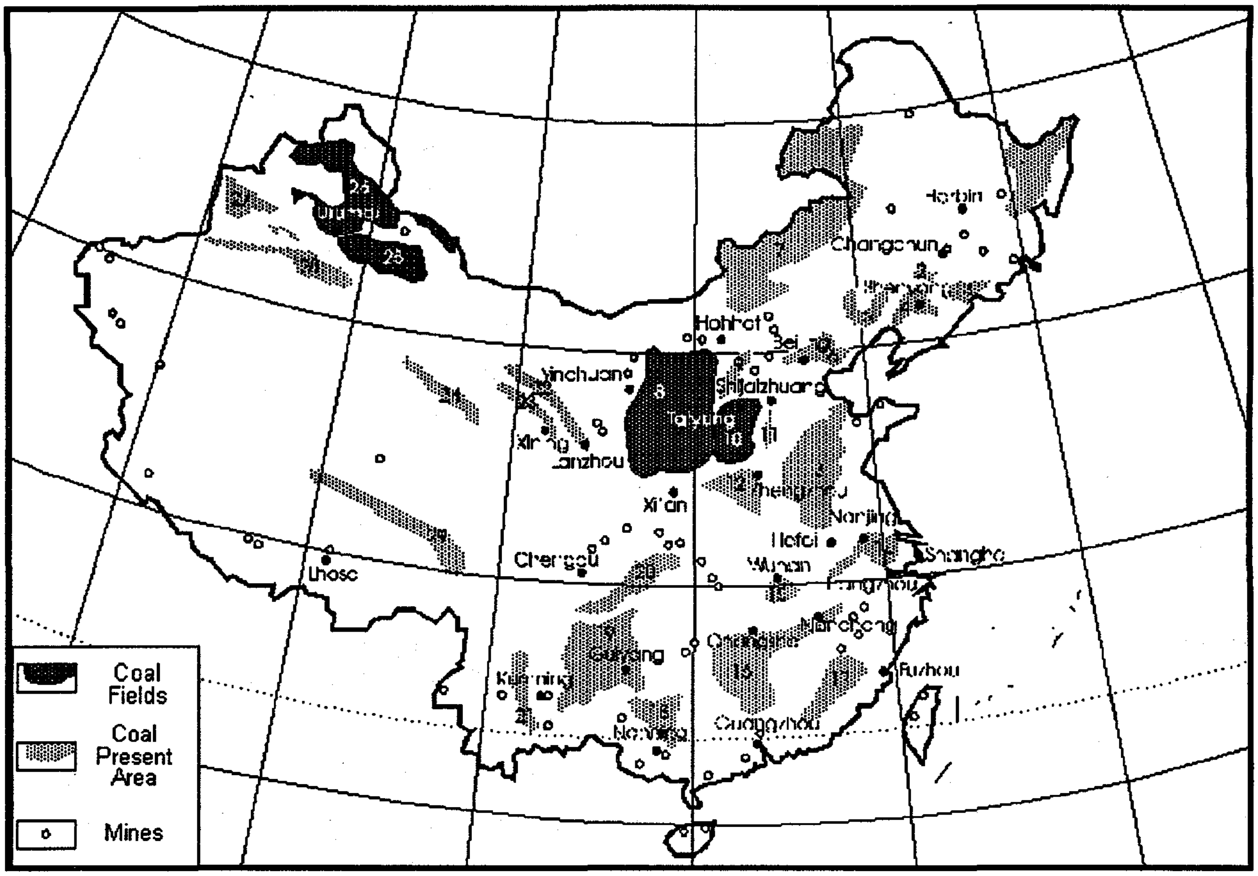

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Figure 1 Distribution of China's Coal Resources

1 – Sanjian Muling area; 2 – Northern Liaoning; 3 – Hun River area; 4 – Liao River and Taizi River areas; 5 – Western Liaoning; 6 –Beijing Tangshan area; 7 – Eastern Inner Aut Region; 8 – Erdousi Coal Field; 9 – Daning Coal Field; 10 – Qinshui Coal Field; 11 – Eastern Foot of the Taihangshan Mountains; 12 – Western Henan Province; 13 – Jiangsu Shandong Henan and Anhui Provinces; 14 – Zhejiang Jiangsu and South Anhui area; 15 – Southeastern Hubei Province; 16 – Hunan Jiangxi and Guangdong Provinces; 17 – Fujian and Guangdong Provinces; 18 – Central Guangxi Zhuang Aut Region; 19 – Guizhou Yunnan and Sichuan Provinces; 20 – Huayingshan Mountain area; 21 – Central Yunnan Province; 22 – Hexi Corridor area; 23 – Datong River area; 24 – Chaibei area; 25 – Tulufan Hami Coal Field; 26 – Zhungeer Coal Field; 27 – Yili area; 28 – Northern Fringe to Talimu; 29 – Northern Tibet Aut Region.

3. Perspective on IGCC in the Chinese Electric Power Industry

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Abstract

Integrated Coal Gasification Combined Cycle (IGCC) is the cleanest, most efficient and most mature among currently available clean coal power generation technologies. It is also an affordable technology for China. To strengthen the safety and diversity of energy supply, industrialized nations continue investing personnel and material resources to develop and improve IGCC. To realize the strategic goal of sustainable development, China has to accelerate the demonstration and development of IGCC based on Chinese energy reserves and the reality that, in China, the price ratio of oil and natural gas to coal is higher than that in industrialized nations. IGCC is a unique clean coal high technology in that it must be largely utilized and developed specifically for the nation in which it is to be used, and then carried forward by the nation.

Capacity and Power Generation in China

The Chinese electricity industry has made great progress since economic reformation and the opening of Chinese society. China's installed generating capacity was only 65,870 MW and annual power generation only 300.6 billion kWh in 1980. Installed capacity had risen to 210,000 MW and annual power generation 900 billion kWh at the end of 1995. Installation of new capacity will be at the rate of about 16,000 MW per year during "the ninth 5 years plan" from the year 1996 to 2000. At the end of the year 2000, the installed capacity is expected to be 290,000 MW and annual power generation 1,400 billion kWh. Both indices for the year 2000 will represent four times those for the year 1980.

Coal is the most plentiful among the verified primary energy reserves in China. Chinese power generation is fueled mainly by coal. Coal-firing accounts for the greatest proportion of Chinese power generation. Hydropower is second behind coal. Table 1 describes Chinese installed capacity, quantity of power generation and the proportion of thermal power and hydropower from the year 1980 to 1992[1]. From the year 1992, thermal power takes about 75 percent of total installed capacity and hydroelectricity about 25 percent. As concerns annual power generation, thermal power takes a greater proportion, about 80 percent, and hydroelectricity about 20 percent. It is predicted that thermal power will take an even slightly large proportion in the longer term, for example, before year 2020. To the end of the year 2000, the installed capacity of thermal power and hydropower is estimated at 220,000 MW and 70,000 MW respectively; and the annual generation capacities of thermal power and hydropower are estimated to be 1,120 billion kWh and 280 billion kWh respectively.

Table 1. Installed Capacity and Power Generation
from 1980 to 1992

Year	Installed Capacity			Power Generation		
	Total MW	Hydro %	Thermal %	Total TWh	Hydro %	Thermal %
1980	65869.1	30.8	69.2	300.6	19.4	80.6
1981	69132.6	31.7	68.3	309.3	21.2	78.8
1982	72359.6	31.7	68.3	327.7	22.7	77.3
1983	76444.9	31.6	68.4	351.4	24.6	75.4
1984	80116.9	31.9	68.1	377.0	23.0	77.0
1985	87053.2	30.3	69.7	410.7	22.5	77.5
1986	93818.5	29.4	70.6	449.6	21.0	79.0
1987	102897.0	29.3	70.7	497.3	20.2	79.8
1988	115497.1	28.3	71.7	545.1	20.0	80.0
1989	126638.6	27.0	73.0	584.7	20.2	79.8
1990	137890.0	26.1	73.9	621.3	20.2	79.8
1991	151473.1	25.0	75.0	677.5	18.4	81.6
1992	166532.4	24.4	75.6	754.2	17.4	82.6

Among the current thermal power capacity, there are about 30 oil- or natural gas-fired combustion turbines, whose installed combined cycle capacity is 1,500 MW. Since the nuclear and new energy power generation accounts for such a very small proportion of thermal power, about 1 percent the above mentioned "Thermal Power" is, essentially, thermal power fueled by coal.

Based on a study of energy strategy in China, the installed capacity of coal-fired power generation in the years 2010, 2020 and 2050 will be 369 GW, 500 GW and 820 GW, respectively; from the perspectives of peak-load requirements and environmental considerations, oil- and natural gas-fired power will occupy a certain proportion, the installed capacity for the years 2010, 2020 and 2050 being 45 GW, 75 GW and 150 GW, respectively.

Coal Consumption and SO_2 Emission in Coal-Fired Power Generation

The current average efficiency of Chinese coal-fired power generation is about 30 percent, that is, the busbar fuel consumption rate is 410 g/kWh. During "the ninth 5 years plan," new units will utilize those technologies with high parameters, high efficiency and capacity over 300 MW per unit. This will improve the overall efficiency and busbar fuel consumption rate to 32 percent and 380 g/kWh, respectively, by the end of the year 2000.

Based on the estimates, coal-fired power generation consumes about 0.325 billion tons of standard coal for the year 1995 and will consume about 0.43 billion tons in the year 2000. By the end of the year 2000, the annual SO_2 emission will be about 6.25 Mton if no means are carried out for desulfurization. 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.

Clean and Efficient Coal-Fired Power Generation

China is actively promoting effective means to reduce SO_2 emissions from coal-fired power generation plants. To enhance the development and acceptance of flue gas desulfurization for conventional PC units, actions include:

- Nuohuang Power Plant in Congqing utilizes wet flue gas scrubbing.
- Huangdao Power Plant in Sandong and Taiyuan Power Plant in Sanxi are to install simple flue gas desulfurization equipment.

- Xiaguan Power Plant in Nanjing will utilize Finland's Lifac desulfurization.

A lot of power plants are actively pursuing suitable desulfurization technologies and will utilize some technology in practical engineering.

Clean coal is the future of Chinese energy. In keeping with national energy reserves, technological and economic development, and the worldwide energy situation, the energy configuration with coal as the dominant energy will remain unchanged to the mid-21st century. It will still be impossible to reduce coal consumption at that time. The crude utilization of a large amount of coal has seriously damaged the resource and environmental bases for sustainable development. The unique opportunity is to develop clean coal technology to reduce emissions and improve efficiency and economic effectiveness. China is actively researching and developing clean coal power generation technologies:

- Develop and utilize the CFBC technology. A 100 MW CFBC has been installed and 200 MW and 300 MW CFBC units are being vigorously developed.

- Study and develop PFBC technology. The first pilot unit in China started construction at Xuzhou in the autumn of 1994.

- Strive for the establishment of the first 200 MW to 400 MW IGCC demonstration power plant in China around the year 2000. This will constitute a necessary basis for the popularization and utilization of IGCC technology at the beginning of the next century for China.

IGCC is the preferred technology, based upon research, development and demonstration of various kinds of clean coal technologies over all the world. The following are the features of IGCC:

- IGCC is the most mature of the emerging technologies. Two 250 MW commercial demonstration plants have been constructed, and another two 250-300 MW commercial demonstration plants are being constructed, and will be finished and ready to operate this year. IGCC is the most mature and largest in capacity among the above three kinds of clean coal technologies.

- IGCC is the most efficient. The constructed 250 MW IGCC plant in the Netherlands achieves the efficiency of 43 percent (LHV). The 300 MW unit under construction in Spain will be at 45 percent (LHV), which is the most efficient coal-fired unit to date.

- IGCC is affordable. It is predicted by METC of DOE, as shown in table 2, that IGCC plants constructed during the years 1995 to 2000 will feature 45 percent LHV efficiency with $1,200/kW capital investment. The initial investment for IGCC will be lower by 20 percent than that for the conventional pulverized coal plant (PC).

- IGCC is the cleanest. IGCC is acknowledged to be the cleanest coal-fueled power generation technology available today. It is very environmentally-friendly. Desulfurization can achieve 99 percent, and $DeNO_x$, 90 percent. CO_2 emission is reduced 30 percent. Therefore, the utilization of IGCC technology will be helpful for the health and quality of life for the current population and their descendants.

Table 2. IGCC Technology Assessed by METC

IGCC (Generation)	Duration	Efficiency (%)	Investment ($/kW)	Compared with PC (%)
the 1st	1985-1994	32-42	3,000-1,500	Higher 15
the 2nd	1995-2000	45	1,200	Lower 20
the 3rd	2000-2010	52	1,050	Lower 25

Primary Assessment on Technology and Economic Aspects of IGCC Development

Energy efficiency and saving are the most effective and economical ways to realize a sustainable development strategy. To create a sustainable power generation system, China places great hopes on IGCC. To establish an IGCC demonstration plant in the nation as soon as possible, some problems do exist and require solutions. The following assessment is just the author's opinion, upon which comments are welcome.

Assessment on the Technology-Maturity of IGCC

Could it be concluded that the IGCC is a mature technology just from the several constructed and constructing IGCC demonstration plants? For example, the so-often-mentioned hot gas cleanup (HGCU) system is not mature. How could IGCC be said to be mature when even the dust removal and desulfurization technologies are not mature?

The HGCU is not mature currently, but that does not necessarily mean that IGCC itself is not mature. The above-mentioned IGCC with high efficiency, 43-45 percent (LHV), doesn't use HGCU. If the HGCU technology becomes mature in the future, IGCC will achieve much higher efficiency. High temperature cleanup is a technology that adds flowers to the brocade for IGCC. It is not the case that PFBC must depend upon the success of the HGCU.

In fact, the current IGCC plant is integrated by two kinds of technologies. The first is the gas-steam combined cycle technology; thousands of units based on such technology are operating successfully all over the world including China. The other is coal gasification and purification technology with hundreds of such units also in successful operation throughout the world, again including China. The current IGCC using an entrained gasification process is mainly the integration of the previous two kinds of technologies, and does not require other innovative technologies except for the necessary control systems and auxiliary equipment. Therefore, if China chooses this kind of IGCC, no great risk in technology exists, and China can benefit from both foreign and domestic experience. Domestic experience includes combined cycle operations in power plants and entrained gasification and low temperature cleanup facilities in chemical industries. It is concluded that IGCC is potentially the most mature and the least risky technology among the clean coal technologies in China.

Assessment on Investment Cost of IGCC

Is it possible that the investment cost of IGCC during the year 1995 to 2000 will be $1,200/kW and lower 20 percent than PC as shown by METC?

The prediction by METC can be believed:

- The prediction by METC of IGCC cost during the years 1985 to 1994 is consistent with the following practices. So, there are reasons for believing METC's prediction of IGCC costs during the years 1995 to 2000. For example, the Wabash River 262 MW IGCC repowering demonstration plant, constructed in 1995, features an installed cost of $1,511/kW and efficiency of 40 percent LHV. This is reduced to $1,366/kW if the

$52 M allocated for the three years' demonstration is deducted. The cost of Tampa Electric's 260 MW IGCC demonstration plant constructed this year is $1,460/kW with 42 percent of efficiency (LHV). The cost of engineering for the above two is even lower than the METC prediction.

- Some European Union (EU) experts also hold opinions similar to those of METC. The cost of IGCC is very close to that of PC+FGD currently, and will be more competitive in the future due to the great potential to reduce cost(4). Investment cost, higher than that of USA, of the IGCC plants both under construction and those already completed are mainly the result of their being first or early demonstration, especially in the case of gasification. As the case in USA, the investment cost of IGCC in the EU will be greatly reduced following the first demonstration. IGCC has greater potentiality than PC for future reduction of investment cost.

Capital cost is an issue that will greatly influence the speed at which China adopts IGCC. Though IGCC is the cleanest most efficient technology, it will not be widely utilized if it is not affordable for China. The driving force toward IGCC applications only exists when the investment cost for IGCC is comparable to, or not much higher than that for PC. When will this situation come? China has no experience building and/or operating IGCC facilities in China but there is plenty of experience abroad with IGCC and market economics. The results from abroad should be believed. Progress and trends abroad are very important. If the investment cost of IGCC abroad reaches a level that is comparable to, or not much higher than PC, it will be appropriate for China to establish a demonstration plant as soon as possible. Of course, the first demonstration will be high in cost. What is the most important is that the nation will dissipate its energy resources if we do not actively develop and utilize improved technology such as IGCC when its capital cost becomes comparable to, and even lower than, PC in the near future.

Assessment on Effects of Dry and Wet Fuel Feed on IGCC Efficiency

In China, it is agreed that the efficiency of IGCC fueled by dry coal can reach 43-45 percent (LHV). There are different opinions whether the efficiency of IGCC fueled by coal slurry can reach 42 percent (LHV). For example, some believe that IGCC with coal slurry feed can reach a maximum of 36 percent LHV after improvements to the Coolwater IGCC design which operated at 32 percent LHV.

Because the efficiency influences the choice of technology, and even the decision, it is necessary to conduct thorough studies of the proposed technology given that, even after a great deal of debate, there exists no consensus concerning IGCC in China. Domestic experts utilized achievements in the analysis and synthesis of energy systems to integrate an IGCC generation system in 1994. This research concluded that the IGCC, fueled by coal slurry, does reach 42 percent LHV. This result was later verified by the IGCC observation group organized by State Science and Technology Commission (SSTC) and Ministry of Electric Power. After HGCU is mature in the future, the efficiency difference between dry coal- and coal slurry-fueled IGCC will reduce from the current one percentage point to 0.5 percent point. To date, all agree that both dry and wet fueling methods can reach high efficiency levels.

If China is to develop IGCC technology, one or several demonstration plants should be constructed first utilizing the IGCC technology that is mature abroad. It is not a fundamental issue whether dry coal or coal slurry fueled IGCC should be constructed first. The efficiency of coal slurry fueled IGCC may be lower, but not much lower, and its investment cost may also be lower. It is suitable for regions where the price of coal is low. The efficiency of dry coal fueled IGCC is higher, and it is suitable for the region where the price of coal is high. It can be predicted that no one kind of process has the market all to itself, either in China or abroad. As for gasification, both the fluidized bed and moving bed technologies will be utilized gradually after the utilization of entrained bed. All IGCC technologies with different gasification processes, including other clean coal technologies, that feature 45 percent LHV efficiency, reasonable cost and excellent environmental qualities, have the potential to contribute to the development of Chinese electricity production as long as China still relies largely upon coal to fuel its power plants, both in the near, and distant future

Assessment on Slow Applications of IGCC

If IGCC power generation technology features such high efficiency and low cost, why is it not being applied quickly? The Cool Water demonstration plant finished its successful demonstration in 1989. Seven years have gone by since 1989. To the end of this year, there is a total of only four 300 MW of scaled IGCC plants constructed over all of the world. So, some ask what are the criteria for application of IGCC technology in China when it has not been widely adopted in the rest of the world.

Some domestic experts inferred that IGCC is not widely used abroad because the actual low efficiency (32 percent, LHV) of the Coolwater demonstration plant broke the good reputation of IGCC, even though it was the cleanest coal-fired plant in the world at that time. The answer is not so simple. The DEMKOLEC power plant in the Netherlands has achieved a net efficiency of 43 percent (LHV). Why, then is it not heard that a second IGCC plant will be built in the Netherlands? On the contrary, the Netherlands will establish 1,700 MW of natural gas-fired, combined cycle during the years 1995 to 1996[5]. So, there are other important reasons why IGCC is not being used widely abroad.

A lot of experts abroad think that the relatively low price ratio of natural gas (including oil) to coal is the main reason why IGCC is not being widely used abroad. Such an opinion is consistent with the current practical situation. While natural gas-fueled, combined cycle features low investment cost and low operating costs with natural gas, IGCC is not competitive with it, and neither is Conventional PC with FGD. In recent years, the number of constructed IGCC and PC plants are few compared with natural gas-fired combined cycles (NGCC).

Table 3 gives some facts verifying the above opinion. Considering the data of ref. 6, the price ratio of natural gas (NG) to coal is 2.65/1.5=1.77 in the United States. For IGCC to be competitive with NGCC, the price ratio between natural gas and coal must increase to 3.3. Otherwise, there will be no economic incentive to build IGCC plants. Recently, IGCC investment cost has reduced to $1,400/kW while efficiency has increased to 42 percent LHV. But, the price of natural gas also has been coming down. So, some experts think a price ratio of 4.0 is the necessary market condition for the wide application of IGCC[7].

Table 3. Cost Comparison among IGCC, NGCC and PC

Data[6]	Technology	NGCC	IGCC	PC
	Investment ($/kW)	680	1,700	1,650
	Efficiency (%, HHV)	47.50	37.95	35.45
	Fuel	NG	Coal	Coal
	Fuel price [1] ($/$10^6$ Btu)	2.65	1.5	1.5
Derived Data	Fuel price	0.105 $/Nm^3	0.041 $/kg	0.041 $/kg
	Fuel consumption	0.181 Nm^3/kWh	0.322 kg/kWh	0.345 kg/kWh
	Fuel cost ($/kWh)	0.0190	0.0132	0.0141
	Depreciation ($/kWh)	0.0146	0.0364	0.0354
	Electricity Cost[3] ($/kWh)	0.0336	0.0496	0.0495

	Notes: 1. According primary operating data, NG price/Coal price=2.65/1.5=1.77 2. Depreciation rate=15%, Operation time=7000 h/y 3. Electricity cost=fuel cost + Depreciation cost 4. If electricity cost of NGCC equals that of IGCC, the price of NG should be \$0.193/Nm^3, i.e., 5/10^6 Btu 5. The necessary condition that IGCC is competitive with NGCC is: NG price/Coal price=5/1.5=3.33

Why do the industrialized countries spend enough personnel and material resources to develop and improve IGCCs even when they are not using the technology in the recent period? The reasons are difficult to guess. Some of them may be as follows:

- The oil and natural gas reserves are not as plentiful as coal. IGCC is currently an effective and economical way to utilize coal efficiently while protecting the environment.

- The pursuit of safety and diversity in the energy supply is served by a reduction of dependence on oil and natural gas. IGCC is the technology that can further that goal.

- The development of IGCC technology may play an important role in prohibiting the utilization and cost of oil and natural gas from rising suddenly and sharply.

- The development of IGCC technology can provide some technological support for the development of more advanced integrated gasification fuel cell technology.

The above analysis and understanding of the status of IGCC development abroad may inspire the decision making for IGCC development and utilization in China. Because the price ratio of natural gas (oil) to coal is about 3 to 4 in China, it is not the case there that IGCC cannot be competitive with NGCC due to fuel price. In addition, the electricity production configuration that utilizes coal as the dominant energy source will remain unchanged to the mid-21st century. Following market economic principles, the situation that IGCC investment costs have been comparative recently and are projected to be even lower in the near future than PC abroad, will also be verified in China. Therefore, current fuel cost conditions in China favor the acceleration of IGCC demonstration and development, unless and until the oil and natural gas prices are suddenly and sharply reduced in China.

Currently, some people hold the idea that IGCC should be imported only after it has been proved through wide use abroad. This idea is incorrect. IGCC units will not be used widely abroad due to lack of market driving force unless the oil and natural prices rise suddenly and sharply in the near future. Based on Chinese energy reserves and the situation of the nation that the price ratio of oil and natural gas to coal is higher than that in industrialized nations, IGCC is perhaps a unique clean coal high technology that must be widely utilized and developed in China in spite of the reluctance of other nations, and then carried forward by the nation.

Concluding Remarks

- During the long time period from the present to the year 2050, coal-fired power generation will be the main fuel for generation of electricity in China.

- To realize sustainable development, clean coal technologies are the future of coal-fired power generation and are the unique way by which coal-firing technology will be developed.

- IGCC is the cleanest, most efficient and most mature technology among currently available clean coal power generation technologies.

- IGCC is an affordable power generation technology for China. IGCC investment cost has been comparative with currently and even lower than projected, near-term PC costs. There is also greater potential for IGCC to reduce cost further.

- IGCC units will not be used widely abroad due to lack of market driving force unless the oil and natural price rise suddenly and sharply in the near future. The preferred power generation technology is oil or natural gas-fired combined cycle abroad. The point-of-view that IGCC should be imported in China only after it has been widely used abroad is incorrect.

- To strengthen the safety and diversity of energy supply, industrialized nations continue investing enough personnel and material resources to develop and improve IGCC. To realize the strategic goal of sustainable development, China is presently in the situation that accelerating IGCC demonstration and development makes sense based on Chinese energy reserves and the fact that the price ratio of oil and natural gas to coal is higher than industrialized nations. IGCC is perhaps a unique clean coal high technology that must be widely utilized and developed firstly in China rather than in other nations, and then carried forward by the nation.

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4. The Application of Coal Gasification Processes in China

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Accumulated Experience of Coal Gasification Process in Chinese Chemical Industry, Particularly for the Entrained Flow Gasification Process

General

27.6 million tons of ammonia and 1.1 million tons of methanol have been produced, and coal as feedstock accounted for about 65 percent of total usage in China in 1995. Before the 1980s, the process for the production of raw synthesis gas for ammonia and methanol with coal feedstock was discontinuous operation fixed-bed in China. It is well known that the shortcomings of this process are not only low-efficiency and high-pollution, but also the demand for anthracite or coke as feedstock. There are only two large mining areas in China – Yangquan and Jincheng, which produced coal amounting to 20.6 million tons in 1994. The ratio of the price of coal mined in these areas to the transit fee is about one to one. Therefore, the traditional coal gasification process is still limited by anthracite output and transit difficulty to further development in the syngas area.

In order to develop our coal chemical industry, to produce more chemical fertilizer and to support agriculture, Lurgi and Texaco gasification technologies have been imported selectively from among modern coal gasification processes that appear promising. Experience has demonstrated that the latter (Texaco) is appropriate to production of ammonia synthesis gas. Jinling, Dongting, Hubei– nine Texaco coal gasification facilities in all – are being demonstrated. The status of imported technologies is as follows as of the end of 1995:

Table 1. Imported Status

Location	Unit Capacities t coal/day	Contractors	Remark
Shanxi	1,200	Lurgi's license and contractor	Commissioning in July 1987
Lunan	350	Texaco's license and PDP, designed by China	Commissioning in Apr. 1993
Wujing	1,500	Texaco's license and PDP, designed by China	Precommission in May 1995
Weihe	1,500	Texaco's license, designed by China contractor: UBE (Japan)	Precommissioning in Feb. 1996
ShouGang	1,000	Texaco's license. Contractor: CTIP (Italy)	Imported all facility in 1989
Jinling, Dongting, Hubei	1,500 x 3	Texaco's license and PDP, designed by China	Start engineering in 1996
Changshan, Quhua, Haolianghe, Huainan, Liujiaxia, Handan	1,000 x 6	Texaco's license and PDP	Feasibility study at present

Shanxi Chemical Fertilizer Plant – Lurgi Coal Gasification

The Lurgi dry-bottom, fixed-bed gasifier is the most widely applied pressure gasifier today. The most important plants are SASOL in RSA (Capacity 30 million tpy of bituminous coal) for the production of synthesis gas for liquid fuels and chemicals and DGC (Dakota Gasification Company) in the United States where 4 million tpy of lignite are being processed into 160,000 normal cubic meters per hour (Nm^3/h) of SNG (Substitute Natural Gas).

The Lurgi gasifier operates in the fixed-bed mode with the coal and the gasifying agent flowing counter-currently. This leads to lower oxygen consumption and higher cold gas efficiency (about 90 percent of the coal's heating value is converted to chemical heat in the product gas), but the gas leaves the gasifier with entrained coal dust, tar, and other organic matters.

Lurgi has supplied complete engineering and equipment for the gasification facility of the Shanxi Chemical Fertilizer Plant, consisting of four (one spare) Mark IV gasifiers, each having an internal/external diameter of 3,848/4100mm, and their ancillaries. These gasifiers operate at 3.1 MPa(A), and have capacities of 16.69 tons of coal per hour per gasifier and produce

36,000 Nm^3/hr syngas. Construction and erection began in July 1983 and the gasification unit commissioning was completed in July 1987. The running results are as follows:

1. The gas leaving the gasifier contains the following composition in percent by volume:

   CO_2=27.28, CO=23.23, H_2=39.08, CH_4=7.93, H_2S=0.08, C_2H_4=0.03, C_2H_6=0.44, N_2=1.31, and Ar=0.62.

2. The flow rate in kg/h is as follows in entrained matter in gasifier exit gas:

   ammonia=516, Chlorine=20, fatty acid=35, Naphthalene=26, naphtha=68, oil=211, tar=358, and particulates=672.

3. After running for about 6 years by the end of 1993, the highest production capacity attained was 90 percent of design value. The gasification unit shut down constantly because of clogging. The clogging units are as follows: coal gasification, ash treatment, gas-water separation, ammonia recovery, gas cooling, carbon monoxide shift, gas purification (Rectisol and liquid nitrogen wash system) and methane reforming. The scaling material consists of coal dust, tar, ammonium carbonate, naphthalene, silicate and soot.

The following conclusions met with general acceptance following 8 years experience:

1. The Lurgi dry-bottom, fixed bed gasification process is not suitable for semi-anthracite and it has specific requirements for feed coal size and coal species.

2. The main failure is clogging, there is no effective separation process for coal dust, tar, hydrocarbon, ammonium carbonate, soot, etc., up till now.

3. The waste water treatment is complex.

Lunan Texaco Coal Slurry Gasification

Facility Design

In view of the anthracite shortage and comparatively high price of coal, the need for an economical and effective process for non-anthracite coal gasification is vital. State Planning Commission, State Science and Technology Commission, and Ministry of Chemical Industry of the PRC paid attention to developing new coal gasification process enough, decided to setup an installation which could serve as a demonstration, so as to change the species of feedstock coal (see 2.2), at the same time, China made an imported program.

Lunan Chemical Industry (Group) Company signed a contract with Texaco Development Corporation of the United States, to procured the license and Process Design Package for Texaco Coal Gasification Process (TCGP). The engineering basic and detail design and the procurement of imported key equipment, valves and metallurgy were completed by the First Design Institute of Ministry of Chemical Industry of China, and became fourth International contractor behind Bechtel (U.S.A.), Uhde (Germany), and UBE (Japan). The project capacity is 350t coal/day to generate 80,000 tons of liquor ammonia per annum. The accumulated design experience is as follows:

1. Developed the technology for adding flux agent (calcium carbonate) into "Qiwu" coal and rubber-lined ball mill.

2. Designed gasifier, slag lock, slurry tank with agitator, Venturi scrubber, scrubber tower, slag driver, pump for scrubber tower and slag lock, heat exchanger, flash tower and so on, the home-designed-made equipment accounts for about 90 percent.

3. Improved the Texaco liquid-level controller of the vacuum evaporator, and developed anti-wear technology for the tubes of flash system.

4. Developed temperature control technology for gasifier by gas composition.

Running Condition

The facility completed precommissioning in February 1993, first produced syngas in April 1993, produced at full capacity in February 1994, and achieved 120 percent of design load in July 1995. The comparison between design and running values is seen in table 2.

Table 2. Comparison between Design and Running values

Project	Unit	Design Value		Running Value	
Gasification pressure	MPa	4.0		2.7~3.0	
Oxygen charge rate	Nm^3/h	10,000		11,500	
Composition of oxygen	%	99.5		99.8	
Slurry	solids %	63 ± 1		65 ± 1	
Load of gasifier	m^3/h	18.6		22.0	
(slurry charge rates per gasifier)	t/h	14.6		17.6	
Syngas composition	v %	CO	45.03	CO	45.1
		H_2	35.1	H_2	35.42
		CO_2	18.53	CO_2	18.54
		N_2+Ar	0.14	N_2+Ar	0.11
Syngas flow rate	Nm^3/h	27,262.5		33,234	
Working time ratio of gasifier	%	100		96.89	
Carbon conversion	%	-		~96	

The improvements of the gasification system in the running course are as follows:

1. Clogging

In May 1993, when the gasifier had run for 600 hours, serious scaling was found in the black/gray water system, resulting in reduced inner diameter in the Venturi scrubber, decreased heat-exchange efficiency and narrowed flow section in the quench ring. Taking aim at these probable occurrences, the following measures were taken after analysis and research.

- The scale in Venturi scrubber was mainly carbon ash, calcium carbonate, and silicate. The clogging was successfully resolved when a new type anti-scaling agent and dispersion agent were added into the gray water and the flow distribution in the Venturi scrubber was modified. No more scaling occurred in the scrubber.

- By adding anti-scaling agent and dispersion agent into the gray water system, problems of gray water heat-exchanger and quench ring were solved to a considerable extent. Now the gray water heat exchanger is cleaned after 4,000 hours, and the operating period of the gray water pump is extended effectively.

2. Refractory brick

Lunan's gasifier has used French ZIRCHROM 80 and ZIRCHROM 90 and China Luo Nai refractory brick, the running status is list in table 3:

Table 3. Running status of refractory brick

Project	Running hours	Erosion ration (mm/h)	Price ratio
Lou Nai	1,877.5	0.0317	0.5
ZIRCHROM 80	4,679.6	0.0412	1
ZIRCHROM 90	1,499	0.016	1

3. Process burner

The Lunan Chemical Industry (Group) Company imported four process burners and six burner heads from the U.S.A. before the start-up in 1993. All of the new process burner heads have been made in Lunan since 1994. Table 4 provides a list of running status.

Table 4. Running status of process burner

Project	Service life
Imported burner	66 days
Lunan burner	62 days

4. Feedstock Coal

The design feedstock coal of the gasification unit is "Qiwu" coal that has higher ash fusion temperature. The fluid point is about 1,510°C. In order to reduce gasification temperature, oxygen and flux agent ($CaCO_3$) requirements, the "Qiwu" and "Baisu" coals were mixed at a weight ratio of one to one as the feedstock coal. The mixture has a lower ash fusion temperature, with a 1,280°C fluid point.

Shanghai Coking & Chemical Plant (Wujing) Coal Gasification

Texaco Slurry Gasification

The facility contains four gasifiers (one spare). The inside diameter of the gasifier shell is 2,800 mm and the inside diameter of the refractory brick is 1,676 mm. The operating pressure is 3.92 MPa, while treating 1,500 tons "Shengfu" coal per day to produce methanol and acetic acid. The Shanghai Coking & Chemical Plant procured the license and a process design package from Texaco. The project was designed by First Design Institute of Ministry of Chemical Industry, with start-up in May 1995. The capacity, gas composition, and carbon conversion numbers all have achieved the design target.

U-Gas Coal Gasification

The Shanghai Coking & Chemical Plant procured the license and a process design package from the Institute of Gas Technology of the United States. The project was designed by the Design Institute of Shanghai Chemical Industry, eight gasifiers with inside diameters of 2,600 mm, operating at 0.6 MPa, converting 8 x 120 tons of coal per day, with start-up in November 1994.

Slag clogging, lower carbon conversion, entrained coal particulates in the gas stream, and so on were found. The longest running period has been 7 days up until now.

Weihe Texaco Coal Slurry Gasification

UBE (Japan) was the contractor for this project and the Sixth Design Institute of Ministry of Chemical Industry of China participated in the basic and detail design. There are three gasifiers (one spare) with inside shell diameters of 2,794 mm, operating at 6.5 MPa, and treating 820 tons of "Huangling" coal per gasifier per day, with start-up in Feb. 1996. The facility is being test-run at present.

The Attained Level of Coal Gasification (Entrained Bed) to Date in China

1. When the license, the process design package (PDP), and the slurry pump, slag crusher, and a small number of key valves, instruments and metallurgy have been procured, the coal gasification unit can be designed, constructed, erected, and operated by China.

2. China had designed, constructed, erected, and successfully operated three coal gasification units – Lunan, Wujing, and Weihe, and, as far as the running time efficiency, technology target, safety and stability are concerned, these units are quite up to the level of Texaco's technology. There have been some developments, for example, the anti-clogging, slurry additive, start up measure and so on.

Applying the Operating and Manufacturing Experience of Coal Gasification Process Plants from Chemical Industry to Development of IGCC Technology

General

IGCC power generation is a kind of advanced technology. Its advantages are high efficiency and environment protection. So it is desirable to develop one kind of coal-based power generation in China. The IGCC consists of several subsystems including air separation, gasification and slag handling, syngas purification, heat recovery, gas turbine, HRSG, and steam turbine. Of these, gasification is the key technology. Currently, most of the large-scale IGCC power stations which have already been demonstrated, utilize entrained-bed coal gasification as discussed below:

IGCC Power Generation Plant Adopted Texaco Coal Gasification Process

The Cool Water plant utilized the Texaco coal gasification technology. The volume of one gasifier is 16.98 m^3 (600 ft^3), having an inside diameter of refractory brick of 1,828 mm and operating at 3.0 MPa, treating 700 tons coal per day; the volume of another gasifier is 25.48 m^3 (900 ft^3), with an inside diameter of refractory brick of 2,430 mm, operating at 3.0 Mpa, and treating 1,000 tons coal per day. The net electrical production of a single train is 100 MW. Start-up was in May of 1984, and the demonstration phase was completed demonstration in June 1989.

The Texaco coal gasification process is being applied by Tampa Electric at their Polk Power Station unit No. 1. The volume of the gasifier is 51 m^3 (1,800 ft^3) and the operating capacity is 2,300 tons per day of coal. It will produce about 257.8MW and will begin commercial operation in September 1996.

IGCC Power Generation Plant Adopted Dow Coal Gasification Process

The Louisiana Gasification Technology Incorporated (LGTI) plant is owned and operated by Destec, a Dow affiliate. It converts 2,400 tons/day of subbituminous coal, operating at 2.8 MPa, and started-up in April 1987. The capacity is 160 MW. The Wabash River Coal Gasification Repowering Project contains two gasifiers (one spare), operating at 2.8 MPa. It converts 2,500 tons coal per day, and it will produce 262 MW (net). It was commissioned in November 1995.

Buggenum Plant

This plant is based on a coal gasification process developed by Shell. The capacity of the gasifier is 2,000 tons coal per day, it produces 253 MW (net) and was commissioned in 1993. The demonstration years will be 1994-1996.

The above programs for entrained-bed coal gasification with IGCC power generation have convincingly demonstrated, on a commercial scale, the economic and environmental characteristics of these technologies. In China, the chemical industry has accumulated experience in the investigation, design, manufacture and operation of coal slurry gasification. This experience, once it is applied to IGCC power generation, will serve to reduce investment, promote safety and reliability of the facility and push IGCC forward in China.

Research and Development of Coal Slurry Gasification in China

The late 1970s, in the process of investigating entrained-bed, pulverized coal gasification, the Northwest Research Institute of Chemical Industry of the Ministry of Chemical Industry started to investigate and develop coal slurry gasification. In the mid 1980s, The First Design Institute of Ministry of Chemical Industry designed a testing facility, treating 24-35 tons of coal per day, and operating at 2.6-3.4 MPa, with slurry concentrations of 55 percent, 60 percent, and 65 percent, and gasification temperatures of 1,350°C, 1,450°C, and 1,550°C. Gasifiers with cooling walls and hot walls (inside diameter of refractory of 770 mm, height of cylinder of 2,400 mm), radiative boiler (inside diameter of 1,900 mm, height of cylinder of 9,070 mm), five burner types and six coal species have been tested. The experience gained provided the practical base that enabled the Lunan and Wujing facilities to be successful.

After Texaco Development Corporation visited the test apparatus and signed a contract with

Northwest Research Institute of Chemical Industry, they will accept the data from this facility as the basis of a process design package.

Operating Experience

The Lunan coal gasification unit will serve as an example for operating experience: it has been run with safety and stability for 3 years. The unit achieved 120 percent of design capacity and 96.89 percent of running time efficiency in 1995.

Slurry Preparation and Coal Species

"Qiwu," "Baisu," "Luoling," "Huangling," "Shengfu" coal species are all successfully adopted as feedstock coal for commercial gasification in China.

The slurry concentration, in terms of percentage of suspended solids, is about 65 percent, and the cost of additive per ton is about ¥ 10 (RMB).

Running Time Efficiency and Burner Exchange

As mentioned above, a 96.89 percent running time efficiency has been achieved and the ratio of charging feedstock coal successfully without having to resort to the start-up burner was 100 percent in 1995. The direct charging of feedstock coal was successfully performed without exchanging burners on December 13, 1994. This performance was repeated on May 28, 1995. The time required for start-up has been shortened greatly through experience. To date, the shortest time required has been only 32 minutes from shut down to start up.

Load and Technology Target

It has been demonstrated that the capacity of the Lunan coal gasification unit has reached 120 percent of its design value, the oxygen consumption per ton of coal has been reduced from the design value of 684.9 Nm^3 to an operating value 653 Nm^3. The product gas make per ton of feedstock coal increased from the design value of 1,867.3 Nm^3/hr to an operating value of 1882 Nm^3/hr.

Design and Manufacture Experience

Gasifier

Six gasifiers with inside diameters of 2,800 mm, for operating pressure of 4.0 MPa were built by Jinzhou Heavy-Duty machinery Works for Lunan and Wujing. The capacity of these gasifiers is about 500 tons coal per day each. As Lunan's gasification pressure was 2.8 MPa, only about 350 tons of coal was treated per day per gasifier. Three gasifiers with inside diameters of 2,800 mm, for operating pressure of 6.5 MPa were built by Haerbin Boiler Works for Weihe. The capacity of these gasifiers is about 820 tons coal per day each. Engineering has begun for nine gasifiers with inside diameters of 3,200 mm, for operating pressure of 4.1 MPa, which will be manufactured for Jinling, Dongting, and Hubei. The capacity of each of these gasifiers will be about 1,200 tons per day.

Refractory Brick

The service life of China Luo Nai refractory brick has reached a level between French ZIRCHROM 80 and ZIRCHROM 90, but the price is only half that of the French brick.

Other Equipment

Other equipment for coal gasification units which can be manufactured by China are ball mills, slag locks, quench rings, slag pumps, Venturi scrubbers, scrubber towers, flash towers, heat exchangers, gray water pumps, precipitation tanks and so on. In short, except for the high pressure positive displacement pump, the slag crusher and the process burner, the manufacturing means and expertise for all of the necessary equipment already exists domestically.

Applying the Experience to the Development of IGCC Technology

1. The Texaco coal gasification experience accumulated to-date by the Chinese chemistry industry can be directly applied to an IGCC coal gasification unit equivalent to 200 MW capacity.

2. China also has the ability to build an IGCC coal gasification unit of 400 MW IGCC generation capacity, based upon the accumulated experience.

3. China has accumulated experience in preparation of operating, maintenance, safety and training procedures, which could be applied to future IGCC plants.

4. The characteristics of coal slurry gasification dictated the lower cold gas efficiency (~70 percent) and worse load-following ability. However, the safety, stability, environmental protection, and high unit capacity could be competitive with other coal gasification processes.

5. IGCC — An Advanced Power Generation System with High Efficiency, Low Pollution, and Low Water Consumption for China

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As a kind of advanced power generation system which combines the efficient combined cycle with clean coal combustion technology, the integrated gasification combined-cycle (IGCC) has drawn warm attention recently. It represents one of the main trends for thermal power development extending into the next century. It is also supposed to be the right technology for China to open up a new thermal power development model characterized by high efficiency, low pollution and low water consumption. It will exert great influence toward assurance of sustained Chinese national economic development in the 21st century.

IGCC is Essential to China

China ranks first in the world in terms of coal production and consumption. In 1995, Chinese coal consumption is 1.298 Gt which accounts for about 3/4 of Chinese total primary energy consumption and 1/4 of the world's coal consumption. Coal takes the largest share in Chinese primary energy owing to its abundant reserves and low price. Its dominant position will remain for a quite a long term. The present coal utilization technology is facing a series of problems, such as low efficiency and serious pollution. The Chinese electricity generation network, of which thermal power is the dominant system (about 90 percent) and the conventional steam turbine as dominant unit (about 85 percent) has three main problems. The first is its high specific coal consumption (413 gce/kWh in 1994), the second is its serious pollution and the last one is its great water consumption which leads to difficulties for application in arid regions.

With the rapid national economic growth, the existing 210 GW giant electricity network will need to be duplicated. The resulting increase in energy waste and environmental pollution would be imaginable unless advanced technology is applied to repowering of the old power stations and the building of new ones. Clean coal combustion technology is the only answer to these problems in China. The ever-worsening pollution problems should be resolved simultaneously with the improvement of energy utilization efficiency.

Among those clean coal generation technologies under development worldwide, IGCC may rank as the most competent one with the following distinctive advantages:

(1) IGCC has the largest potential for raising net thermal efficiency. The net efficiency of IGCC has reached 40-46 percent and is expected to exceed 50 percent in the next century.

(2) It is easier to reach commercial scale, for example 300-600 MW.

(3) It is much more environmentally friendly. It can satisfy strict waste emission regulations even while burning sulfur-rich coal. The level of desulfurization can reach 98 percent or more. The amount of solid residue generated is small, and the byproduct can be sold.

(4) It is suitable for various coals and available to provide starting material for synthetic utilization. Combined with the coal chemical industry system, the multi-generation system can be utilized to provide electricity, heat, fuel gas and chemical products.

(5) It consumes 30-50 percent less water than the conventional steam station does, which not only makes it suitable to the arid areas, but also meets the requirements to build stations in mining fields.

(6) Based on the present level of experience in running combined cycle with coal gasifiers, the accumulation of technology for IGCC is close to being mature. The stream factors demonstrated by the demonstration plants (80 percent or more) can meet commercial operation requirements.

(7) The relevant technical achievements can be shared widely, it offers good prospects for new and advanced technological industries, such as the subcritical/supercritical IGCC, IGHAT and IGFC-CC, etc.

Key Factors for IGCC Commercialization in China

In recent years, most of the world's major petroleum/coal companies and power manufacturers have joined the IGCC R&D. Some significant progress has been achieved with the application of great manpower and material resources. Quite a few demonstration plants have been put into commercial test operation. The major competitors of IGCC in China are the conventional pulverized coal steam station (PC), the supercritical steam station (PC-SC) and the Pressurized

Fluidized Bed Combustor Combined Cycle (PFBC-CC). All three of these generation technologies will be developed at different levels and take shares in the versatile Chinese thermal power market. The portion of IGCC in The chinese generation network will largely depend on its thermal performance and economic properties, which are also key factors for commercialization of IGCC in China.

For quite a long period, the focus of developing IGCC has been put on thermal performance improvements, such as the advanced gas turbine and combined cycle, various gasification technologies, cold/hot gas purification technology, optimization of system integration including air separation and the steam circuit.

The combined cycle block is one of the cores of the IGCC technology, so the improvement of gas turbine performance is prerequisite to the development of IGCC. The typical values of gas turbines and IGCC are listed in the table below.

Table 1. Thermal performances for gas turbines and IGCC

		Simple Cycle		Oil/Gas Fired CC		IGCC	
	Gas Turbine Inlet Temp. (°C)	Power Capacity (MW)	Efficiency (%)	Power Capacity (MW)	Efficiency (%)	Power Capacity (MW)	Efficiency (%)
1980s	1,100	100	32-34	150	45	180	36
1990s	1,250-1,288	230	34-38	350	55	400	40-46
2000	1,430	280	38-40	480	60	600	-50

It is obvious that the IGCC with the 1980s-era gas turbine inlet temperature of 1,100°C can not compete against a steam turbine station. However, with a batch of the advanced gas turbines available in the 1990s, large-scale IGCC plants can raise their net efficiency to 40-46 percent, and thus can compete against conventional pulverized coal power stations. Therefore, economics are the most important factor for IGCC commercialization.

The specific investment of the earlier IGCC demonstration plant was $2,500/kW. It still ranges in the $1,500 to $2,500 per kW range for the projects under consideration. The following need to receive special attention to reduce the IGCC specific investment and generation cost:

(1) Performance can be improved through the improvement of key equipment, system optimization and simplification, e.g., the application of the new generation gas turbines ("G" and "H" series), the HGCU technology, the optimization of integrated air separation subsystems, R&D of IGHAT and IGCC multi-generation systems, etc.

Initial capital cost will drop significantly with technology progress and performance improvement. The relationship between IGCC technical performance and its investment cost given by GE (GER-3650C) is listed in the following table:

Table 2. IGCC technological performance and its investment cost

	Type of IGCC System	Gas Turbine Inlet Temp. (°C)	IGCC Eff. % (LHV)	Specific Investment Cost ($/kW)
Early 1990s	Conventional PC Unit		36-37	1,200
	Conventional IGCC Cold cleanup, Independent air separation	1,260 (F type)	38-42	1,400-1,600
Middle 1990s	Cold cleanup, Integrated air separation	1,260 (F type)	43-46	1,350-1,550
	Hot cleanup, Integrated air separation	1,260 (F type)	45-48	1,180-1,380
Late 1990s	Hot cleanup, Integrated air separation	1,370 (G, H types)	46-50	1,130-1,330

(2) Continuously enlarge the capacity of IGCC stations to reach economic operating scale. Larger capacity gasifiers and gas turbines should be used and spare furnaces eliminated if possible. Research work indicates that capacity has great influence on initial investment: specific investment cost will drop 10-20 percent when power output is doubled.

(3) Standardized plant designs should be established as early as possible. By this means, the specific cost of the Nth standard plant will be remarkably lower than that of the first one. The relationship of standardized plant design and the cost of a 500 MW IGCC plant was investigated by the CRSS Company in the United States. The result showed the investment in the Nth plant to be 40 percent lower than that of the first one. The investment reduction coefficient is commonly used in the economic analyses: for the first unit, R=1.1; second one, R=0.9; and the value will be 0.8 and 0.7 for the third and forth ones, respectively.

(4) Owing to the lower cost of labor, the investment required to establish a generation station in China is notably lower than that in the United States. Taking a PC station as an example, the specific cost will be $500-700 for the Chinese-made unit, and up to $800-1,000 when the chief equipment is imported from abroad, which are 50 percent and 20 percent cheaper respectively compared with costs for similar stations in the United States. Similar conclusions have been drawn for IGCC plants: if the specific price for a newly-built IGCC power station is $1,500/kW in the United States, then it will drop to $1,200/kW for the same unit in China.

(5) High-sulfur coal should be used to lower generation cost even further. Generation cost will drop 10 percent or so if the high-sulfur coal price is 10-25 percent cheaper than that of conventional PC power station, and can be even lower in the case of byproducts utilization (including elemental sulfur and glass-like residue).

Scientists both in China and abroad made comprehensive comparative analyses of IGCC, PC and PFBC-CC. Typical data are shown in table.3.

Table 3. Comparison of several generation technologies

		PC		PFBC-CC	IGCC
		Conventional	With FGD		
Capacity MW	Present	300-1,300	300-1,300	80-350	200-600
	2010			500	1,000
Net eff.	Present	36-38 (SC: 40-42)	34.5-36.5	36-39	40-46
	2010			45-50 (2nd generation)	50-54
Water consumption		100	100	70-80	50-70
Waste emission (%) (Compared with PC steam station)	SO_2	100	6-12	5-10	1-5
	NO_x	100	18-90	17-48	17-32
	dust	100	2-5	2-4	2
	solid waste	100	120-200	95-600	50-95
	CO_2	100	107	98	95
Specific investment ($/kW)		1,160	1,400	1,300-1,400	1,400-1,700
COE* mills/kWh		48-57	56-66	54-66	49-63

* Extraction from the Economic Analyses Report of Corp. (Based on 1991 U.S. dollars)

Explicit conclusions can be drawn from those analyses:

(1). The advantages of IGCC in environment protection and water consumption are indisputable. Waste emission is notably lower than that of the two others. The PC power station with FGD is just equivalent to PFBC-CC, and still can not compete against IGCC.

(2). Net efficiency of IGCC has already exceeded that of conventional PC and PFBC-CC (by 10 percent) and is currently equivalent to that of the supercritical steam station. The superiority of IGCC in thermal performance will increase continuously. For example, the steam parameters of IGCC can be supercritical also.

(3). The key factor for IGCC commercialization is economic. Its specific investment and generation cost are 10-20 percent and 6-10 percent higher respectively than that for the other two technologies. The specific investment will hopefully drop as the technology develops further and economic scales of production are reached, and is predicted to reach the level of PC (with FGC) in the early 21st Century.

China is Engaged in the R&D of IGCC with Great Enthusiasm

China had intended to build a pilot plant on two occasions about ten years ago. Although it was finally canceled owing to technical and financial difficulties, relevant R&D work never stops.

At the beginning of the 1980s, the late famous scientist Prof. Wu Zhonghua (C. H. Wu) proposed a policy of developing combined cycle: on one hand, oil/gas fired systems should be developed first at places where these fuels are available, which would provide practical experiences and save energy for the users; on the other hand, coal combustion technology should receive more attention, and then the technologies combined. For example, the Institute of Engineering Thermophysics of CAS, Tsinghua University and Thermal Power Research Institute of Electricity Ministry have been working at the fundamental and applied research of combined cycle total energy systems and have already made great progress in the research of system configuration, optimization and application.

Tens of combined cycle plants (the majority of which were imported) have been built in oil fields and at coastal cities, and a wealth of operation experience has been accumulated.

Nanjing Turbine and Generator Works, in collaboration with GE, has produced MS6001 gas turbines and combined cycle units. Harbin, Shanghai and Dongfang Steam Turbine works developed several types of gas turbines in the past years, and they are seeking international cooperation to develop large-scale gas turbines with good performance. Many engine works of the Aeronautical Ministry are working at aero-engine revisions for stationary engine use. Shenyang Metal Institute of CAS has developed M38 super alloy suitable to be used for 1,100°C turbine inlet temperature. Three power station equipment production bases have been established in Harbin, Shanghai and Sichuan Province to produce various types of steam turbines and boilers.

Chains Coal Chemical Institute of CAS began development of the air-blown fluidized gasification furnace in the 1980s, Northwest Academy of Chemical Ministry is working at various coal gasification experimental studies involving the Texaco furnace. Beijing Institute of Coal Chemistry of Coal Science Academy is engaged in experiment research on various gasification techniques.

Quite a lot of coal gasification equipment has been imported in different places, such as Lunan Chemical Fertilizer Factory (350t/d), the Capital Steel Company (1,000t/d), Weihe Synthetic Ammonia Works (2@820t/d). Harbin Steam Boiler Works and Jinzhou Heavy Machinery Plant have manufactured gasification installations with international cooperation. Chinese chemical industries are capable of designing and manufacturing cold and wet gas cleanup technology systems and have accumulated a lot of application experience.

Research work on HGCU technology has already begun. Some progress has been made in the gas-solid flow, desulfurization and purification processes.

Having worked hard for several decades, China now has a favorable foundation and good conditions for IGCC development. Great attention has been paid to international technological communication and cooperation with the United States, Europe and Japan. Now China is exploring international cooperation to go into R&D of key IGCC technologies and to set up a large demonstration plant.

In 1994, the State Science & Technology Commission and Ministry of Electric Power organized a convention of scientists from the whole country to make a feasibility study on the 200-400MW IGCC demonstration plant, which is supposed to be the new model for the Chinese coal-fired power station development as well as the training base for technician development.

Besides those mentioned above, some local governments have also considered building 50-100 MW IGCC plants and have carried out the relevant technical economic feasibility studies.

In general, China has realized the importance of clean coal generation technology and given it great emphasis in the following documents: the national energy policy and the program of energy development; the long and middle term science and technology development program for electricity industries, the priority projects in Chinese 21st Century Agenda.

There is a Good Market for IGCC in China

Various types of IGCC can be used in different departments in China.

(1) As a base load unit in a large electricity network: the total installed capacity of national power stations is predicted to reach 290 GW in 2000 and rise at 25 GW per year during the period of 2000 to 2020. The annual generated electricity will be 1400 TWh, most of them will be thermal power stations.

In the 21st Century, with improved performance, more advanced technology and further reduction in cost, IGCC will be in a better position compared with other generation technologies. There will be a market with an annual capacity of 3,000 MW for IGCC if it shares about 15 percent in the newly increasing capacity.

(2) Existing power station repowering with IGCC technology. Suffering from the problems of high specific coal consumption and serious pollution, the existing power stations urgently need repowering, especially those medium and small ones using old technology and performing poorly. Repowering by IGCC is proven to be an effective measure for old station rehabilitation. An IGCC station can be created simply by attaching a gas turbine and gasifier to the existing steam plant. The investment is low, owing to the reuse of some original equipment and factory buildings. It can also effectively enlarge capacity, reduce emission pollution and lengthen the technical economic life span of the old plant. The huge investment of building new stations can be avoided as well.

(3) IGCC power station construction at coastal areas. Because of rapid economic growth, there is a great demand for electricity in the coastal areas. For example, about twenty 600 MW coal-fired units are required now in the Pearl River area.

The method of building IGCC step by step (gas turbine first, then converting to oil or gas fired combined cycle plant, finally IGCC) has the advantages of short construction time, low initial investment, high efficiency and low pollution, thus it is deserving of application and dissemination in some areas in China.

(4) IGCC multi-generation system. Besides providing fuel gas to drive a combined cycle, coal gasification can produce chemical raw materials and urban gas simultaneously. The multi-generation system has good prospects for application because of its remarkable potential for reduction of investment as well as coal synthetic chemicals utilization. One IGCC multi-generation system is proposed to be established in Shanghai Wujing Coking Factory.

IV. U.S. FIVE IGCC EXPERTS DISCUSSION

1. **Overview of Clean Coal Technology in the United States**

   Dr. Benjamin C. B. Hsieh

2. **Short and Long-term Market Potential for IGCC in China**

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   Charles R. Black and Stephen D. Jenkins

1. Overview of Clean Coal Technology in the United States

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The Clean Coal Technology (CCT) Demonstration Program is a cooperative effort between the U.S. Department of Energy (DOE) and U.S. industry to demonstrate a new generation of technology for transforming coal into electricity. Those technologies that show the most promise for increasing the efficiency of energy use and enhancing environmental quality are to be moved into the domestic and international marketplaces.

U.S. Clean Coal Technology Demonstration Status

The worldwide demand for power is increasing every year at the same time the demand for a cleaner environment is mounting. Realizing that coal has been and will continue to be a major fuel source for power production, the U.S. DOE began the CCT program in 1985 to ensure that technologies will be available to allow the use of coal to meet these two demands. The clean coal technologies are demonstrated at commercial scale, and all projects are at least 50 percent funded by the industry partners.

Forty three CCT projects were selected in five competitive solicitation rounds over a span of nine years. The first three rounds concentrated on technologies that could mitigate the potential impact of acid rain. The last two mainly addressed the energy needs of the next century with technologies that promise very high efficiencies and extremely low emissions. Eighteen of the projects have been completed, 8 are now operating, 14 are undergoing construction or design, 2 have been canceled, and 1 (from the last solicitation round) is in negotiation. Over $7 billion in capital investment has been made with an average industry cost share of 67 percent of the total.

The projects (Figure 1) are categorized into four market sectors: Advanced Power Generation Systems, Environmental Control Devices, Coal Processing for Clean Fuels, and Industrial Applications.

The coal-fired power plant is being brought into the 21st century by the 14 projects in the Advanced Power Generation Systems sector. These projects total more than 1,000 MW of new power generation capacity and more than 800 MW of repowered capacity, at a total value of more than $4.6 billion. The projects offer significant improvements in plant thermal efficiency and cost of electricity, integral control of sulfur dioxide (SO_2) and oxides of nitrogen (NO_X), the mitigation or elimination of solid waste management problems, fuel flexibility, and increases in power output capacity for repowering applications of up to 150 percent. The predominant technologies in this sector are the Integrated Gasification Combined Cycle (IGCC) with five projects, and Fluidized Bed Combustion, with six projects.

To address the environmental performance needs of current coal-using power plants, 19 projects valued at more than $686 million have been selected in the Environmental Control Devices sector. The technologies feature high SO_2 and NO_x capture efficiencies, low capital cost, and mitigation of solid waste problems, all designed to meet the requirements of the 1990 Clean Air Act Amendments.

The five projects in the Coal Processing for Clean Fuels Technology sector are valued at more than $519 million and represent a wide range of technologies that help process coal into a cleaner and more valuable fuel.

Another diverse portfolio of technologies is encompassed by the Industrial Applications projects. These five projects with a total value of more than $1.3 billion, address the use of coal in industrial and production environments, such as substituting coal for coke in iron ore reduction and reducing coal-burning emissions in cement kilns.

U.S. Clean Coal Technology IGCC Projects

IGCC technology is one of the largest clean coal technologies both in the number of projects and in total dollar value. This is because IGCC technologies already deliver very strong environmental performance at competitive coal-use efficiencies, and promise even higher efficiencies at a lower cost of electricity in the near future. The five IGCC projects are the Wabash River Coal Gasification Repowering Project, the Tampa Electric IGCC Project, the Piñon Pine IGCC Power Project, the Combustion Engineering IGCC Repowering Project, and the Clean Energy Demonstration Project.

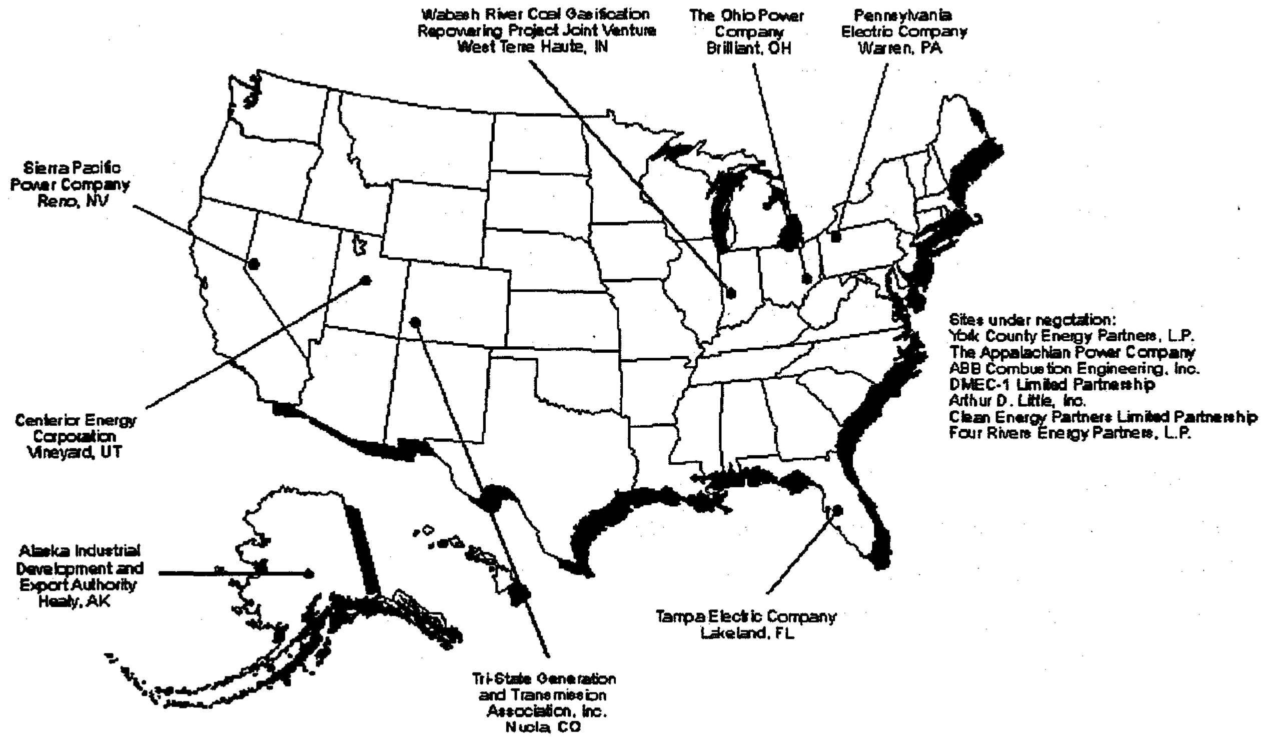

Figure 1. United States Clean Coal Project Locations

- ***The Wabash River Coal Gasification Repowering Project*** – This project is at the most complete stage of development of the five IGCC clean coal projects. It began officially operating on November 30, 1995, and will continue DOE co-founded operation through 1998. The project was selected in 1991 at a total cost of $438 million and is a joint venture between PSI Energy, Inc., and Destec Energy, Inc. The project produces 262 MW in a repowering application at a facility in West Terre Haute, Indiana, and is the largest single-train coal-gasification combined-cycle power plant operating in the United States. The gasifier technology is Destec's two-stage entrained-flow oxygen-blown slurry-feed system, and the combined-cycle system uses a General Electric (GE) 7FA gas turbine fueled by coal gas to repower one of six existing steam turbine/generators. A conventional cold gas cleanup system reduces SO_2 emissions by more than 98 percent and NO_X emissions by 90 percent, and a hot filter system removes particulates. The anticipated net heat rate for the repowered unit using high sulfur bituminous coal is approximately 2,150 kcal/kWh, or 40 percent LHV efficiency. Operation results in 1996 indicated that power output and heat rate met and exceeded the design values. The commercial offerings of this technology will be based on a 300-MW train. In a green field (new power plant) application, the technologies should produce at least a 20 percent improvement in efficiency compared to conventional pulverized coal plants with flue gas desulfurization.

- *The Tampa Electric Integrated Gasification Combined Cycle Project* – This project in Lakeland, Florida, is currently nearing construction completion and operation is planned to begin in September 1996. The total value of the project is $550 million, and it will produce 250 MW of electricity as the first part of the new 1,150 MW Polk Power Station. This project uses Texaco's slurry-feed oxygen-blown entrained-flow gasifier technology and will demonstrate both conventional cold-gas cleanup and the new hot-gas moving-bed desulfurization system on the medium Btu coal gas produced. The power block area includes the GE frame 7FA gas turbine, steam turbine, and a Henry Vogt HRSG. About 98 percent of the sulfur pollutants and particulates will be captured and will be processed into by-products, sulfuric acid, and slag that can be sold commercially. The net heat rate for this demonstration is expected to be approximately 2,050 kcal/kWh, or 42 percent LHV efficiency. This federally co-funded demonstration will run through 1998, and then the plant will operate commercially.

- *The Piñon Pine Integrated Gasification Combined Cycle Power Project* – In Reno, Nevada, the Sierra Pacific Company has chosen to install an IGCC system to meet anticipated load growth, citing the technology's advantages of flexibility, diversity and reliability. The Piñon Pine IGCC Power Project is nearing construction completion and operation is planned to begin in February 1997. The $309 million project demonstrates the KRW dry-feed air-blown fluidized-bed coal-gasification system with a GE Frame 6FA gas turbine, and is expected to produce an expected 99 MW of electricity. The KRW gasifier was developed in DOE's research and development program, and is one of the most efficient gasifiers, producing electricity at a net heat rate of 2,000 kcal/kWh or about 43 percent LHV efficiency. The gas cleanup system includes in-bed sulfur capture by crushed limestone injection, high temperature ceramic candle filters for particulate removal, and a regenerable metal-oxide hot-gas desulfurization system. Using Western U.S. bituminous coal (0.5-0.9 percent sulfur), this system is expected to reduce NO_x emissions by 94 percent and SO_2 emissions by 90 percent, and to remove virtually all ash impurities. The compact design of the KRW gasification system reduces space requirements compared with other coal-based power systems, and the fluidized-bed gasifier is capable of gasifying all types of coals, as well as bio- or refuse-derived wastes. The only solid waste from the plant is a mixture of ash and calcium sulfate produced in the gasifier, which is a nonhazardous waste suitable for landfill.

IGCC Status – Past, Present, and Future

Gasification of coal and other carbonaceous materials is not a new concept, and has been occurring for thousands of years in nature under certain conditions as carbonaceous materials decompose. In the early 1900s, human efforts at coal gasification were evident when town gas was provided for many communities by early batch-type fixed-bed units. During the 1930s and 1940s, Germany used gasifiers to reduce their national petroleum consumption. These earliest efforts have evolved into continuous throughput fixed-bed units such as the pressurized Lurgi gasifier, and then to entrained-flow gasifiers (Koppers Totzek) and the fluidized-bed (Winkler) gasifier, which were widely used in Europe and South Africa in the 1950s and 1960s.

IGCC was proposed as an alternative coal-fired power plant after October 1973, when political conflicts and rising oil prices occurred. At that time, the net efficiencies of combined-cycle plants were beginning to exceed the 38 percent LHV net efficiency of conventional steam plants, and the conventional steam-cycle plants of the 1970s were reaching their technological limits. In addition, the Clean Air Act of 1970 was forcing further reduction in power generation efficiencies, by such means as adding flue gas desulfurization (FGD) systems.

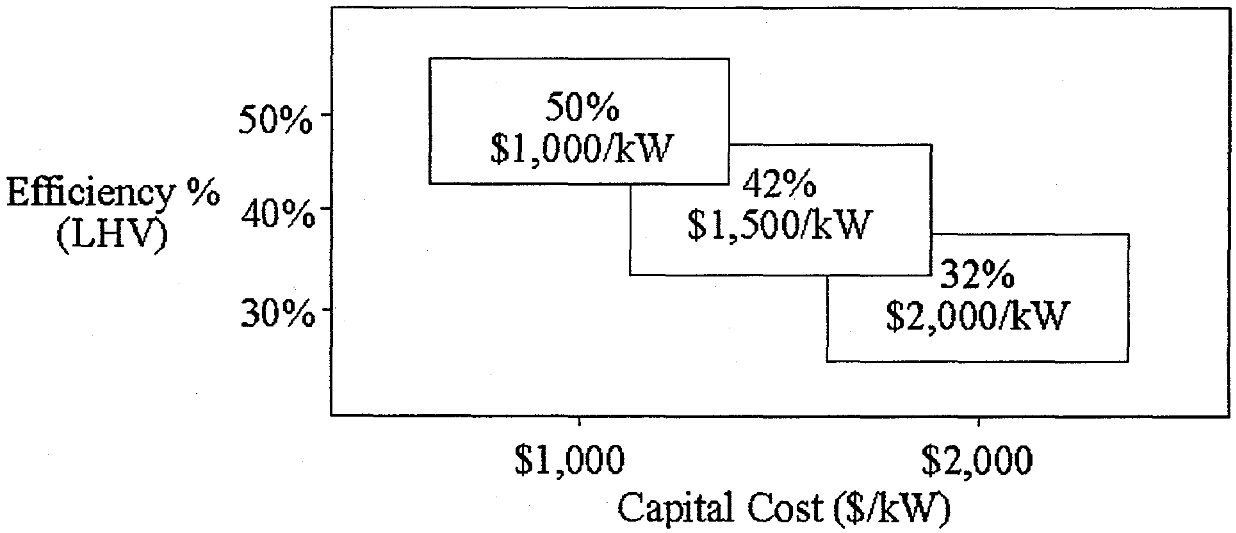

Figure 2. IGCC LHV Efficiency vs. Capital Cost

The gas turbine is a critical part of the combined cycle system and, in turn, also for the IGCC system. So-called industrial gas turbines were developed based on aircraft jet engines and the first gas turbine was operated in the U.S. in 1949. The gas turbine was rapidly developed during the

1950s. Until the 1960s, gas turbine technology was mostly used as a simple cycle for peaking purposes, since a gas turbine can be put on-line quickly without disturbing the normal operation of a base-load plant. During the 1960s, gas turbine technology became more efficient and more flexible for both intermediate-load and peaking service.

During the oil embargo of the 1970s, when dependency on foreign imports of petroleum was a problem in the U.S., larger gas turbines were successfully operated on natural gas and fuel oils in combined cycle mode. Gas turbine combined-cycle efficiency was also improved and by the 1980s, total combined-cycle net efficiency reached 45 percent LHV, which was about 10 percent greater than pulverized coal-fired power plants.

The first stage of IGCC development was marked by the Coolwater Project which featured a Texaco gasifier and a low-temperature cleanup system (CGCU) in combination with a General Electric 7E gas turbine and steam turbine IGCC system. Coolwater operated from 1984 to 1989 at a 100-MW scale, and demonstrated the viability and the excellent environmental performance of IGCC. This spurred development of several different gasification systems that are now commercially available. The Texaco gasifier, low-temperature cleanup system, and combined-cycle system used at Coolwater are now being improved and demonstrated on a much larger scale in the Tampa Electric IGCC Clean Coal project.

Combined-cycle net efficiency in the 1990s approaches 55 percent LHV. Gas-turbine combined-cycle technology has emerged as a leader for both base-load and peaking service for the production of power at low cost in high reliability and low maintainability operation. Further development and improvements in advanced gas turbine technology are expected to raise combined-cycle net LHV efficiencies to the 60 percent-plus range. IGCC power plant efficiencies account for about 80 percent of the combined-cycle system efficiencies that are used in the IGCC systems. Therefore, the net efficiencies of future IGCC systems could be close to 50 percent LHV (Figure 2).

Current commercial IGCC systems have demonstrated exceptional environmental performance at high efficiencies compared with the pollutants emitted from conventional coal-fired plants. Unparalleled success has been shown in reduction of SO_2 and NO_x emissions and in particulate removal. SO_2 and NO_x emissions are less than one-tenth of that allowed by New Source Performance Standards environmental control limits. While this level of environmental performance is not presently required in all world markets, the trend in all areas is for tighter environmental controls in the future. Thus, IGCC Technology is a safe hedge against future uncertainty.

Today's mature IGCC technologies have net efficiencies that exceed 42 percent LHV. By comparison, conventional coal-fired steam plants have increased net efficiencies from 27 percent LHV 50 years ago to 36 percent HHV net (at best), and supercritical PC steam plants to 38 percent HHV net to meet the requirements of the 1990 Clean Air Act Amendments today. Conventional PC and supercritical PC plants are limited to the efficiency of the Rankine (steam) cycle, while IGCC plants take a step up in efficiency by combining the Rankine cycle with a Brayton (gas) cycle.

The capital cost of today's proven IGCC technology ranges from $1,400 to $1,600 per kilowatt in new power plant installation based upon "F" class turbine technology. Current conventional IGCC with low-temperature cleanup system and "G" class turbine technology is expected to yield 45 percent efficiency (LHV) with costs $200 less than the case with the "F" class turbines. The same system with the "H" class turbine technology would yield 50 percent efficiency and $400 lower cost per kilowatt than the "F" class turbine technology.

More advanced IGCC systems, featuring currently-available technology and "G" class turbines under development and demonstration today for commercialization after the year 2000, target net efficiency levels of up to 45 percent LHV and reduction of capital costs to $1,200 per kilowatt. These advanced IGCC systems will differ from those commercially available today in that they may use hot gas cleanup at 800 to 1,200°F, with air-blown gasifiers operating at 1,800°F. The lower capital costs and increased efficiencies will lower the cost of electricity, while maintaining the exceptional environmental performance.

Improvements in gas turbine technology and advanced gasifier systems will mark the development of IGCC systems that will show net system efficiencies of 50 percent LHV by the year 2010 or earlier. The exact timing will depend upon the cost and availability of natural gas. Innovations from DOE's Advanced Turbine System program will be adapted to coal gas, allowing higher efficiencies, and by 2010, capital costs are expected to be even lower at $1,050 per kilowatt. Given the expected price rise in other fossil energy fuels such as natural gas, the future IGCC system will not only be superior in cost of electricity versus conventional coal power plants, but also will be competitive with natural-gas combined-cycle plants in environmental performance.

Benefits of IGCC for Utilities

In addition to superior environmental performance, high efficiency, potential lower capital costs, and lower cost of electricity, IGCC systems have several other benefits that are important to utilities making decisions about new power generation capacity. IGCC technology is suitable for repowering existing power plants. Adding a gasifier and gas turbine to the steam turbines and other miscellaneous systems of an older power plant allows major improvements to plant performance without the total cost of a green field (entirely new) facility. Repowering can dramatically reduce a plant's pollutant emissions and increase the generating capacity up to 250 percent.

Many gasifiers are fuel flexible; that is, they can gasify high or low-rank coals and many other carbonaceous feedstocks. IGCC systems can also allow fuel flexibility through staged construction. For example, a first-phase installation might include only a gas turbine that would burn natural gas to meet topping loads (intermittent use). Adding a steam turbine would create a combined cycle system, which would increase plant output and efficiency when needed. A third phase of installation would integrate a gasifier and gas-cleanup system when justified by low coal prices, lack of natural gas availability, or the need to convert the plant to base-load capacity (constant use). The small footprint and modularity of several gasification systems make them ideal for this application.

Other environmental advantages of IGCC systems include low water use and low carbon dioxide (CO_2) emissions. The water required to operate an IGCC plant is only 50-70 percent of that required to run a pulverized coal plant with an FGD system. Because their higher efficiency translates to less coal consumed per unit of power produced, IGCC systems offer significant reductions in total CO_2 emissions.

Mature IGCC systems also have the advantage of high throughput and large power production from a single train (system). Circulating fluidized bed combustion (CFBC) systems are generally limited to less than 100 MW per train because they operate at atmospheric pressure. IGCC systems, on the other hand, provide up to 300 MW per train. Although pressurized fluidized bed combustion (PFBC) systems overcome this limitation by operating at high pressure, none are commercially available today. After the year 2000, CFBC systems could produce 250 to 300 MW per train. However, IGCC systems should produce 450 to 550 MW in single train.

Currently available IGCC systems offer considerably improved RAM (reliability, availability and maintenance) performance, making them attractive for base-load power generation. Today's pulverized coal plants have availability rates of 60 to 80 percent, while IGCC systems have greater than 90 percent availability.

Waste disposal is minimized by the production of salable by-products. Ash and other trace elements are melted in the IGCC system, and when cooled, they form an environmentally safe, glass-like slag that can be used in the construction or cement industries. Sulfur in the coal can be captured by the gas cleanup processes and turned into marketable elemental sulfur or sulfuric acid. The waste disposal stream is minimized by gas-cleanup systems that employ reusable sorbents to remove the sulfur from the coal gas. By contrast, FGD in traditional coal-fired plants uses sulfur sorbents that require large amounts of solid waste disposal.

IGCC technology can also be much more than just an electricity generating system. The coal gasification process can be diverted to co-produce such products as methanol or gasoline fuels, urea for fertilizer, hot metal for steel making, and chemicals. The large quantities of low-level heat available in the IGCC system make it ideal for co-generation use in manufacturing processes that require steam, such as paper mills, or in district heating.

2. Short and Long-term Market Potential for IGCC in China

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Introduction

Global power generation markets have experienced a growing penetration of GT/CC technology for oil and gas fired power generation applications. This is primarily due to the fact that the gas turbine technology has reached higher and higher power densities with very high levels of efficiency and reliability. The current technology levels of the GT/CC can now also be used to lower the cost of electricity and increase environmental acceptance of fuels such as coal, heavy oil, petroleum coke and waste products through the application of clean coal technologies.

Four different technologies are in various stages of development, including slagging combustors, Pressurized Fluidized Bed Combustion (PFBC), Externally Fired Combined Cycle (EFCC) and Integrated Gasification Combined Cycle (IGCC). At this point in time, the only technology considered commercial is IGCC.

Wide ranging research and development efforts have been focused on combining the fast growing combined-cycle power generation technology with gasification using low cost fuels. The IGCC technology has been proven through pilot plant and demonstration facilities. The technical/ environmental features and suitability for power generation plants were demonstrated in the 1980s. However, the economics were disappointing until the next generation GT technologies became commercially available in 1990. As a number of IGCC projects were ordered for commercial operation in the mid-1990s, some of them still with development support from the US Clean Coal Technology (CCT) Program, we are on the threshold of demonstrating commercial IGCC economic viability. Currently there are over 10 projects under various levels of construction and start-up with commercial operation dates between 1996 and 2000.

The following discussion will focus on the potential penetration of IGCC technology into the electric power system of the PRC. Current GT/CC technology will be assumed for the short-term time period, including a full-size demonstration facility. Long-term penetration will be discussed based on the next generation of GT/CC technology assumed as available for commercial operation around year 2000. The electric power system data used in this discussion was obtained from the publication "Electric Power Industry in China 1994" edited by Information Research Institute MEP and published in 1994.

Power Generation Market Issues

On a world-wide basis, the market for heavy-oil and coal power plants is quite large, estimated at around 350 GW of orders during the next 10 years. The characteristics of this market is somewhat different for each region and country. These differences typically stem from regional or country cost characteristics, population distribution, environmental concerns and characteristics, type, cost and availability of fuels, and the availability of hydro and other renewable energy resources. In particular, for segments where the concerns about the environment is strong, even current IGCC technology will compete favorably with other generation technologies.

Efficiency and plant cost are the most significant factors to determine IGCC penetration, even in environmentally sensitive segments, as they are the major factors in determining the cost of electricity.

The current levels of GT/CC technology can compete where environmental concerns force utilization of poor quality fuels and also where it is possible to take advantage of the IGCC technology's ability to co-produce chemical products like hydrogen or methanol in addition to steam and electricity.

The next GT/CC technology level is expected to yield IGCC plants with economic characteristics, like plant cost and efficiency, that would be superior to conventional coal-fired power plants in many of the market segments. Table 1 below shows plant sizes, efficiencies and projected plant cost levels for current and the next level of GT/CC technologies.

Table 1. IGCC Technology Reference Data

GT/CC Technology	Plant Sizes MW	Plant Cost Range $/kW	Efficiency Range % (LHV)
Current	120 - 390	1400 - 900	40 - 46
Next Generation	460 - 550	1000 - 800	49 - 51

Data Source: General Electric Power Systems

Some regions and countries of the world have current plant cost and fuel cost levels where the general conclusions above may not be appropriate. Plant costs for large field-constructed power plants, like conventional steam plants and IGCC plants are affected by local labor and manufacturing costs for components and systems that can be produced locally as well as the cost of construction. In China, for an example, the cost levels of a coal-fired steam turbine power plant with all in-country content have historically been well below the world average plant cost levels for comparable plants. Flue-gas scrubbers for de-sulfurization have not been applied widely in China which has also contributed to relatively lower plant cost levels. This will cause a slower penetration of IGCC technology in China in the short term. The plant cost relationships between IGCC and conventional steam coal plants in China is also affected by a current absence of significant domestic gas turbine manufacturing capability. Future increases in the application of air pollution abatement equipment, a narrowing trend in general cost levels and possible increased domestic gas turbine manufacturing capability in China will likely contribute, over time, to relative plant cost relationships similar to typical world averages. This will allow the IGCC technology to compete more favorably with conventional coal-steam plants.

Generation Additions Alternatives in China

Installed generation capacity in China was approximately 183 GW in 1993. Thermal generation was around 75 percent of this amount with Hydro power at 25 percent. Most of the thermal generation consists of steam power plants burning coal. It is expected that over 15 GW in generation capacity per year must be added in order to reach the projected 300 GW in generation capacity around year 2000. The overall goal is to keep the 75/25 percent relationship between thermal and hydro capacity. Nuclear power will continue to be added, but the vast majority of the new thermal generation will be coal-fired.

With this scenario as a reference, there is likely to be more than 10 GW in coal-fired generation added per year to the China electric power systems both short- and long-term. Additions of IGCC technology to the China power systems should start around the year 2000. Initially, current GT/CC technology should be the technology to be utilized, but as the next generation of GT/CC technology gains operational experience on natural gas, the economies of scale gained from the increased CC output is proven, starting late in this decade, the transition to IGCC plants utilizing that GT/CC technology level should be happening smoothly. Technology programs to test and assure the proper combustion of the coal-gas in the next generation GT/CC technology are already in place and will be completed well before this technology is applied in and IGCC plant.

The long-range penetration of IGCC is likely to be supported strongly by generation economics.

The IGCC plant costs, after the introduction of the next GT/CC technology is expected to be the same or lower than a conventional coal-steam power plant with FGD equipment. The IGCC efficiency (LHV) will be about 50 percent compared to around 38 percent for the coal-steam plant, resulting in about 80 percent lower coal consumption due to the efficiency difference. Operations and Maintenance costs are expected to be similar for the two generation plant options. These economics should favor the IGCC option all the time.

In addition to economics the important characteristics of a power plant is reliability and operational characteristics. These characteristics are normally not fully accepted before a proper demonstration program has been conducted. Accordingly, for China, it is imperative to install and operate a full scale IGCC demonstration facility as soon as feasible. As much as possible should be learned from the current family of commercial operational IGCC plants to minimize the time needed to become familiar with the operational aspects of the IGCC technology. Fortunately, the current family of IGCC facilities are based on several different gasifier technologies and several different fuels hence careful monitoring of the status of these facilities should allow China to get the most experience possible out of the first IGCC facility. The first IGCC in China will be an important step in the IGCC learning process also for other countries interested in the IGCC technology. Success with the initial China IGCC facility needs to be recognized prior to a large scale generation additions program for China based on IGCC technology.

Another issue of importance is the acceptance of the IGCC technology needed in the electric power industry. This is not only true for China, but in many other countries as well. An electric plant operator used to steam boiler technology 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 to achieve general acceptance of the IGCC technology in the regional electric power systems in China.

As the acceptance of the IGCC technology increases, a general shift in domestic manufacturing capability to provide gas turbines, heat recovery steam generators and steam turbines suitable for combined cycle will be necessary. As mentioned earlier, this transition process is another factor affecting the speed of introduction of IGCC technology in China. Initially, a relatively high portion of imported components of an IGCC plant may be acceptable, but to allow optimum penetration of IGCC technology in the electric power systems in China, a significant portion of the plant equipment needs to be manufactured domestically.

Estimated IGCC Penetration in China, Short-term and Long-term

As mentioned in the discussions above, if economics alone would be the only determinant for IGCC penetration, the penetration would approach 100 percent of the coal fired, base loaded power plant additions after the first few years of the next century. In reality, it is not likely that IGCC would exceed 25 percent of annual generation additions prior to year 2010. As GT/CC technology continues to improve with increasing efficiencies and lower plant costs, relative to conventional coal steam plants, IGCC penetration may go even higher than 50 percent of new coal fired base loaded plant additions in the 2010 to 2020 period. Since it is not likely, however, that any prediction today about the year 2020 will prove correct, the discussions above should be looked at as a possible scenario as viewed from what we know and understand today.

Example of Power Generation Economics

A simple example of relative power generation economics will be discussed below. Since the variations in plant cost and fuel cost are significant from one country and region to another, the calculations below are for illustration purposes only. Plant costs and fuel costs will be treated parametrically to allow the reader to use his or her own cost data to draw general conclusions about the relative economic trade-off between conventional coal steam power plants and power plants utilizing the IGCC technology. No credit will be taken for environmental performance other than the assumption that the effects of FGD systems is included in the plant cost and in the efficiency assumptions for the conventional coal steam plant. Operations and Maintenance costs between the two alternatives are assumed equal when applying the conservative assumption that the revenues from the potential sale of elementary sulfur and environmentally benign slag are part of the net Operations and Maintenance costs.

The economic parameters used in this example are shown in Table 2 below. For the purposes of comparison, the capital cost for a conventional coal-steam plant is assumed to be 1000 $/kW. The capital costs for the two IGCC technologies compared with the conventional coal-steam plant are treated as variables. The efficiencies for each of the plant options are shown as heat rate in kcal/kWh. Coal-steam is assumed to have a net plant efficiency of 38 percent (LHV), the IGCC based on F technology at 42.7 percent (LHV) and the IGCC based on H technology at 50 percent (LHV). The other cost parameters are assumed to be the same for all the options.

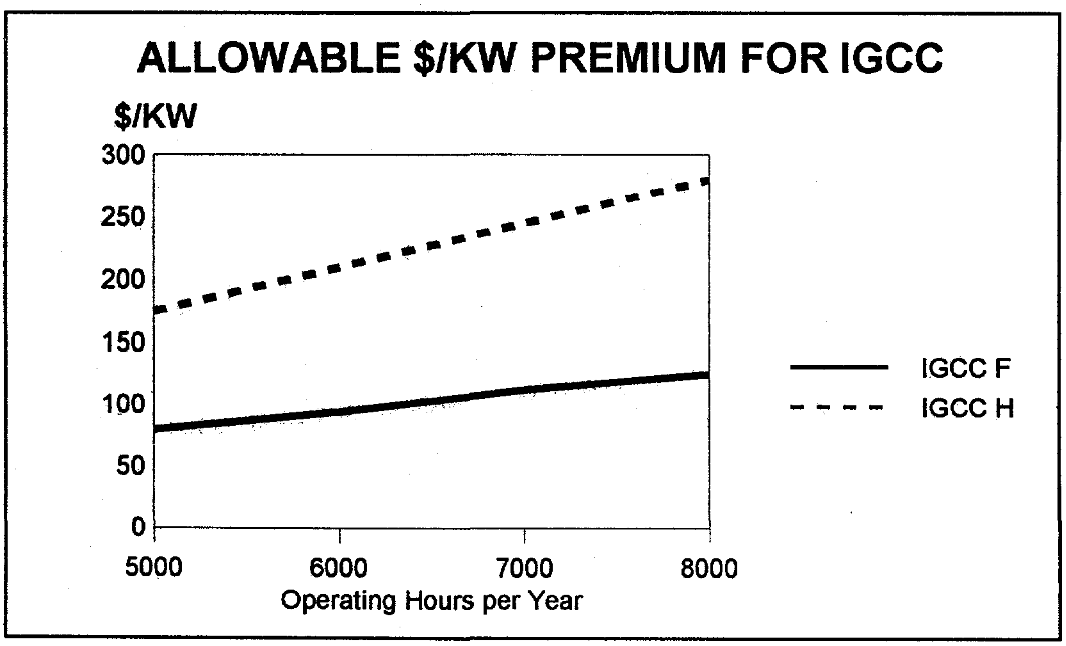
Since the plant cost is the only variable parameter in these calculations, the results show the allowable capital cost premium for the IGCC technologies to break even with a conventional coal-steam plant were based on levelized cost of electricity over a 25 year period. Values were calculated for operating scenarios between 5000 and 8000 hours per year of operation. The results of these calculations are shown in Figure 1.

Table 2 Economic Reference data

Generation Type	Plant Cost $/kW	Heat Rate LHV kcal/kWh	Fuel Cost LHV $/Gcal	O&M Fixed Cost $/kW/yr.	O&M V'ble Cost mills/kWh
Coal-Steam	1000	2250	6.00	10.00	4.00
IGCC F Tech	variable	2000	6.00	10.00	4.00
IGCC H Tech	variable	1700	6.00	10.00	4.00

All costs are assumed to inflate = 4%/yr.
Interest rate (cost of money) = 12%/yr.
Study Period = 25 years

Figure 1



As an example, the plant cost for an IGCC plant, assuming 7000 hours per year operation is 1,110 $/kW which is 110 $/kW higher than a coal-steam plant when considering current GT/CC technology. For an IGCC with the next generation GT/CC technology the break-even IGCC plant cost would be $1,243/kW or $243/kW higher than a coal-steam plant. These plant cost differences are caused by the improved efficiency of the IGCC plants only.

Conclusions

In conclusion, there should be strong economic and environmental reasons for significant participation of IGCC technology in the regional electric power systems in China. The level of penetration will be dependent on many factors, but a possible IGCC penetration scenario would expect about 25 percent of new coal-fired power plants to be IGCC by year 2010 with possible higher penetrations in later time periods.

In addition to the economic benefits possible, a significant environmental impact is expected. The emission of SO_2, CO_2, NO_x, and particulates would be significantly improved and also the coal burned would be substantially less, reducing the need for coal transportation.

3. IGCC IN CHINA: Market Definition and Basis of Need

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Introduction

Development Schedule

The market potential for IGCC in China hinges on the Country's goals of controlling emissions from power generating plants and improving the efficiency of the electricity generating process. Both goals are important to China. Emissions reduction because of China's desire to minimize its contribution to the Global Emissions Budget. Fuel conversion efficiency because of the ethics of minimizing waste is of increasing importance in their planning of infrastructure systems.

These goals impact the following areas in the power industry in China:

1) *New Plant Construction* – New construction will need to increasingly consider the application of the more effective emission control technologies – IGCC will likely become gradually a leading candidate in this area, in particular in the larger power plants in areas with access to coal of suitable composition.

2) *Rehabilitation/Repowering of Plants in Non-Compliance with Emission Standards* – It is unlikely that IGCC will play a role in this area ahead of IGCC application in new plants. However, the repowering approach is desirable and a survey of power plants where there could be a good fit needs to be conducted in the near term (technical feasibility and economic benefit considering existing equipment and plant layout).

3) *Decommissioning of Plants in Gross Non-Compliance with Standards* – This concerns the smaller generating units (under 100 MW) in power plants which cannot be considered for rehabilitation/repowering or conversion to heat-and-power cycles. The accelerated decommissioning of these units is expected for fuel efficiency and environmental reasons. These events will affect the generating capacity requirements in China's power grids and bring about new plant construction, which may or may not involve IGCC.

4) *Based on the above the market potential for IGCC in China* (defined as actual IGCC units operating in power plants) can be seen as a long term rather than a short term development.

Power Groups and Coal Quality

The overall power grid of China can be broken down into the following Power Groups, Provincial Power Companies and Autonomous Regions:

1) North China Power Group
2) Central China Power Group
3) East China Power Group
4) Northeast Power Group
5) Northwest Power Group
6) Shandong Provincial
7) Fujian Provincial
8) Guandong Provincial
9) Guanxi Provincial
10) Guizhou Provincial
11) Sichuan Provincial
12) Yunnan provincial
13) Hainan Provincial
14) Xinjiang Autonomous
15) Xizang Autonomous

The coal mines in the Shanxi Coal Basin (e.g., Datong, Shanxi Province) and the Sichuan Coal Basin; as well as mines in the East China Power Group (e.g., Huaibei), Shandong Provincial, Central China Power Group (e.g., Kailuan) and Northeast Power Group (e.g., Fuxin, Fushun, Jixi and Hegang) produce most of the high rank coal in China. It is in these areas of China that the IGCC market initiation is expected to develop.

Accordingly, to obtain a perspective on the nature of the potential IGCC market in China, it is of interest to examine the energy picture in Asia, the role of China in the region, and the impact of the energy conversion processes practiced in China on the worldwide picture.

Energy Demand Growth in China Relative to Asia And The World

Population Growth

The Asia region (both OECD* Asia and non-OECD Asia) represented 58.7 percent of the total world population in 1990. It is projected that the population for this region will represent 57.8% of the world's population in 2025. Exhibits 1 and 2 show the world population distribution for

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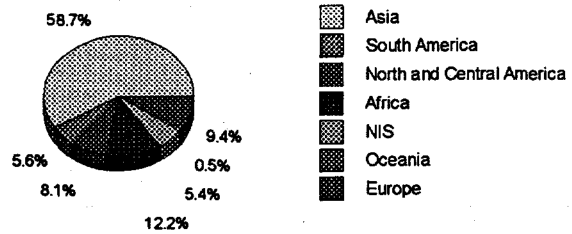
* Organization for Economic Cooperation and Development (OECD): Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. This group of countries represented 17% of the world population in 1994.

Non-OECD Asia: Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia, China, Fiji, French Polynesia, Hong Kong, India, Indonesia, Kiribati, Laos, Malaysia, Macao, Maldives, Mongolia, Myanmar, Nauru, Nepal, New Caledonia, Niue, North Korea, Pakistan, Papua New Guinea, Philippines, Singapore, Solomon Islands, South Korea, Sri Lanka, Taiwan, Thailand, Tonga, Vanuatu, Vietnam, and Western Samoa. This group of countries represented 52% of the world population in 1994.

Exhibit 1

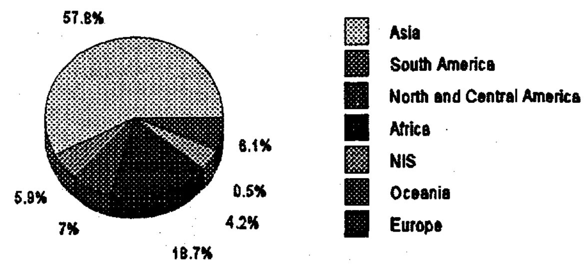
World Population Distribution for 1990



Reference: World Resources, WRI, 1990

Exhibit 2

World Population Distribution Projection for 2025



Reference: World Resources, WRI, 1990

1990 and projections for 2025.

The world population is expected to increase by more than 2 billion people between 1990 and 2010. Exhibit 3 presents the distribution of population for 16 selected Asian countries. China and India lead the list of countries with the biggest population. It is expected that the population in China and India will increase by 23.9 and 40.9 percent respectively by the year 2025. Increased energy availability and consumption for this burgeoning population will lead to corresponding increases in overall standards of living, with corresponding impacts to be addressed as a result of this growth environmental, energy efficiency, etc.

Energy Consumption in Asia

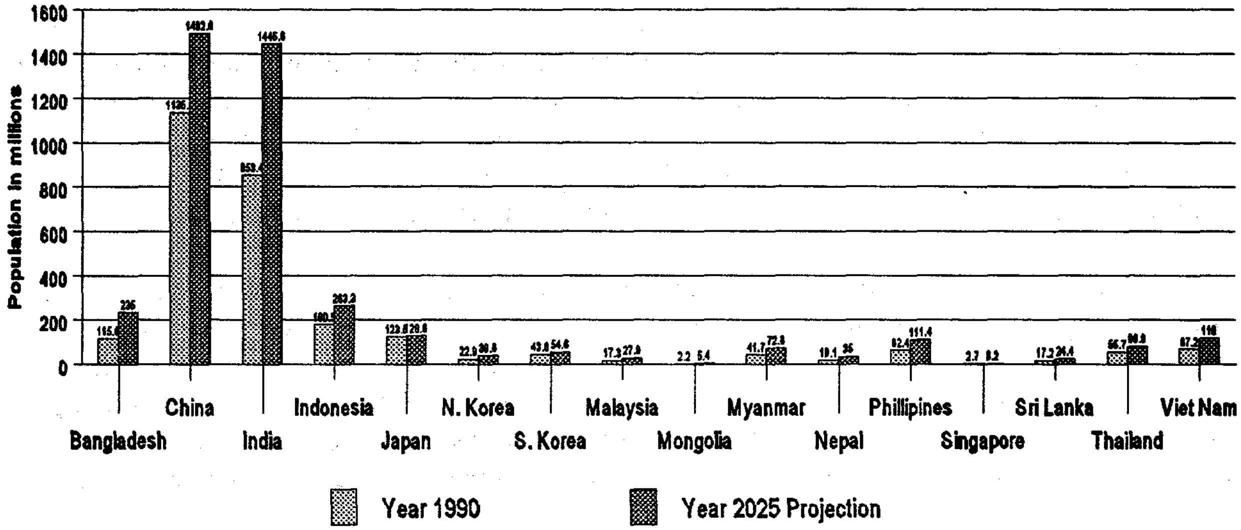
World energy consumption is undergoing continued growth and change in regard to energy sources and means of utilization. World energy consumption is projected to increase from 346 quadrillion Btu (quads) in 1990 to 472 quads in 2010. Recognizing that growth is faster in certain regions versus others, as an average, this represents more than a 1.6 percent increase annually on a world-wide basis.

Energy Consumption by Country

The largest gains in energy consumption are expected in Asian countries with rapid economic growth. Among the larger countries in the region, China and India, as the two largest, have pursued aggressive policies to encourage economic development and are expected to continue these policies through 2010. Based on this assumption, Exhibit 4 shows that China will reach 55.6 quads of total energy consumption by 2010.

Exhibit 3

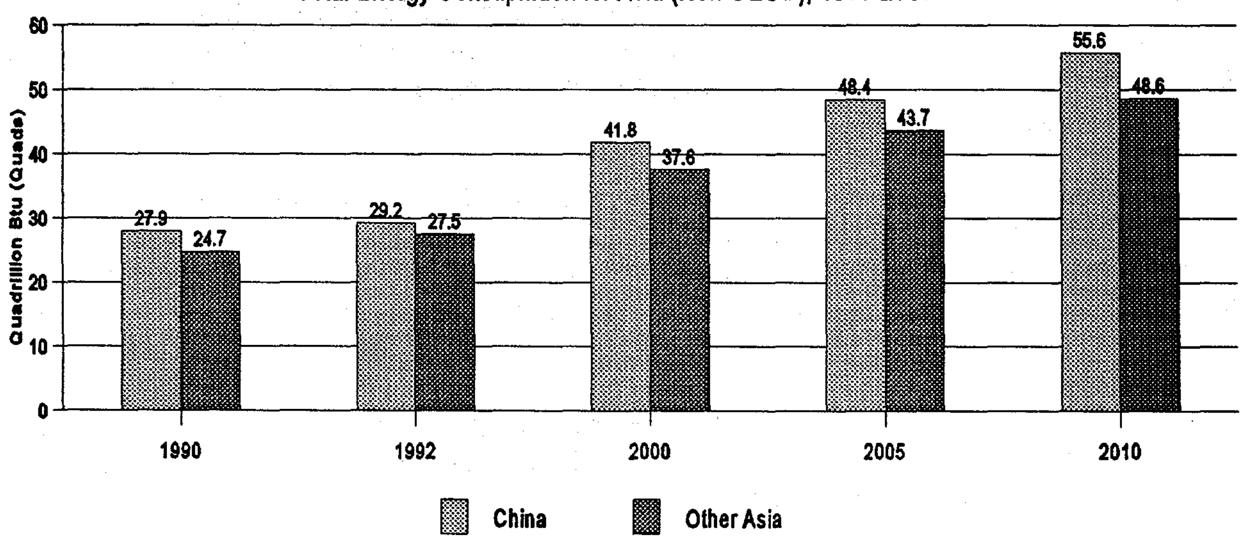
Population for Selected Asian Countries



Reference: World Resources, WRI, 1990

Exhibit 4

Total Energy Consupmtion for Asia (Non-OECD), 1990-2010



Asia (Non-OECD) Includes Countries with 53% of World Population
Reference: International Energy Outlook 1995, U.S. DOE

Energy consumption in the non-OECD region is expected to grow by 1.8 percent annually over the 1990-2025 period. Energy consumption has increased more rapidly in the non-OECD economies relative to those of the OECD since 1970. As a result, non-OECD consumers will account for about 50 percent of the total world energy consumption by 2010.

The industrial and residential energy sectors are still the major energy consumption sectors in the Asian region. Exhibit 5 presents figures showing that China and India were the leaders in 1990 energy consumption in the industry sector category, which amounted to 354 and 67.6 million TOE, respectively. China, South Korea, India, and Indonesia proved to be the largest energy users in the residential/commercial consumption sector in the region during 1990.

Significant growth is expected in the transportation sector, which is relatively underdeveloped at present. In the residential sector, additional growth is expected to result from energy use shifts such as replacement of non-commercial fuels, e.g., plants and animal wastes, by conventional fuels such as propane and other fuels when more advanced heating and cooking equipment is adopted in some of these countries. China and several other countries in the region are expected to continue to have rapid growth in economic activity, accompanied by rapid growth in energy consumption.

Energy Consumption by Fuel

Between 1970 and 1990, energy consumption in the world increased by approximately 140 quads, reflecting an annual growth rate of 2.6 percent. During this period, oil provided the largest share of energy supply, but its share of total energy has been declining. Among the fossil fuels, natural gas consumption rose most rapidly. The share of non-fossil fuel consumption rose substantially, from 6 percent to 13 percent, between 1970 and 1990.

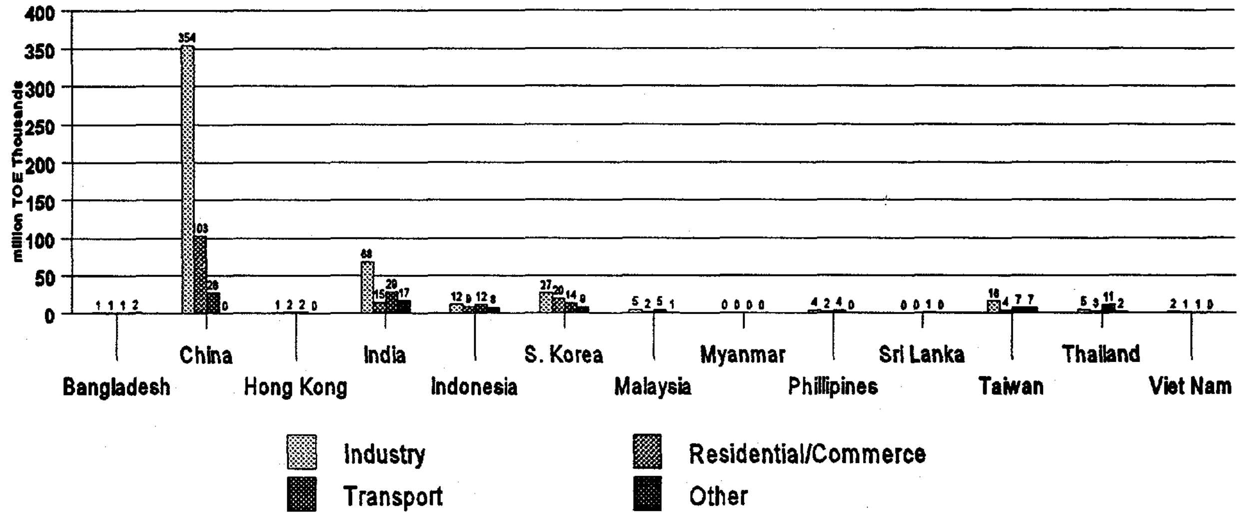
As shown in Exhibit 6, coal and oil contribute the largest share of energy supply in non-OECD Asia. By the year 2010, total energy consumption is expected to be 52.8 quads for coal and 34.6 quads for oil in this region. The projected figures for 2010 represent almost a doubling of the 1990 energy consumption figures.

Coal – Coal remains one of the major world energy sources in terms of primary energy consumption as shown in Exhibit 7. The amount of coal consumed in Asia is expected to increase very significantly over the period 1990-2010. Increased coal use in China alone is expected to account for more than three-fourths of the projected increase. Coal consumption worldwide in 2010 could be as high as 7,379 million tons.

Exhibit 8 demonstrates the distribution of indigenous energy production and energy imports for selected Asian economies. The projected exceptional economic growth in this area will give rise to large coal imports for those economies.

Exhibit 5

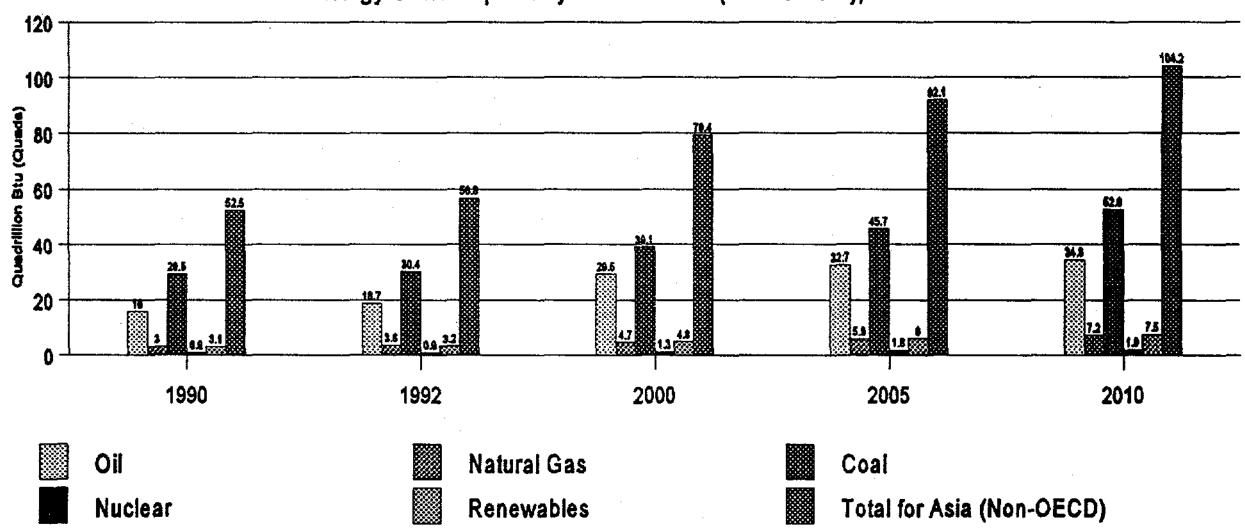
Final Energy Consumption for 1990



Reference: World Resource, WRI, 1990

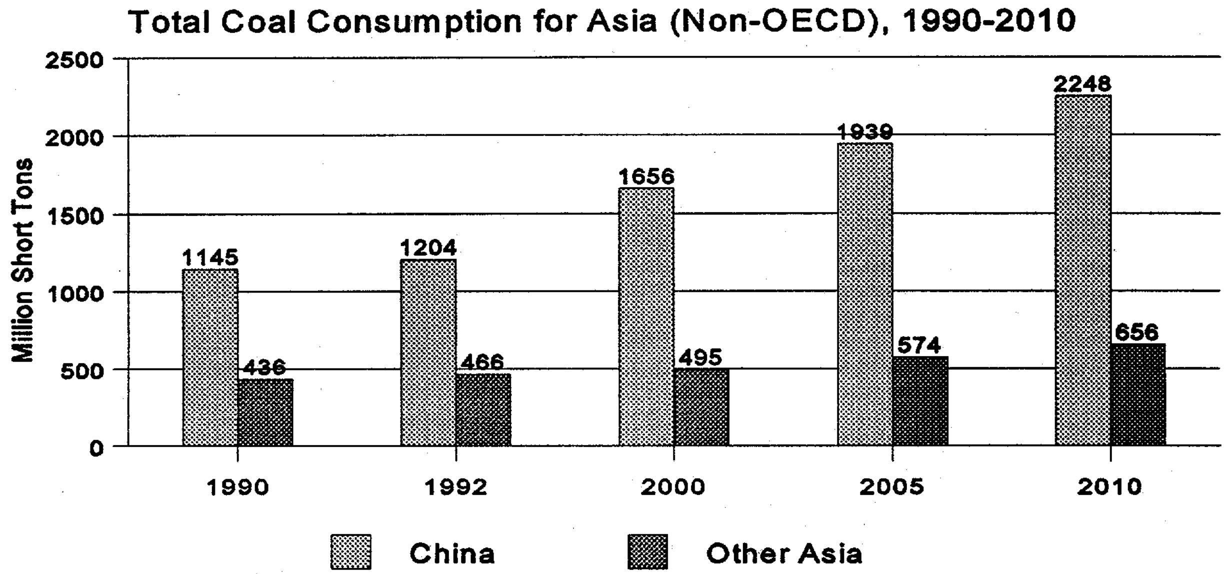
Exhibit 6

Total Energy Consumption by Fuel for Asia (Non-OECD), 1990-2010



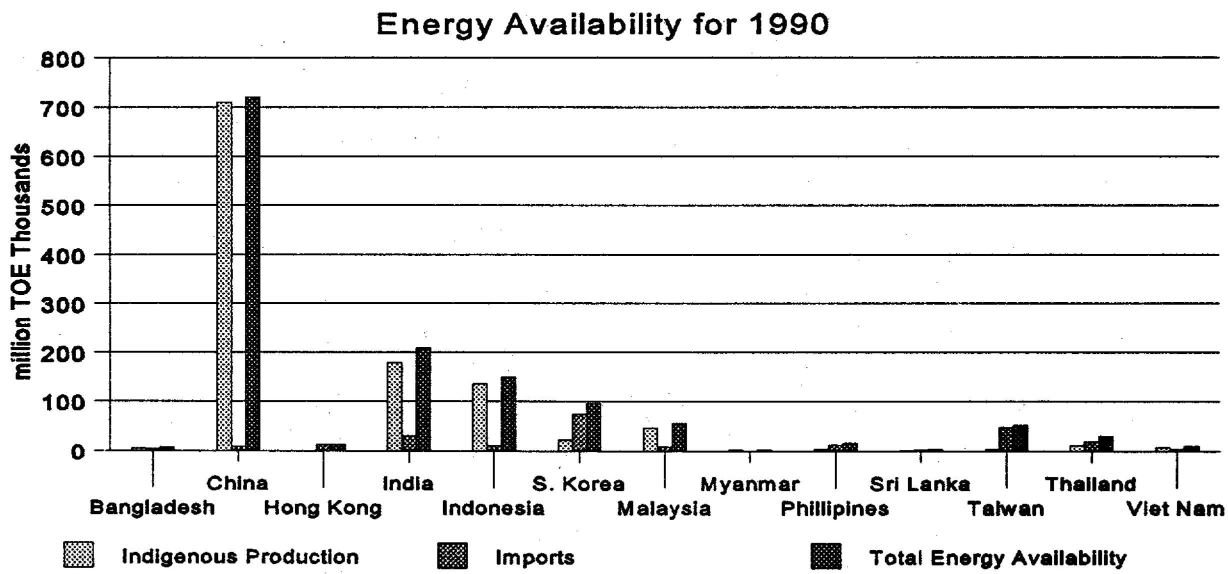
Asia (Non-OECD) Includes Countries with 53% of World Population
Reference: International Energy Outlook 1995, U.S. DOE

Exhibit 7



Asia (Non-OECD) Includes Countries with 53% of World Population
Reference: International Energy Outlook 1995, U.S. DOE

Exhibit 8



Reference: Energy Indicators of Developing Member Economies, ADB, 1992

China accounts for more than 80 percent of the growth in the region. Both India and China are expected to implement large construction programs for new electric power generating plants in the future. China may use imported coal for some regions because doing so may well be more economical than mining and shipping its own coal to the sites of the new generating units. Indonesia and China, Asia's own coal export suppliers, are making considerable advances in the export market, and are thus already well-positioned to benefit from plans for expanded coal consumption in the Asian market.

As a result of fast-paced economic growth in the region, coal consumption is expected to grow most rapidly in non-OECD Asia, which is projected to account for 44 percent of total world coal consumption by 2010, compared to 31 percent in 1990. Consumption in the Asian region is projected to grow by 84 percent from 1,581 to 2,904 million tons between 1990 and 2010. China, alone, is expected to increase its coal consumption by 1,103 million tons, nearly doubling the current level of domestic consumption. Assuming no change in fuel use policies in China, coal should continue to provide close to three-quarters of all energy consumed there in 2010. In Asia overall, coal imports are projected to rise during the next two decades, from 184 million tons in 1990 to 385 million tons in 2010.

Oil – In brief the projections for oil resources worldwide as of 1991 are as follows:

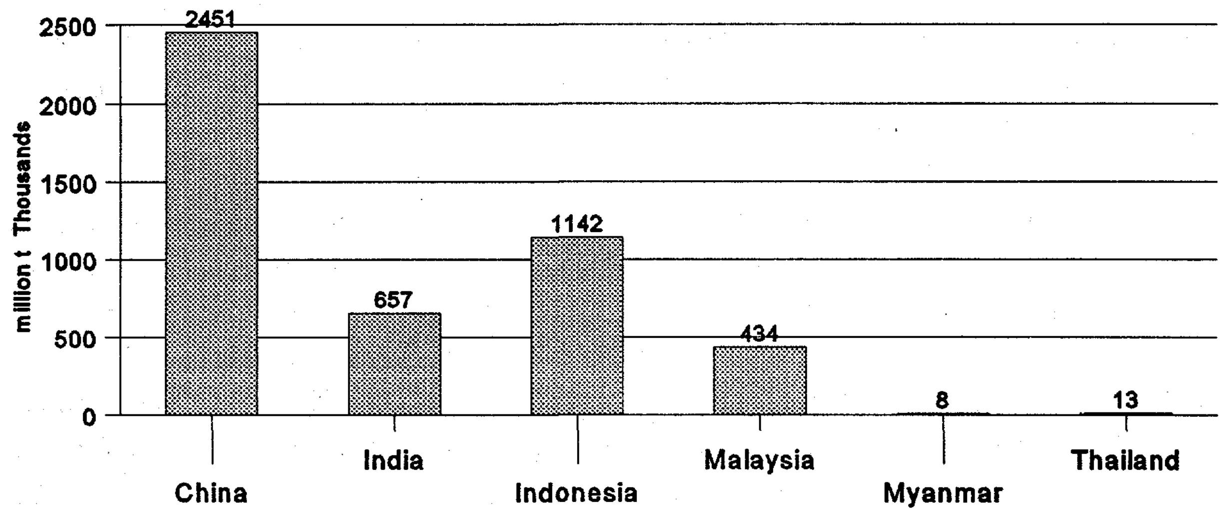
Place	Billion barrels
Persian Gulf	483-620
North America (including Mexico)	139-281
Russia and Eastern Europe	130-274
Far East (including China)	81-198
South and Central America	75-136
Western Europe	45-78
Australia and New Zealand	4-13

The projected growth in oil consumption for non-OECD Asia is expected to average 3.9 percent per year for the region over the 1990-2010 period. China's oil consumption is expected to grow by 2.8 percent per year, from 2.3 to 4.0 million barrels per day. Exhibit 9 shows a detailed breakdown of recoverable reserves of crude oil in Asia.

Whereas world coal resources of significant scale are probably fairly well known – although revised assessments of new mineable coal deposits do come up periodically – the oil and gas exploration industry is continually and aggressively looking for major new finds. In the 1980's,

Exhibit 9

1987 Crude Oil Recoverable Reserves for Selected Countries



Source: World Resources, WRI, 1990-91

with a few exceptions, major new finds have proved elusive in new areas, where oil reserves appeared promising but unproven. In the 1990's, the oil exploration industry seems to have shifted gears and appears to be concentrating in incremental production from areas where oil has already been found. In the greater Asia region, these efforts seem to be focused on locations in Russia, Kazakhstan, Indochina, China (onshore) and others.

The transportation sector, the chemical and other industries, and certain power generation and heating/cooling applications using diesel-type fuels will continue to depend on oil for the foreseeable future. Oil demand for these type of users, in particular transportation, is expected to accelerate in the Asia region. This demand together with the expected constraints in the local refining infrastructure will limit the use of oil as a fuel for power generation.

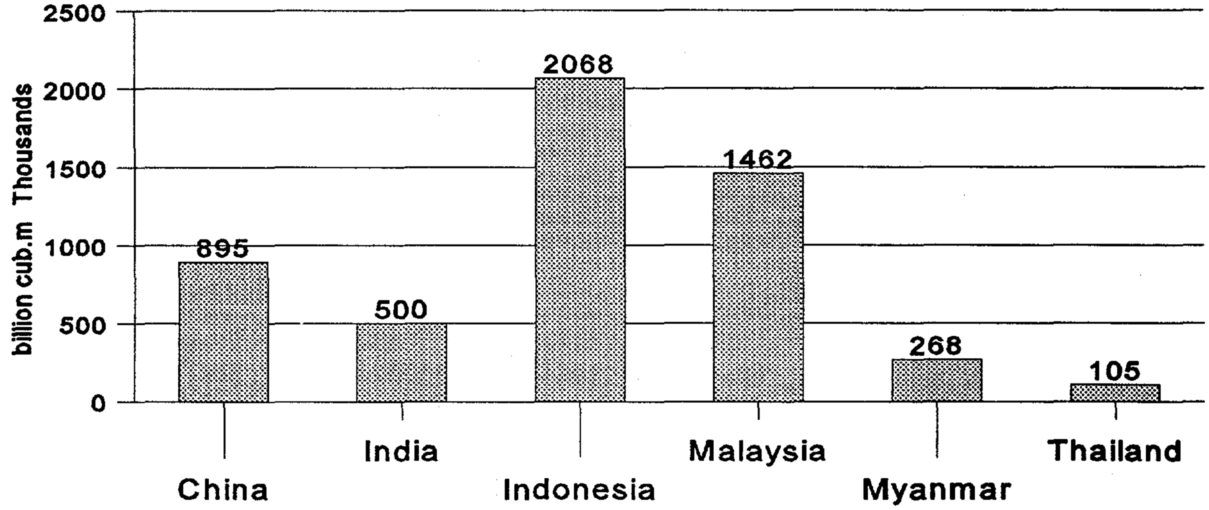
Gas – A number of relatively recent events in the worldwide energy industry are likely to figure prominently in the future of natural gas and its increased use for electricity generation. Technological advances concerning system efficiency in gas-fired power generation and the environmental advantages of natural gas make it an attractive fuel for China and other Asian countries which currently rely heavily on coal.

Exhibit 10 shows a detailed breakdown of known resources of recoverable natural gas in Asia. In this region, natural gas has been gaining increasing importance as a fuel and feedstock to industry.

Developed countries like Japan have been importing gas from local Asian sources and the Persian Gulf for power generation and industrial uses. This gas has been committed through long term

Exhibit 10

1987 Natural Gas Recoverable Reserves



Source: World Resources, WRI, 1990-91

contracts. Less developed countries are planning to accelerate industries such as plastics production and others, which utilize gas as feedstock, as well as to utilize it for power generation blocks to quickly meet electricity shortfalls.

The capital requirements for gas transmission (pipelines) or transportation (liquefied form) are expected to localize the availability of gas for energy and industry users to the large bulk buyers with long term commitments and the users near the gas producers in the region. With a few significant exceptions, such as the proposal for a pipeline traversing South East Asia (feeding from fields in Malaysia, Indonesia and Brunei) – or longer term pipeline concepts bringing gas from Central Asia, Siberia or even North America – gas may not be readily available to significant areas of the Asia region.

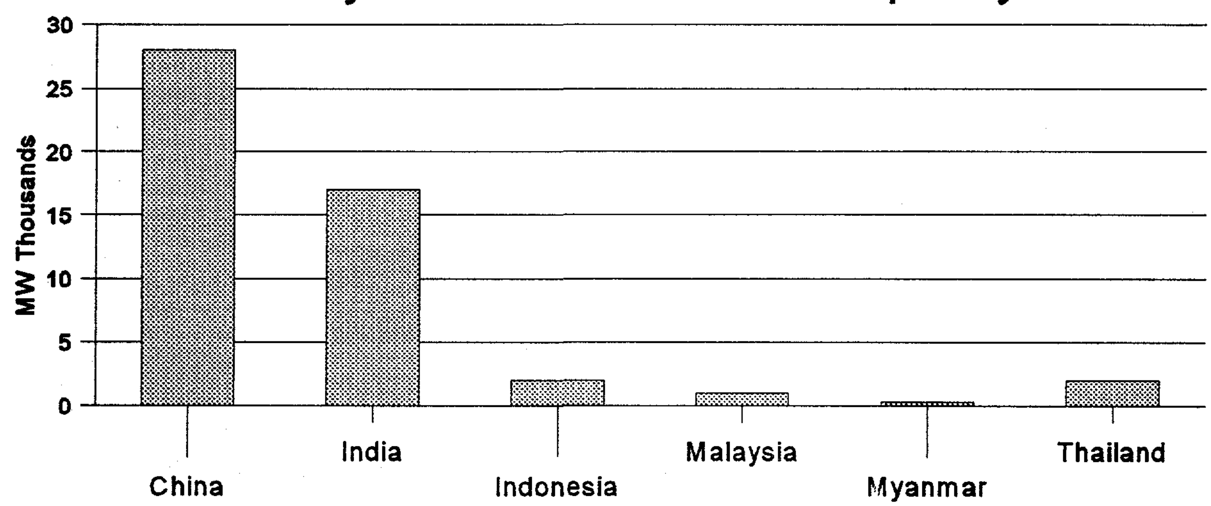
Most of the world's liquefied natural gas (LNG) trade has centered in the Asia/Pacific Rim region, which accounts for about three-quarters of all LNG trade. Indonesia, Malaysia, and Australia are the primary exporters, and Japan, South Korea, and Taiwan are the main consumers. These six economies will most likely remain the centerpiece of LNG trade. Although neither country will operate at a level comparable to those mentioned above, both Myanmar and Thailand have the potential for significant growth in natural gas production. China has substantial gas reserves, and its clean-burning qualities make it an attractive alternative to coal where applicable. Significant efforts are also being dedicated by China to exploit natural gas associated with coal beds. This could amount to a large supplemental gas source.

Nuclear – China, South Korea, Taiwan, India, and a few other economies in Asia are currently operating nuclear power plants and have major programs for nuclear expansion. With the exception of South Korea, these programs are small, relative to their in-country energy demands, but are expected to grow in the future. By 2010, additional programs are expected to be operating in the Philippines and North Korea. Nuclear capacity for the region is projected to be between 27.7 and 35.7 gigawatts by 2010.

Renewable Energy – Asia is projected to experience fast-paced growth in consumption of hydroelectricity and other renewable resources. In non-OECD Asia, consumption of these resources is expected to more than double between 1990 and 2010, from 3 to 8 quads. Many countries in the region have relatively large hydroelectric resources. China's consumption of renewable resources in 2010 is expected to be more than three times its 1990 level. Most of the increase in its consumption of renewable energy is attributable to hydroelectricity.

Exhibit 11

1987 Hydroelectric Installed Capacity



Source: World Resources, WRI, 1990-91

It is evident that Asia has significant hydroelectric potential, which however will need to be carefully examined in planning its development. China has large hydroelectric development potential; according to some estimates, more than 350 gigawatts. Exhibit 11 shows a breakdown of Asian hydropower resources.

Other than hydropower, wind and solar energy resources are expected to play a significant role in the supply of energy, particularly to dispersed communities and users which account for a significant fraction of the demand in the region. Windpower development in particular offers much potential for many countries in the region.

Energy Production and Fuels for Power

Exhibit 12 provides the distribution for different fuels as primary energy supply sources for 1990. China and India lead the list of Asian countries with coal as their primary energy supply fuel, with 514.96 and 100.83 million TOE, respectively. South Korea, Indonesia, and Taiwan have oil as the primary energy supply source.

The 1987 electricity production for selected Asian economies by the type of generation is presented by Exhibit 13.

Carbon Dioxide Emissions

Almost half of all carbon dioxide (CO_2) emissions come from coal use. In 1990, on a world-wide basis, CO_2 emissions from coal use were 2,343 million metric tons. By the year 2010, it is projected that total non-OECD CO_2 emissions from coal use will be approximately 1,352 million metric tons.

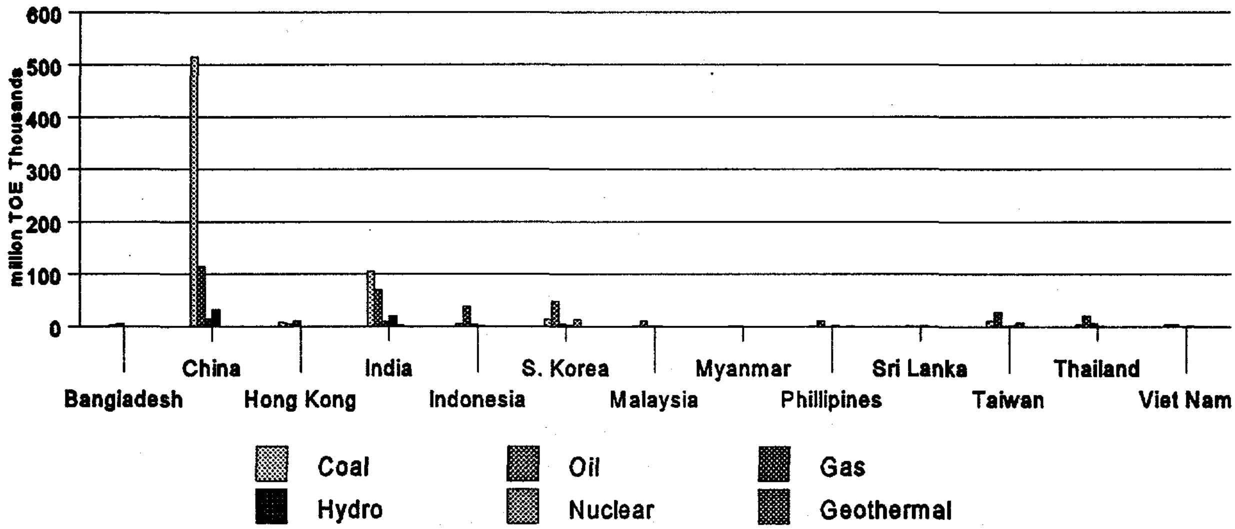
Exhibits 14 and 15 show total CO_2 emissions for Asia and total carbon dioxide emissions from coal use. China is estimated to have produced 1,145 million metric tons of CO_2 emissions in 1990. The CO_2 emissions are expected to increase by the year 2010 to about 2,248 million metric tons. However, the application by China of power generation processes such as IGCC which provide improved control of emissions and fuel efficiency will go a long way to improve the overall emissions picture on a worldwide scale..

Conclusions on Market Potential for IGCC in China

It appears evident that the market potential for IGCC in China is substantial particularly in the longer term (15 to 20 year horizon). However, 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.

Exhibit 12

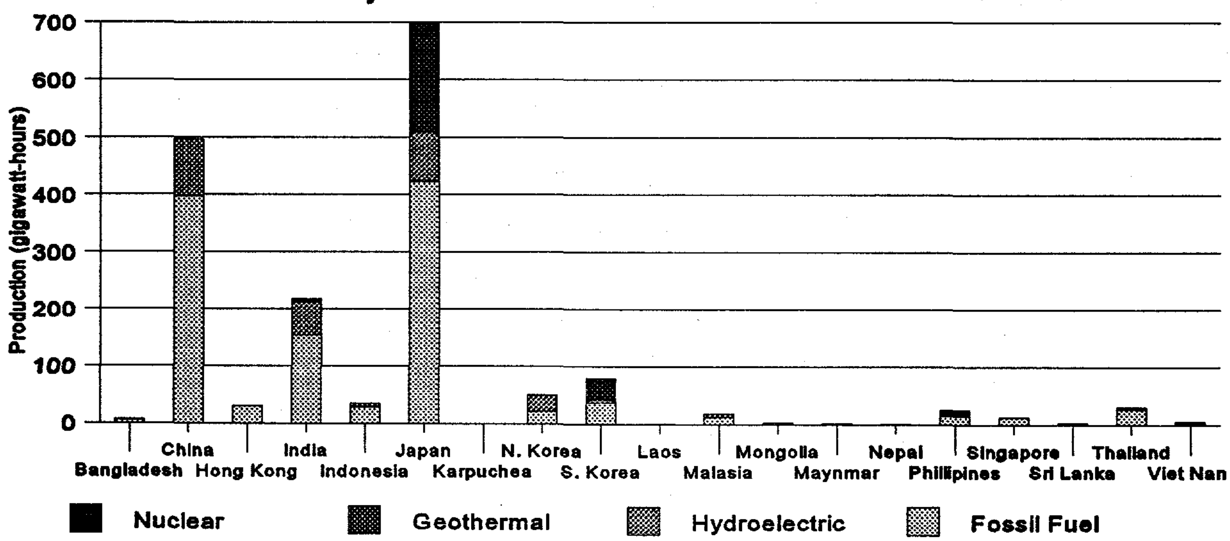
Primary Energy Supply for 1990



Reference: Energy Indicators of Developing Member Economies, ADB, 1992

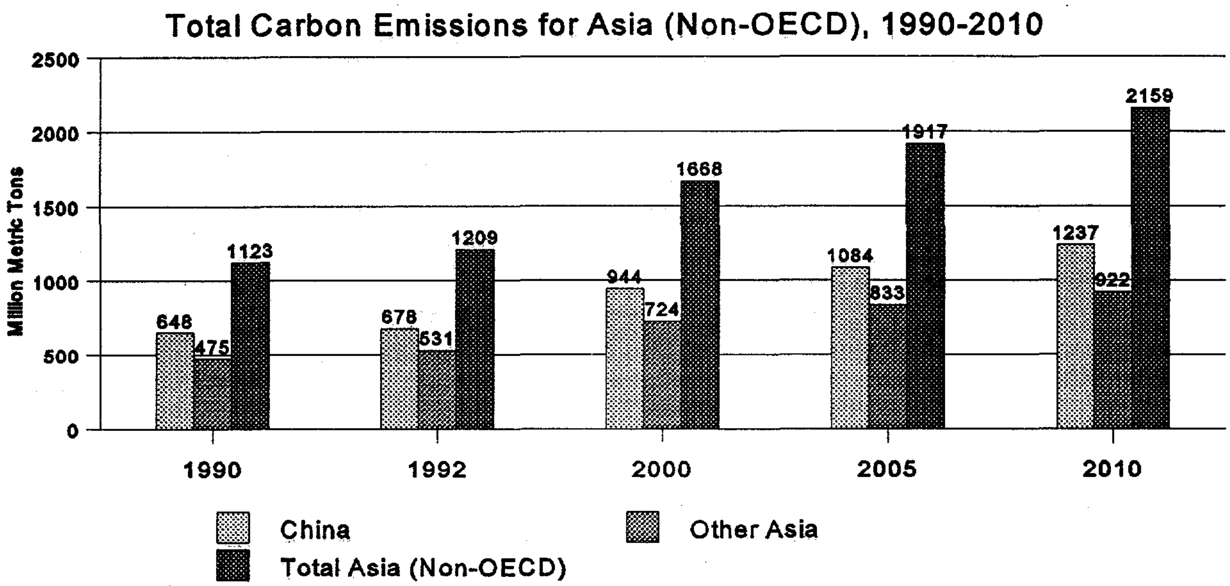
Exhibit 13

1987 Electricity Production for Selected Asian Economies



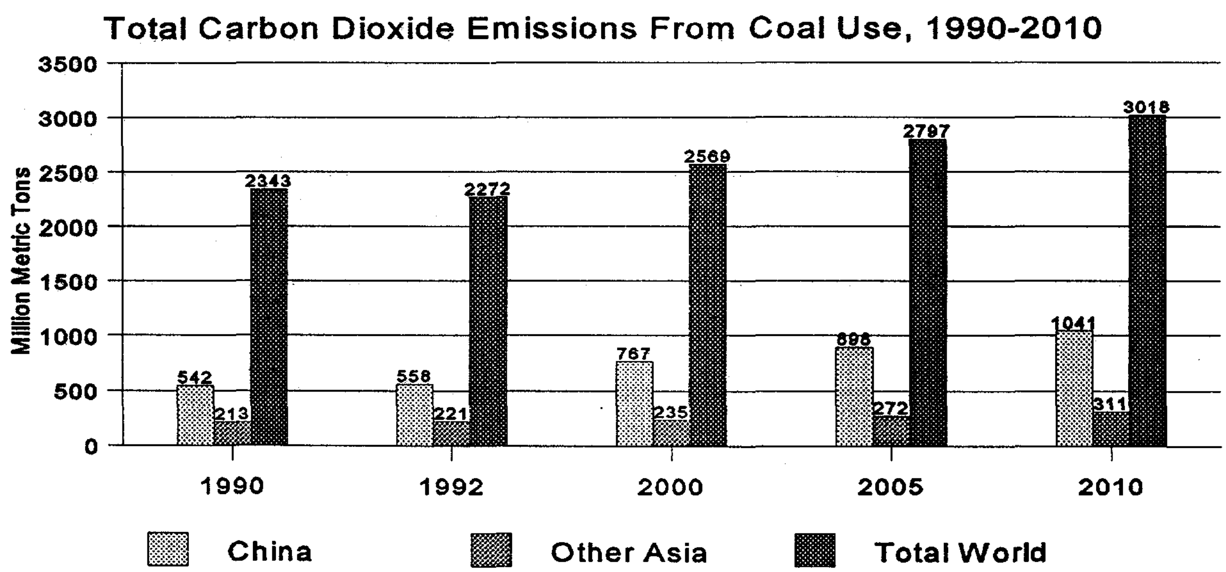
Reference: World Resources, WRI, 1990

Exhibit 14



Asia (Non-OECD) Includes Countries with 53% of World Population
Reference: International Energy Outlook 1995, U.S. DOE

Exhibit 15



Asia (Non-OECD) Includes Countries with 53% of World Population
Reference: International Energy Outlook 1995, U.S. DOE

4. The Potential Impact and Benefits on Global Environment of US IGCC Technology in China

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Potential Impacts of IGCC Adoption in China on the Global Environment Based on the Reduction of Polluting Emissions

The very rapid movement of China to use coal for power production presents a real concern about local and global environmental impacts. If new information on global warming increases the importance of controlling CO_2 emissions, the impact could be even more dramatic. Chinese power plants do not have even the most rudimentary pollution control devices for controlling SO_2 or NO_x 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 greenhouse gas emissions. In north China particulate concentrations are 4-6 times higher than the 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 greenhouse gas 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.

According to various energy reports, China is in need of adding 17 GW of new generating capacity per year for at least the next 10 years. The demand for electricity is now outrunning supply by more than 20 percent. China is said to be planning to meet this need by increasing its generation capacity from the current 165 GW to 265 GW in ten years. This is equivalent to adding two hundred, 500 MW IGCC plants. While this is not possible, projections have been made for the projected market share of IGCC plants to the year 2020. The market share could be:

0%	1996 to 2005
2%-3%	2005 to 2010 (1 to 1.5 GW or 2-3, 500 MW IGCC plants)

5%-10%	by 2015
15%-20%	by 2020

If the 15 percent estimate is realized, the market could be more than 3,000 MW of IGCC power plants. In addition, it is known that IGCC is an effective technology for repowering old coal burning power plants by adding a gas turbine and gasifier to the existing plant using the existing equipment and structures. It is also a low cost method for increasing capacity and lengthening the technological and economic life span of old plants, avoiding large investments of building new plants.

Table 1 provides the production of electricity by country and the estimated growth of power production. This table is shown to give some idea of the relative effect China's power production can have on global environment issues.

Table 1. Electric Power Production

	Electric Power Production 10^9 kWh	**Growth, Percent**	**Growth 10^9 kWh/yr**
World Total	11,771.0	3.63	427.8
United States	3,040.9	2.59	78.8
Russia	1,726.0	2.92	50.5
China	**621.6**	**7.54**	**46.8**
India	286.0	9.14	26.1
South Africa	166.7	6.41	10.7
Indonesia	44.3	12.05	5.3
Czech-Slovakia	89.3	2.08	1.9
Bulgaria	41.3	1.73	0.7
Hungary	28.4	1.74	0.5

Since roughly 75 percent of China's power is produced by coal, any improvement in the emissions of pollutants by technology changes can have a significant impact on the global environment. The use of IGCC, which is currently the cleanest advanced power producing technology, (see Table 3) can reduce the negative impacts of China's emissions further than other competing technologies.

Economic and Social Benefits of IGCC Demonstration and Adoption in China for Power Generation

China needs big power increments and is willing to participate in an IGCC demonstration, although timing and financing are not clear. There are additional benefits that would result from the use of IGCC in China for power production apart from the obvious superior environmental characteristics as compared to other coal burning systems.

Water is scarce in China. IGCC plants use comparatively much less water (30 to 50 percent) than other coal burning technologies. These plants can be constructed in areas with low water resources where conventional plants cannot be operated. Because of lack of transmission capability, this can mean that power can be added to places where insufficient water resources prevented the installation of large power plants. Economic development in rural areas depends on availability of commercial energy.

IGCC plants have high availability, 85 percent as compared to 50 to 70 percent now typical for Chinese power plants. IGCC plants will be dispatched first which will reduce the amount of brownouts and blackouts being experienced on a frequent basis in all sections of the country. Economic growth and public welfare are hampered by the country's frequent blackouts. The main benefit of new power plants in today's China market is stopping the blackouts.

IGCC plants can operate with a wide variety of coals and biomass which could help solve waste disposal problems.

Advanced IGCC plants will be available within ten years that will have efficiencies of up to 50 percent while maintaining unmatched environmental performance, including greater potential CO_2 benefits.

IGCC can be started incrementally in phased construction by installing a natural gas fired gas turbine followed by combined cycle, followed by installation of a gasifier. This can reduce the initial cost and have other financial benefits. One benefit is that developers can get into the market with little initial capital cost. In China, which does not have abundant supplies of natural gas, this is less of a benefit.

IGCC, which is capable of utilizing relevant new technology, offers good prospects for new and advanced technology industries, such as subcritical/supercritical IGCC using advanced turbine technology with high steam parameters, the IGHAT with high efficiency and low cost by using humid air, and the advanced IGFC-CC by using fuel cell technology.

Identification of Technical and Economic Risks Associated with the Use of IGCC Technology in China

The gasification of coal is not a new technology. Various coals and biomass have been commercially gasified for many years to produce town gas and chemicals. In China, Texaco and IGT have supplied gasifiers for the production of chemicals for fertilizers and other uses. However, gasifiers have not been used for power production in China and no demo plants have been planned for IGCC power plants. The acceptance of IGCC chemical plants by utilities would be a concern in China as it is in the U.S. Additionally, China is inclined to favor entrained bed gasifiers, oxygen blown. Even with cold gas cleanup, this technology would have to be demonstrated in China using Chinese coals before it can be considered for a large power producing plant. A 50 MW IGCC power plant is planned to be installed by 1997 by Shanghai Coke and Chemicals. This would be a very small IGCC plant and may use the existing low pressure U-Gas gasifier.

There are other technical considerations that apply to IGCC plants as well as other technologies. While there are abundant supplies of coal and mining capability in China, the transportation infrastructure is liable to limit its use in areas that need additional electric power. Power is needed in the coastal areas but the coal sources are far from the coast. Mine mouth plants are a consideration but transmission and distribution lines are not as extensive as in developed countries. Therefore the location of a large IGCC power plant becomes an important consideration. Even after locating and installing a large plant the reliable delivery of coal to the plant is questionable and could be a risk which is usually not a concern in other countries.

Texaco has recently signed an agreement to provide nine coal based gasification plants for fertilizer production. There are now fourteen Texaco gasification plants in China and eight of them use coal. The first was licensed in 1978. This experience will assist in proving the applicability of gasifiers using Chinese coals; however these are not IGCC plants. Texaco has over 20 licenses to put gasifiers in China and at least one company is approved to do engineering work.

Commercially, the Texaco gasifier is offered with a quenched gas, producing some power level steam and a clean particulate, alkali, and ammonia free gas. When oxygen blown, the gas has a HHV of 300 Btu/scf, a suitable for combustion in a gas turbine without preheating. This gasifier combined with a Selexol to remove H_2S, and a GE Frame 7F GT in combined cycle can produce a net 300 MW of power. This system demonstrated using some Chinese coal would be commercially guaranteed and is a near-term IGCC option.

From the standpoint of the Chinese, who would be purchasing a large power producing IGCC, once a demo plant has been operated satisfactorily there would be no technical or economic risks that would be of great concern even though IGCC promoters in China have expressed the usual concerns such as commercial availability, technical guarantees, capital costs and COEs, gas turbine life when burning low Btu gas, low sulfur coal use and competition with other technologies. However, the Chinese do not have the ability to finance the new power plant projects and would have to rely on vendors from other countries to provide technology, expertise and funds. Chinese officials have said that they plant to spend $200 billion for power plants by 2010, much of it with foreign financing. These financiers/vendors would be faced with a number of problems which would be considered risky. These include:

- government policies,
- a too rapidly expanding economy,
- guarantee of fuel supply and delivery,
- reliable operation by Chinese personnel,
- timely approvals and permitting by three levels of authorities,
- currency conversion,
- differences in contractual policies,
- unfavorable rate of return,
- financing from provincial or foreign sources,
- much of the added capacity will be built on a build-operate-transfer basis (BOT)
- lower productivity of Chinese labor,

- lack of respect for intellectual property,
- foreign ownership cannot exceed 49 percent.

Finally, the IGCC vendor will have to compete in a very competitive international market which might result in bidding with less of a contingency in order to get the first project. U.S. manufacturers would need to get the price of IGCC down to \$800 to \$900/kW in order to compete.

The Chinese have formed a Clean Coal Commission and a program called Agenda 21. The focus of this agenda is to implement IGCCs in China in 20 years. A key question is to determine whether an IGCC should be installed in the next 5 to 10 years or wait until later. The Agenda 21 schedule showed a completion date of 1995 for a pre-feasibility study and a solicitation in 1996. This schedule has been changed because of funding problems and the status is not known.

Potential Impacts of IGCC Adoption in China on the Environmental Externalities Associated with Polluting Emissions

While it is extremely difficult to quantify the potential economic impacts of pollutants on the economy of a country some attempts have been made. In a study done for an eastern European country, monetary values corresponding to the costs of damages to the population and to the environment were estimated. These are shown in Table 2. Cost data like this is used in economic analyses to compare and evaluate technology options. Because IGCC emits much less of the pollutants compared to conventional PC plants and fluidized bed coal combustors, these external costs would favor IGCC over the other options.

Table 2. Environmental Costs

Item	External Cost
CO_2	US\$ 25/ton
SO_2	US\$ 590/ton
NO_x	US\$ 300/ton
Dust	US\$ 2,590/ton

Table 3 shows the emissions from a supercritical PC boiler and an IGCC. Both use advanced methods for pollution control. It is clear that IGCC emissions are less than PC plant emissions. In China the PC boilers have essentially no pollution controls. The emissions from Chinese PC plants are not known.

Table 3. Comparative Emissions

Item	Supercritical PC (65% CF) $lb/10^6$ Btu	Oxygen Blown IGCC (Destec) $lb/10^6$ Btu
SO_2	0.34	0.04
NO_x	0.30	0.08
Dust	0.004	0.004
CO_2	204.3	204.3

A further comparison of emissions from IGCC and conventional PC plants is given in table 4:

Table 4. IGCC vs. PC

Technology	Cost $/kW	Potential reductions (% change)			Efficiency
		SO_2	NO_x	CO_2	(%)
Pulverized coal with emission controls	1,500-1,800	90-95	60	NA	33-35
IGCC (Greenfield)	1,100-1,300	95-99	90	20-40	39-47
IGCC (Repowring)	950-1,200	95-99	90	20-28	39-42

The advantages of using IGCC technology for new power production, as far as impacts of pollutants is concerned, is obvious as the above tables indicate. Until emission regulations are promulgated and enforced in China, the true cost impacts cannot be estimated. If future emission regulations in China for coal fired power plants are less severe than those in other industrialized countries, then the cost of IGCC versus more polluting technologies may not be justified.

5. U.S. Electric Utility Perspective of IGCC Technology

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Introduction

Integrated Gasification Combined Cycle (IGCC) technology has become a reality in the U.S. for power generation. With one unit in operation, and two more in the final phases of construction, there will soon be over 600 MW of IGCC at a commercial scale. This paper looks at IGCC from the perspective of a utility company in the U.S. Subjects covered in this paper are: 1) efficiency benefits, 2) emission reductions, 3) fuel flexibility, 4) by-products, 5) repowering, and 6) new unit additions. A description of Tampa Electric Company's Polk Power Station IGCC Project is also covered.

Technology

During the 1960-1970 high-growth period in the U.S., the amount of installed capacity doubled from 190,000 MW to almost 400,000 MW. The prevalent choice for power generation was large pulverized coal-fired steam generating units, with sizes up to 1,000 MW. With these large units, the electric utility industry realized its most efficient power generation year during 1968. During the period 1970-1984, much more capacity was installed, almost doubling again. During that period of time, the electric utility industry was made subject to an ever-increasing number of environmental laws and regulations, covering emissions of air, water, and solid waste. The addition of flue gas desulfurization systems and electrostatic precipitators for fly ash removal caused significant decreases to generation efficiency. Using coal and meeting stricter environmental standards became more costly and difficult.

Combustion turbine technology has been available to electric utilities for many years. Since they were primarily used for peaking power needs, the low efficiency and high fuel cost were not a big concern. Recent developments from the aircraft engine industry have highlighted fuel diversity and efficiency. Many new installations are taking advantage of 150-200 MW (at 60 Hz) combustion turbines with efficiencies of 40 percent in simple cycle operation, and well over 50 percent in the combined cycle mode. Many of the newest power generation installations in the U.S. have utilized natural gas-fired combustion turbines in the combined cycle mode. With low gas prices, combustion turbines have become the technology of choice for most new installations.

Gasification technology has been available for many years in the chemical industry, but is very new to the electric utility industry. During the 1970's and 1980's, the U.S. faced oil supply crises, and the government and industry realized that the growing dependence on foreign oil was a strategic disadvantage for the U.S. Research expanded quickly into technologies that could utilize the vast coal resources in the U.S. The ability to convert low cost coal into a clean gas and then burn it in an efficient combustion turbine/combined cycle was seen to have significant potential for solving energy strategy concerns.

During the late 1980's, the Cool Water Gasification Project became the first IGCC unit in the U.S. Its purpose was to demonstrate the integration of coal gasification technology with the increasingly efficient combined cycle technology. Several years of testing proved that IGCC was technically successful, and that it was available for commercial development for large power generation projects. With decreasing coal prices, and increasing prices for natural gas, utilities began to seriously evaluate IGCC. The Department of Energy's Clean Coal Technology Program gave IGCC its entrance at the large, commercial scale.

Efficiency Benefits

Even with the use of supercritical pressure operation, and improvements to steam turbines, the large, pulverized coal units still can only reach about 40 percent efficiency. Through the use of the very efficient combustion turbine technology, IGCC now offers efficiencies greater than 40 percent, with 45 percent expected in the next few years. The average heat rate for U.S. steam electric generating units is 10,568 Btu/kWh. The IGCC projects being developed under the Clean Coal Technology Program have design heat rates in the range of 8,500-9,000 Btu/kWh. Therefore, IGCC can offer 10-20 percent greater overall efficiency than other commercially available technologies. In a business environment that is becoming more competitive, greater efficiency and lower fuel costs can provide many benefits to an electric utility facing increasing gas prices and an aging fleet of generating units.

Emission Reductions

The Clean Air Act Amendments of 1990 require major reductions by utilities of SO_2 and NO_x. These reductions will total about 10 million tons of SO_2 and 2 million tons of No_x. The reductions will be accomplished in two phases. Phase I began in 1995, when reductions were required at 110 power plants. For the most part, these were the largest units in the country, burning high sulfur coals. Most of these units were able to comply with the reduction requirements by switching to low sulfur coals. Others installed flue gas desulfurization (FGD) systems.

Phase II will begin in 2000, and will affect essentially all of the utility generating units in the U.S. The sulfur reduction requirements are even greater than in Phase I and will require major changes to either fuel type or the addition of very efficient FGD. However, there will be many older units where FGD will not be cost effective for a short remaining life. The acid gas removal systems used in IGCC recover sulfur compounds more efficiently than the limestone based flue gas desulfurization systems commonly used on coal-fired units. Research and development on zinc-based hot gas cleanup technology may provide hydrogen sulfide removal approaching 99 percent. IGCC technology provides the additional benefit of allowing a utility to continue to use low cost high sulfur coal, while achieving very high sulfur removal efficiency. This will allow utilities that are considering retirement of an older unit to repower it with the same or higher output, and comply with the Clean Air Act Amendments.

The IGCC process is also inherently low in NO_x emissions. Due to the burner enhancements being made on combustion turbines, NO_x emissions below 10 ppm are available with natural gas firing. Development of combustors to burn syngas with these low levels is proceeding quickly. NO_x control with IGCC is very effective when using nitrogen injection from the air separation plant. Nitrogen injection cools the flame, reducing NO_x formation, so that downstream removal technologies such as selective catalytic reduction (SCR) are not needed. This allows for low cost compliance with NO_x regulations.

Table 1 shows the emissions of SO_2 and NO_x for several different power plants. It presents these emissions in pounds per megawatt-hour generated. This index is more accurate than using pounds per million Btu of heat input, since it takes into account the inherent efficiency of the IGCC unit. The units described are the Wabash River unit before and after the repowering, the Indiantown fluid bed combustion unit, the conventional coal-fired Orlando Utilities unit, Polk Power Station(IGCC), and the DEMKOLEC IGCC unit in the Netherlands. The DEMKOLEC unit has very low emissions of SO_2 since it burns low sulfur coal. As the reader can see, IGCC can provide an efficient and effective method for meeting compliance on new or repowered units.

Tablee 1. Emissions per MWh

	lbs. SO_2	lbs. NO_x
Wabash River Unit #1 Coal	32.4	7.9
Wabash River Unit #1 IGCC	2.3	0.8
Indiantown FBC	1.76	1.76
Orlando Utilities Station Unit #2 Coal	1.58	1.58
Polk Power Station Unit #1 IGCC	1.49	0.87
DEMKOLEC IGCC	0.48	1.36

Fuel Flexibility

As Table 2 shows, the gasification process brings significant fuel flexibility to the utility industry. In addition to the conventional fuels that utilities use (coal and oil), a wide range of "feedstocks" can be used to generate power from this chemical process. With fuel being the largest single cost of producing electricity, every utility must find ways to lower fuel cost. This is becoming more important as competition increases in the electric utility industry.

Tablee 2. Fuel Flexibility

- High sulfur coal
- Low sulfur coal
- Petroleum coke
- Blends
- Waste Fuels
- Heavy Oil

In order to comply with the Clean Air Act Amendments of 1990, many utilities have switched to eastern low sulfur coal. In many cases, that low sulfur coal costs more than the higher sulfur coal. However, the increasing use of inexpensive western Powder River Basin coal has caused a significant drop in the cost of compliance. Utilities have opened up their markets to many types of coals, including those from foreign countries. The Phase II requirements will cause utilities to look more seriously at SO_2 removal technologies, since coal sulfur content may not be low enough to assure compliance.

By repowering or retrofitting with IGCC, the utility can open up its fuel market to low quality, yet high carbon content, fuels. These include low volatile coals, petroleum coke, waste fuels, heavy oils, and numerous blends of all of these fuels. Since the gasification process simply requires a carbonaceous feedstock, the utility can now look at fuels that it could never before consider due to the narrower design fuel range of a coal-fired boiler. IGCC can provide both environmental compliance and lower fuel cost.

By-Products

A conventional coal-fired unit produces one or more of the following combustion by-products: fly ash, bottom ash, slag, flue gas desulfurization sludge, and flue gas desulfurization by-product gypsum. Many utility companies sell these by-products for re-use in industry. Where there is no market for these by-products, the utility is left with several hundred thousand tons of solid waste to dispose of each year at great expense. Large tracts of land must be dedicated to disposal. In the case of new units, or existing units where the addition of FGD is planned for compliance purposes, these large amounts of solid waste can lead to community opposition. The ability to produce saleable by-products is becoming more important to utilities and the communities close to the power plants. IGCC can produce saleable slag, sulfur, and sulfuric acid, all of which have well developed international markets. This can solve both the cost and community concerns.

Repowering

A large percentage of the generating capacity in the U.S. is over 30 years old, the common design life basis during the 1960's. Through some life extension efforts, there are many units approaching 50 years of operation. Many utilities are now facing difficult decisions on whether or not to continue life extension projects, with the addition of expensive SO_2 and NO_x controls, or retire the older units. With the difficulty of finding and obtaining environmental permits for new sites, repowering has become an important option for these older units.

For example, Public Service of Indiana's Wabash River Unit #1 went into operation in 1953. That coal-fired unit was sized at about 100 MW. By repowering with IGCC, under the Clean Coal Technology Program, the new Unit #1 will have a net output of 262 MW. That utility was able to increase its generating capacity without the expense of a new site, and with only a minimal environmental permit process.

Repowering with IGCC offers the benefits of greater efficiency, higher output, and extended life, all at low incremental cost. This option will become even more important as the U.S. utility industry becomes more competitive, units continue to age, and more stringent environmental laws are passed.

New Units

As the population of the U.S. continues to grow, the need for additional capacity will grow with it. Utilities will continue to need new capacity. With the problems inherent with new sites, environmental impacts, and other community concerns, the siting and permit process can add many years and considerable cost to the generation expansion project. Given all of the benefits previously noted, such as efficiency, low emissions, low cost fuel, saleable by-products and superior environmental performance, IGCC is a technology of choice for new generation. Partly due to the higher efficiency, the IGCC process uses less water for cooling and other purposes than a conventional coal-fired boiler.

The regulatory agencies are becoming more aware of the merits of IGCC, and are better able to evaluate it along with other potential technologies. A main selling point is the low emissions in pounds per megawatt-hour generated, compared to other technologies. Future potential controls on air toxics, such as mercury, will provide even more needs for IGCC, since much, if not all, of the mercury is tied up in the slag that exits the gasification process.

Tampa Electric Company Polk Power Station

The Site

Tampa Electric Company (TEC) is an investor-owned electric utility, headquartered in Tampa, Florida. It is the principal subsidiary of TECO Energy, Inc., an energy related company involved in coal mining, transportation, and utilization for power generation. TEC has 3,415 MW of generating capacity. About 97 percent of the generation is from coal-fired units. TEC serves about 500,000 customers in and around Tampa, Florida.

Florida is a fast growing area of the U.S. In its generation expansion planning process, TEC evaluated many different processes and fuels sources. During that period of time, the Department of Energy's (DOE) Clean Coal Technology Program was trying to find a site for an oxygen-blown IGCC plant. TEC and DOE reached an agreement whereby DOE is funding 20-25 percent of the cost of TEC's new generating plant, called Polk Power Station Unit #1.

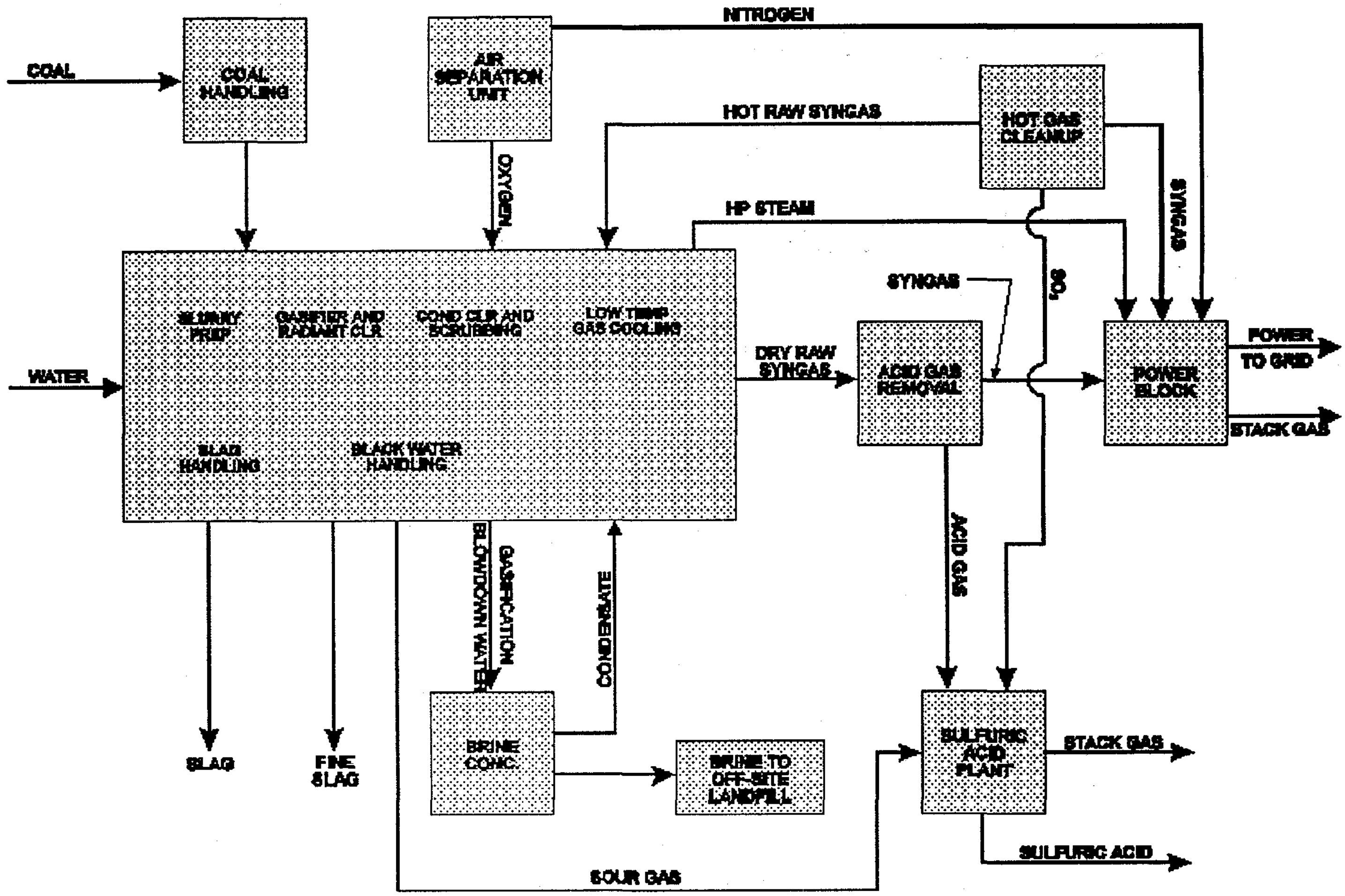
The Polk Power Station is being constructed on an inland site in Polk County, Florida. The site was previously mined for phosphate and is being reclaimed as a part of the plant site development. The site was selected by an independent Community Siting Task Force, commissioned by TEC to locate a site for future generating units.

The seventeen person group included environmentalists, educators, economists, business people, and community leaders. The study, which began in 1989, considered thirty-five sites in six counties. The Task Force recommended three tracts of land in southwestern Polk County that had been previously mined for phosphate. These sites had the best overall environment and economic ratings from the Task Force. The total area for the site is 4300 acres (17.4 square kilometers). About one-third of the site will be used for the generating facilities. TEC is responsible for site development. As part of this overall plan, the existing mining cuts have been modified and used to form an 850 acre (3.4 square kilometer) cooling reservoir.

Gasification Technology and Process

The unit will utilize Texaco's oxygen-blown, entrained-flow gasification technology. A general process flow diagram is shown in Figure 1. Coal will be ground and slurried in rod mills to 60-70 percent solids. The unit is designed to process about 2,000 tons coal per day. The coal slurry and oxygen (from the air separation plant) will be mixed in the gasifier. The coal slurry will be partially oxidized at a temperature in excess of 2,500°F (1,370°C). This will produce syngas at about 250 Btu/scf (LHV). The syngas will exit the gasifier and enter a radiant syngas cooler, where the syngas will be cooled to about 1,300°F (700°C). The radiant syngas cooler will produce high pressure steam at 1,600 psia (110 bar), which will power the steam turbine. From the radiant syngas cooler, two 50 percent streams will enter convective syngas coolers, which will also produce high pressure steam. After those coolers, the syngas will enter gas/gas exchangers that will be used to heat up nitrogen gas and clean syngas, prior to their going to the combustion turbine. The slag formed in the gasifier will be collected at the bottom of the radiant syngas cooler, and then sold to local industry. The cooled syngas will then enter the acid gas removal system, where over 95 percent of the sulfur compounds will be removed. The conventional cold gas cleanup (CGCU) system will use MDEA as the absorbent. The concentrated hydrogen sulfide stream will go to a sulfuric acid plant.

Figure 1. PPS-1 Block Flow Diagram



The air separation plant will use ambient air to produce oxygen for use in the gasifier and nitrogen for the combustion turbine and for ash removal in the radiant syngas cooler. This plant is sized to produce about 2,100 tons oxygen per day, and 6,300 tons nitrogen per day.

As a part of the demonstration project with DOE, the IGCC unit will test a hot gas cleanup (HGCU) system. This will be sized to treat about 10-15 percent of the syngas, and provide sulfur removal using metal oxide (zinc or zinc oxide base) pellets at about 900°F (480°C). In CGCU, the gas must be cooled, cleaned, then re-heated prior to entry to the combustion turbine. The potential advantage with HGCU is that it avoids the irreversible thermodynamic losses of the

CGCU. The HGCU system will also test chloride removal using sodium bicarbonate, and downstream ash removal using a barrier filter.

Combined Cycle Process

The key components of this part of the plant are the combustion turbine, heat recovery steam generator, and the steam turbine. The combustion turbine is a GE 7F. At full load, it will produce 192 MW with syngas and nitrogen injection. The steam turbine is a double flow reheat turbine with low pressure crossover extraction. The unit is designed for highly efficient combined cycle operation with nominal turbine inlet throttle conditions of 1,450 psia (100 bar) and 1,000°F (540°C) and 1,000°F (540°C) reheat temperature. Under normal operation, the combustion turbine will start up on diesel oil, and then transfer to syngas and nitrogen at a higher load.

By-Products

The concentrated hydrogen sulfide from CGCU, and the concentrated SO_2 from the HGCU will flow to the sulfuric acid plant for final treatment. The sulfuric acid plant will produce up to 210 tons of 98 percent sulfuric acid per day. This will be sold to the local phosphate industry, where it will be used in making phosphate fertilizer.

The slag from the gasifier and radiant cooler will be sold to local industry. Slag from TEC's existing coal-fired units has been sold for almost 30 years. It is used in sand blasting grit (for surface preparation prior to painting), roofing tiles, and asphalt filler for paving roads.

The chlorides from the coal will be recovered as ammonium chloride in a brine concentration system. This by-product is expected to be used in the galvanizing industry. Therefore, all of the by-products from this IGCC plant will be sold and used commercially. This will show another one of the benefits of the IGCC process.

Schedule

Construction was completed in early July, and the gasifier was fired with coal slurry for the first time on July 19. Unit shakedown occurred during August and September. As of the first part of October, several hundred hours of gasification operation have been accomplished. Performance testing is scheduled for the balance of October, followed by commercial operation of the unit.

V. CONCLUSIONS AND RECOMMENDATIONS

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The conclusions that can be drawn from this report regarding the potential for IGCC in China are positive and supportive for its demonstration and commercial use in China in the long term. China needs economic growth, electric power plants, coal resource development, and environmental protection controls. At the economic growth rates demonstrated in the past ten years, China needs 15-18 GW per year of new generating capacity for the next 20 to 50 years. Coal is China's primary energy resource to be used as fuel for electric power generation. The annual production of raw coal in China is over 1.2 billion tons. Coal accounts for over 80 percent of China's total energy requirements and over 70 percent of the fuel used for electric power generation in China. Chinese industrial sectors also depend upon coal as an energy source and raw materials for the production of chemicals. To maintain a clean environment China needs to control emissions of SO_2, NO_x solid and liquid wastes resulting from the burning of coal which requires more efficient and high performance coal conversion technologies that have low water consumption. The market for high efficiency and clean coal utilization IGCC technology is clearly shown in China's 9th five year plan which states "the development of clean coal technology should be suited to the transition of the state macro development strategy". IGCC utilization for the production of electric power beyond the year 2000 is also supported by "China's 21st Century Agenda" which clearly defines the Chinese development route to be changed from the traditional development mode to the sustainable mode for the high efficiency utilization of its coal resources.

IGCC is the most clean, most efficient and most mature technology among currently available clean coal power generation technologies. It is also a more environmentally friendly technology than any other coal-based power generation technologies and contributes to the reduction of global emissions and improvement of air quality. China needs this IGCC clean coal technology to support its growing economy and will profit from the U.S. experience gained from the U.S.

Department of Energy (DOE) Clean Coal Technology Program (CCT). The DOE CCT Demonstration Program IGCC projects are in various stages of completion and demonstration at the intermediate utility scale (250MW). The CCT Wabash River IGCC Repowering Project (250 MW) has reached the stage of commercial operation in the production of electricity, and the CCT Tampa Electric IGCC (250MW) project has also reached a stage of commercial operation. The results of a China demonstration of a large scale IGCC technology for power production will assist in proving technology reliability, availability, and maintainability at the larger utility scale and will encourage the use of more efficient CCT technologies in China. The demonstration will also assist in the commercial acceptance of IGCC technology as a high efficiency and environmentally friendly approach for producing power from coal to be used in global utility power plant applications. Demonstration of this high efficiency and non-polluting coal based technology is required at utility sizes greater than 250MW to prove technology scale-up and reliability at the utility scale.

Based upon the favorable results of the U.S. CCT Program, China believes that IGCC is now mature, reliable, flexible and suitable for a variety of coals that can be found in China. Many Chinese coals have been tested and used in gasifiers manufactured in China. A large scale demonstration of IGCC is needed to assure commercial readiness of this technology in China. This approach will allow China to obtain first hand know-how and experience from operating the China IGCC demonstration plant. China already has extensive experience in coal gasification from the chemical industry where 80% of China's chemical production is based on coal. China also has experience with combined cycle power plant operation from projects supported by the Ministry of Electric Power. A recent proposal to build an IGCC plant with refinery residue oil as feed provides a step closer to the IGCC plan for commercialization with coal as feed.

Based upon the U.S. IGCC demonstration experience, the risks for the China IGCC demonstration project will be greatly reduced. Use of equipment made in China will also reduce power plant capital and investment costs compared to U.S. IGCC demonstration plant costs, since the U.S. costs for non-proprietary equipment and systems are significantly higher than similar equipment and associated plant costs in China. Current levels of plant costs, fuel costs, and environmental regulations, which affect overall project costs for large field-constructed power plants, vary within regions and in different countries. In addition, plant costs are also affected by local labor productivity, cost of labor, manufacturing, and costs of components. Systems that can be produced locally in China will be greatly reduced in cost, compared to foreign imports, as will the costs of construction which must be performed by Chinese. Therefore, IGCC plant costs in China can be significantly further reduced based on technology demonstration and associated operating experience gained from the performance of the China demonstration project.

China offers a unique opportunity for additional demonstration of the IGCC technology in larger scales which will improve the reliability, availability and maintainability of the use of this technology in commercial applications in China, the U.S. and in other countries. The adoption for the more efficient and environmentally friendly IGCC technology has a much better opportunity in the Chinese market place where economic growth is the driving factor. In addition, fuel is the largest single cost of producing electricity and electric power generation projects must find ways to lower the cost of fuel over the life of the power plant by using more efficient technology such as IGCC which will provide a 20% margin in efficiency over conventional technology.

The only way China will confirm economic and technical performance of IGCC technology compared to other options will be through the construction and operation of a 200 – 400 MW project. IGCC technology was not given serious consideration in the U.S. and Europe until the clean coal technologies were demonstration to be competitive with natural gas. Through the experience of this project China will incur actual capital and operating costs that will provide useful information for improving the economics of future projects. This focused U.S./Chinese effort to demonstrate IGCC in China will set an example for potential future collaborative efforts in identifying and addressing the world wide need for highly efficient and environmentally friendly technologies such as IGCC.

VI. ACRONYMS AND DEFINITIONS

APPENDIX 1. ACRONYMS AND DEFINITIONS

BFBB	bubbling fluidized-bed boiler
BOT	Build-Operate-Transfer (basis)
Btu	British thermal unit
CAS	Chinese Academy of Sciences
CCT	Clean Coal Technology
CFB	circulating fluidized bed
CGCU	cold (low-temperature) gas cleanup unit
CO_2	carbon dioxide
COE	cost of electricity
DOE	Department of Energy (USA)
EFCC	externally-fired combined-cycle
EU	European Union
FC	fuel cell
FGD	flue gas desulfurization
G	giga - billion - (10^9)
gce/kWh	gram standard coal equivalent/kilowatt-hour
Gtce	giga (billion - 10^9) tons standard coal equivalent
GW	giga - billion - (10^9) Watts
ha	hectare
HGCU	hot gas cleanup unit
HHV	higher heating value
HRSG	heat recovery steam generator
Hz	Hertz – cycles per second
IGCC	integrated gasification combined-cycle
IGFC-CC	integrated gasification fuel cell combined-cycle
IGHAT	integrated gasification humid air turbine
kgce	kilo (thousand - 10^3) grams standard coal equivalent
kha	thousand (10^3) hectares
kt	kilo (10^3) tons
kWh	kilowatt-hours
LEAP	Long-range Energy Alternatives Planning
LGTI	Louisiana Gasification Technology Incorporated
LHV	lower heating value

MCI	Minestry of Coal Industry
MDEA	methyl diethanolamine
MEP	Minestry of Electric Power
MF-T	modified Fischer-Tropsch synthesis
Mha	million (10^6) hectares
MMI	Ministry of Machinery Industry
Mpa	mega (million - 10^6) Pascals
MRF	multistage rotary furnace
Mt	million (10^6) tons
Mtce	million tons standard coal equivalent
MW	mega (10^6) Watts
NGCC	natural gas (fired) combined-cycle
Nm^3	normal cubic meter
No_x	oxides of nitrogen
PC	pulverized coal (firing)
PC-SC	pulverized coal (fired) supercritical boiler
PDP	process design package
PEO	primary energy output
PFBC	pressurized fluidized-bed combustion
PFBC-CC	pressurized fluidized-bed combustor combined-cycle
ppm	parts per million
PRC	People's Republic of China
psia	pounds per square inch, absolute
quad	quadrillion (10^{12}) Btu
R&D	research and development
RMB	(phonetically – Ren Min Be) PRC People's Currency
ROM	run-of-mine
RSA	Republic of South Africa
SASOL	Suid Afrikaanse Steenkool, Olie en Gas Corporasie
SCR	selective catalytic reduction (of NO_x)
SETC	State Economic and Trade Commission
SNG	substitute natural gas
SO_2	Sulfur Dioxide
SPC	State Planning commission
SSTC	State Science and Technology Commission (PRC)
T	tera - trillion (10^{12})

TOE	tons of oil, equivalent
TSP	total suspended particulates
TWh	trillion (10^{12}) Watt-hours
UNDP	United Nations Development Program
US	United States of America

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鸣　谢

负责本报告最后准备及印刷工作的人员希望代表全体工作人员向最初倡议这项工作的人们以及在中国，美国及其它地方为这项工作作出贡献的人士致谢。感谢所有从事幕后工作的人们，参加了专家会议的人，提供纸张以及书写，安排，起草，编辑和印刷本报告的人们，谢谢你们作出努力，贡献你们的知识，更重要的是感谢你们相信，通过采用本报告中的很多观点，中国以及世界将从中获益。

前言

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CAS

中国科学院

CHINESE ACADEMY OF SCIENCES

众所周知，随着改革开放政策的实施，中国的国民经济出现了飞速发展。电力是国民经济的基础工业，是衡量一个国家发展水平的重要尺度。目前中国电力工业的装机容量已跃居世界第二位，年增长速度已达 15GW/a 。

由于中国是一个以煤为主要能源的国家，在较长时期里，火力发电厂将占主导地位，因此提高燃煤火力发电厂的热效率和降低排放污染是关系到保持本国国民经济进一步持续发展和为改善世界环境作出贡献的重要措施之一。1992 年巴西联合国环境和发展大会后，中国认真履行了自己的承诺，编制并经国务院批准了“中国 21 世纪议程”，正式提出要对大气污染进行有效控制，并致力于发展洁净煤技术。

整体煤气化联合循环（简称 IGCC）技术是一项七十年代发展起来的燃煤发电新技术，具有高效率、低污染、少用水的优点，获得国际上广泛重视。

1994 年 5 月中国政府成立三委三部 IGCC 示范项目领导小组，与美国能源部建立联系。为了使 IGCC 技术能在中国尽早实施，中国科学院和美国杜兰大学共同提出，组织中美有关专家对 IGCC 技术作出客观评述，为在中国推进这一技术作出努力。这一建议获得中国国家科委和美国能源部的支持，并商定将这一评估报告列入中美化石能源合作议定书附件九：洁净煤技术合作项目中。

本报告是由中美双方有关专家从不同角度对 IGCC 技术进行评估，并对在中国发展这一技术提出自己的观点。中国是一个发展中国家，经济实力有限，但市场广阔，因此在引进国外先进技术的同时必须更多考虑如何吸收消化，并有效地利用本国已有技术和制造能力以便降低新建 IGCC 电站的造价。

只有这样才能为在中国建设和发展 IGCC 电站提出一个合理的投资估价，同时也对国外希望在中国推广 IGCC 技术的厂商提供一个现实的市场信息。

希望本报告的完成将为中美两国政府和有关厂商以及其他国家关心在中国发展 IGCC 技术的人士提供有意义的分析依据。

中国科学院院长　周光召　院士

United States Senate

WASHINGTON, DC 20510-1802

美国和中国都在通过使用更有效和有利于环保的技术来解决共同面临的对能源需求的不断增长。整体煤气化联合循环 (IGCC) 技术是这方面的一个极好例子，它是燃煤发电及用煤生产其它产品的最清洁和最有效的手段。在中国为持续发展而制订的 21 世纪议程中，发展 IGCC 已被列为重点。美国在过去二十年里一直发展 IGCC, 并已在这项技术的提高和商业化方面处于领先地位。在这份报告中美中双方共同努力分析了 IGCC 的优势和潜力，并将作为今后共同致力于解决全球公共环境和能源生产问题的一个合作摸式。

我很高兴能为这份报告撰写前言。由于使用新的技术生产电力具有高度的技术和财政上风险，因此研究、发展和示范到商业上能接受需要一条漫长而艰苦的路程。 IGCC 在美国的示范及其在满足中国今后能源需求方面的潜力是令人激动的，值得受到重视就如为写这份报告所作的努力。这份报告将有助于估价 IGCC 对缓解 CO_2 排放带来的气候变化，同时提供最佳利用中国煤炭的选择，这些选择包括利用 IGCC 来生产化工产品、汽车燃料、民用和工业用燃料以及许多其他煤的衍生产品。

通过对这一报告的共同努力认识到在能源和环保技术的广阔领域里美国和中国具有共同的兴趣和目的，我相信这份报告将为今后双方的合作提供一个有用的框架。

美国参议员 尊敬的 J. 贝内特. 约翰斯顿 先生

摘　要

本报告是由在整体煤气化联合循环 (IGCC) 发电站方面有声望的中美专家撰写，目的为提供高层决策者参阅，为在中国加速实施 IGCC 示范项目作出推动。报告分析了 IGCC 系统在中国的潜在市场及其与其他洁净煤技术的竞争前景，这些信息不仅对中国政府而且对美国厂商都有用。为了对美国洁净煤技术转让到中国的可行性作出公正和合理的评估，报告着重分析了中国的能源供应结构，中国的能源和环保需求以及中国的潜在能源市场。本报告是由中美专家合作撰写而成，并将由中国科学院领导呈送国家计划委员会，以便对 IGCC 在今后中国电力生产中的重要性进行考虑。

中美 IGCC 专家报告

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中国是一个发展中国家，国土广阔，人口众多。随着近二十年开放政策的实施，中国国民经济有一个飞速发展，它的速度和持续时间均引起世人注意。能源和电力与其他工业和人民生活有直接联系，它能反映一个国家的发展水平。目前中国电力工业的装机总容量，已跃居世界第二位，年增长速度达15GW/a。根据预测在“九五”计划期间其装机容量增长速度在16GW/a左右。

从总的形势看中国的能源储量不算贫乏，品种也较齐全，但由于人口众多，因此按人均占有量来算就比较低。而且由于能源品种和地理分布的不均衡，使能源生产与消费之间形成不相适应，这就造成了对国民经济发展的约束条件。

根据能源分布现状，中国在相当长时间里将以煤作为最主要的一次能源。在中国已探明的煤矿储量非常丰富，而且已建立起相应的煤生产工业，所以中国电力工业以燃煤为主的格局，今后也不会有太大变化。

据能源战略研究表明2010,2020和2050年煤电装机容量将分别达到369GW，500GW和820GW，这说明中国是21世纪世界和亚洲的最大煤电设备市场。中国和外国政府、厂商和研究机构都可参与做大量工作，包括竞争和合作。

燃煤电站有它固有的缺点，对大气的排放严重，包括 SO_2, NOx 和飞尘，都会构成对环境污染。受经济力的限制，直到目前中国的燃煤电站，绝大多数是没有脱硫装置，更不会去考虑降低 NOx 的措施。同时大部分电站热效率较低，因此每年构成的排放量实属惊人。由于大气不分国界，中国燃煤形成的大气污染不仅对本国也对周边国家形成威胁，引起世界各国的关注。

由中东战争引起的七十年代石油危机，促使西方发达国家重新考虑燃煤的发电技术。当然在重新发展燃煤电站时必需认真改善对环境的影响，否则无法获得世界舆论的认可。在这方面，美国能源部于 1985 年开始陆续推出 5 期洁净煤技术发展计划，其中有 43 个项目，这些项目经费由美国能源部和厂商共同负担，目前这些项目有的已建设完成，进入商业示范运行。在这些项目中最有发展前景的是整体煤气化联合循环（简称 IGCC ）发电技术，它具有高效率、低污染、少用水的特点，对煤种也不苛求。 1995 年已有一个项目（ Wabash Project ）建成投产，目前进入商业示范运行；另一项目（ Tampa Project ）也将于最近建成投入运行。除美国外，欧盟在荷兰也建成一个 IGCC 项目（ Demkolec Project ）。根据 IGCC 所具有的特点，特别适用于新建的承担基本负荷的大型电站同时也适用于老电站改造，增容扩建。

对于中国来说为了保持 21 世纪经济持续发展必须把改善环境提到日程上来，必须选择一个适应于我国能源结构，以煤作为主要一次能源的发电新技术，它就是 IGCC 技术。1994 年 5 月中国政府为发展这项技术，正式成立了三委三部（国家科委、国家计委、国家经贸会、电力部、机械部和煤炭部）IGCC 示范项目领导小组，对 IGCC 技术作了系统调研，并与美国能源部建立了联系。中国科学院于 1995 年与美国杜兰大学共同提出组织中美有关专家，对 IGCC 技术作出客观评述，为在中国推进这一技术作出努力。这一建议获得中国国家科委和美国能源部的支持，并商定将其列入中美化石能源合作议定书附件九：洁净煤技术合作项目中。

从发展看，美国已有较成熟的 IGCC 技术，而中国正需要这种技术来满足它的快速经济发展。作为发展中国家，中国在发展 IGCC 技术时最好争取“主要设备引进—吸收消化—充分利用本国制造能力”的模式，因为只有这样才能降低 IGCC 电站的造价，符合中国国情。本报告是由中美双方专家从不

同角度对IGCC技术进行评估，并对在中国发展这一技术提出自己观点。现特将其论点综述如下。

1．中国的能源形势

中国有丰富的煤炭资源和水能资源，已探明的煤炭储量为1Tt左右，可开发的水能资源达379GW。根据1993年完成的全国油气评价，中国石油总资源量为94Gt，天然气资源为38Tm^3。中国每年消耗的生物质能资源约0.3Gtce。

中国的现代化面临人口、资源和环境的巨大压力。能源和这三个制约因素密切相关。

虽然中国拥有比较丰富而多样的能源资源，但由于人口众多人均拥有量就显得不足。根据现有的技术经济条件可采出的煤炭储量为114.5Gt，人均值仅为世界平均水平的二分之一。

英国石油公司“1995世界能源统计评论”数据，中国1994年末石油探明剩余可采储量为3.3Gt，人均只有2.75t，仅为世界平均值的11%。

为了使国民经济能持续发展，结合本国的能源形势，中国计划建立与经济发展相适应并有益于环境的综合能源规划。除了在管理上进行有效措施外，在技术上应提高能源的利用效率并历行节能，因为目前中国单位产值的能耗是发达国家的3-4倍。推广国际上已成熟的洁净煤技术和结合中国自身条件开发利用新能源和可再生能源都是进一步发展能源的有效和合理措施。由于中国长期将以煤作为主要能源，所以大力开发和引进洁净煤技术是一项有战略意义的措施。

2．中国的煤炭资源和生产情况

煤是中国的主要能源，根据成煤的历史条件，中国的北部和西北部是主要的煤储区，相对来说南部和东南部煤储量较少，而中国的工农业发达地区却在南部和东南部，这就构成了煤资源和消费地区的不合理分布。为了克服

这一不平衡，必须耗去不少能源用于煤的运输或二次能源的输送。

根据成煤条件，中国煤的灰分一般都较高，原煤中灰分大部分在 25% 以上，且高硫难选煤比重较大。中国煤的平均硫分在 1995 年为 0.77% 。高硫煤主要在西南部，但不少北方煤中硫含量随开采往深度发展而提高，这说明今后煤利用中脱硫将越来越显得重要。

煤的储量占中国能源的 90% ，石油储量相对较少。为了满足国民经济高速发展，能源中煤的比重在今后 30-50 年内不会有大的变化。煤在中国一次能源生产中的比重会长期保持在约 70% 的水平。电力工业中，火电占总发电量的 80% ，其中燃煤电站占总发电量的 76% ，所耗煤占生产量的 30% 。在其他工业的燃料与动力所用能源中，有 75% 是从煤获得，其消费量占煤产量的 33% 。其中化肥工业 60% 的原料来自煤。民用燃料中 80% 是煤，占煤生产量的 20% 。冶金工业用煤占煤生产量的 8% 。

煤是固体化石能源，中国煤灰分较高，硫含量也有逐步增多趋势，因此在利用煤作为能源时必然会对环境形成污染。目前燃煤电站对烟尘治理较好，1990 年除尘效率就达 93.9% ，全行业 TSP 合格率达 90% ，但对 SO_2 治理基本上没有进行。联合国几年前一项报告中列举空气中 SO_2 含量最高的十大城市中国就占了三个，沈阳、西安、北京分别列为第二、第七、第八位。

综上所述，作为燃煤大国，中国必须把发展洁净煤技术作为一项重大国策以保证中国的能源与环境协调发展。

3．中国的电力工业现状和展望

改革开放以来，我国电力工业取得了极为可喜的成绩。1980 年全国发电装机容量仅为 65.87GW ，年发电量为 300.6TWh 。到 1995 年底，装机总容量已达到 210GW ，年发电量达到 900TWh 。在“九五”计划期间，予计每年新增发电设备容量约为 16GW ，到 2000 年底，总容量可达到 290GW ，为 1980 年总装机容量的 4.4 倍；年发电量达到 1400TWh ，为 1980 年发电量的 4.6 倍。因此，2000 年的发电装机总容量和发电量两项指标均将比 1980 年翻两番以上。

根据专家予测，在今后较长时期里，无论是装机容量或年发电量，火电比例会升高一些，水电比例会降低一些。予计到2000年底，火电机组总容量约为220GW，水电机组总容量约为70GW，合计为290GW；2000年火电机组年发电量约为1120TWh，水电机组年发电量约为280TWh，合计为1400TWh。

从上面数字可以看出为了满足国民经济迅速发展的需要，中国政府在电力工业增加容量方面的确有了较周密的安排。但由于中国电力工业的主要一次能源是煤，在完成能量转化时不可避免地要对大气造成污染，因此如何在发展火电设备容量的同时，对大量的排污进行有效控制，看来还没有一个妥善的安排。因为燃煤电站污染处理需要技术和大量资金，对目前中国来说都是难题。另外对已有电站的改造，由于参数较低，效率较差在改造过程中更是困难重重。但中国在1992年联合国环境和发展大会后，已认真履行自己的承诺，编制并经国务院批准了“中国21世纪议程”，正式提出要对大气污染进行有效控制，并致力于发展洁净煤技术。

4. 中国需要洁净煤利用技术

中国电力工业以燃煤为主，由于机组更新较慢，所以平均净热效率较低，目前仅为30%（LHV）左右。改革开放促使中国国民经济和电力工业都有迅速发展，在伴随这种发展的同时，因燃煤引起的大气污染也达到了惊人的程度。由于国内提供的燃煤发电设备目前只限于烟尘处理，对于排烟中的SO_2和NOx根本没有处理。

虽然也进行了某些技术的研究如磷铵肥脱硫技术，石灰洗涤法，旋转喷雾吸收干燥法和炉内喷钙脱硫等，但都在试验阶段未进入工程应用。

通过常规蒸汽电站设备引进的同时引进烟气脱硫装置，例如重庆珞璜电厂，南京下关电厂。由于引进装置投资太高，看来也没有推广价值。

降低大气污染的另一途径是采用高效率的发电装置，因为它降低单位功率的烟气排放量，中国在这方面也进行了工作，包括大功率的循环流化床（CFBC）锅炉电站和增压流化床（PFBC）联合循环电站。由于PFBC工程功

率太小，只有 15MW，参数选择不尽合理，因此它无法反映 PFBC 技术的特点。

作为下一世纪的承担电网基本负荷的发电装置，中国政府选择 IGCC 作为候选技术，组织了三委三部示范项目领导小组，组织有关专家进行 200-400MW 规模的工程预可行性分析。IGCC 具有高效率、低污染、少用水的优点，适宜于发展大功率，作为世纪之交的 90 年代后半叶，中国政府准备要为 21 世纪电力工业的发展找到合适的发电机组。

5. 中国应该发展 IGCC， IGCC 可以在中国获得发展

由于中国火电动力以常规汽轮机为主（约 95%），由此产生三大问题：煤耗高；有害物排放量大；耗水量大。随着国民经济的发展现有约 210GW 的庞大火电网还将成倍扩大，若不采用先进技术改造现有电站和建设新电站，则能源浪费和环境污染问题势必更为严峻。

IGCC 是最有发展前景的洁净煤发电技术，其优点可归纳如下：

(1) 具有提高发电系统热效率的最大潜在能力，目前其供电效率可达 40-46%，下世纪有望突破 50%；

(2) 易大型化，装机容量已能做到规模经济等级（300-600MW）。

(3) 污染问题解决得最彻底，即使燃用高硫煤，也能满足严格的环保标准要求，脱硫率 ≥ 98%，废物处理量最少，副产品有用；

(4) 适用煤种广，能和煤化工结合成多联产系统，能同时生产电、热、燃料气和化工产品；

(5) 耗水量比常规汽轮机电站少 30-50%，适用于缺水地区；

(6) 示范装置运行率达到 80% 以上，能满足商业化的要求；

(7) 有广阔的产业发展前途，例如可以进一步发展成具有更高效率和更好性能的亚、超临界蒸汽参数的 IGCC，整体煤气化湿空气透平循环（IGHAT），整体煤气化燃料电池联合循环（IGFC-CC）等等。

根据中国成煤和产煤条件今后煤中含硫量将逐年增加，同时中国产煤地区的水源并不丰富，通过一系列的分析与比较，正象上面列出的优点可以表明 IGCC 是最适合于今后在中国发展。

6．全球环境保护是一个刻不容缓的课题

随着全球性工农业生产迅速发展和人类生活水平的提高，能源的消耗以惊人的水平发展。由于目前最广泛使用的一次能源还是化石能源，因此在它转化过程中必然会伴随产生大气污染，这已引起国际社会的广泛关注。地球只有一个，全人类共同居住在这里，为了使世界经济能持续发展，为了使人类永远能健康地生存下去，全球环境保护已是一个刻不容缓的课题。

特别值得一提的是近二十年来东亚和南亚经济相对发展较快，但这些国家的单位产值能耗又远远落后于发达国家，这就造成了每年大量消耗一次能源。同时，这些国家的能源结构又受到一定限制，大量以煤作为一次能源消耗，而且是以非常低水平的生产方式加以利用，因此造成对环境的污染是惊人的。

中国是世界上少数几个以煤为主要能源的国家，是世界上最大的煤消费国，1994 年煤消费量占世界的 26.6%，全国（不含乡镇工业）SO_2 排放量达 18.25Mt，烟尘排放量达 14.14Mt。由于对 SO_2 排放控制不力，目前据专家估计已有三分之一国土形成了酸雨区，一些城市燃用 1 吨煤产生的 SO_2 和酸雨污染造成的经济损失达 50-70 元人民币。另外，中国排放的 CO_2 也已占世界第三位。

由于对环境保护的认识不够同时也受资金条件的限制，一般已建的燃煤电站，大部分未安装控制 SO_2 和 NOx 的设备，对于除尘则开始比较注意。但大部分中小型的燃煤电站和绝大部分工业燃煤锅炉和窑炉连除尘也不加考虑。因此中国北方地区不少城市空气中的粉尘和 SO_2 含量大大超过国际卫生组织

的规定，特别在冬季整个城市笼罩在烟尘和污染之中。这种对全球大气污染严重影响的现象已引起周边国家和世界组织的关注，当然作为中国政府为了自身国民经济能进一步持续发展和为全球环境保护作出贡献已编制“中国 21 世纪议程”正式提出要对大气污染进行有效控制。

7．美国在洁净煤技术方面在国际上有明显优势

七十年代中东战争引起石油危机，使国际能源界重新把目光转移到煤炭上。美国把发展洁净煤技术作为一项具有战略意义的工作确定下来，由能源部从 1985 年开始陆续推出 5 期洁净煤技术发展计划，是国际上最早由政府来组织有计划地推行洁净煤技术研究与开发的国家。其目的不仅是为美国本身将来一旦发生石油危机可以利用煤作为清洁能源来加以利用，同时可以把发展成熟的洁净煤技术推向国际市场，为广大的以煤为燃料的发展中国家提供先进的洁净煤利用技术，为保护全球环境作出贡献。

经过 9 年的投标选择，前后共计划进行 43 个项目，投资金额达 70 亿美元，其中 67% 由有关厂商分担，能源部投资 33% 。重点是实现 21 世纪先进的燃煤电站，其中 5 个是整体煤气化联合循环（IGCC）发电技术， 6 个是流化床燃烧技术。这些项目中包括提高发电热效率；降低电价；整体化控制 SO_2 和 NOx ；降低烟尘排放；扩大燃煤适用品种和提高增容达 150% 。这 11 个项目和另 3 个项目加在一起投资共达 46 亿美元。其中 Wabash IGCC 电站增容项目已于 1995 年建成，目前已转入商业示范运行； Tampa IGCC 新建电站项目也将于最近建成。该两示范电站的主要性能指标如下：

	功率 MW	净热效率 (LHV)	脱硫率	造价
Wabash 增容电站	262	40%	> 98%	USD1366/kW
Tampa 新建电站	260	42%	98%	USD1460/kW

应该提出的是上述两电站的性能指标是完全建立在切实可行的技术措施上，脱硫和净热效率的计算在常规冷煤气脱硫的技术上进行，因为热煤气脱硫技术还不成熟，故在示范工程中未被采用。由此说明美国在发展 IGCC 技术上并不片面地追求高性能指标，而是建立在可靠实用有推广价值的技术措施

上。1994 年中国政府组织了一个 IGCC 技术考察团去美进行研究考察，对上述论点有深刻的印象。根据 1996 年报导，实际 Wabash 电站的运行性能超过了上列设计数据，同时证明气化系统和发电系统之间能完全达到商业运行率的要求，这些结果充分说明美国在洁净煤技术领域里，包括 IGCC，在国际上是处于明显优势。

8. 对 IGCC 技术的发展和商业化是美国对世界能源和环境的一大贡献

从长远看煤炭肯定将是一种重要的一次能源，美国集中资金来发展洁净煤技术，特别是 IGCC 技术，是一项具有战略意义的措施。随着世界经济的快速发展，单一的依靠石油和天然气是不可取的，必须合理和洁净地利用煤炭资源。目前各发展中国家，特别是经济正处于蓬勃发展的那些国家，都已基本上认识到保护环境的重要性，但由于受到经济实力和国家资源的限制，始终在采用洁净煤技术道路上徘徊不前。美国在这一时刻，把 21 世纪的先进发电系统 IGCC 开发成具有商业化价值的技术推向市场是对世界能源和环境的一项重要贡献。对于发展中国家来说它们首先没有先进的技术基础，同时又没有大量的发展资金，而限于本国能源条件又必须发展燃煤电站，所以要靠发展中国家自身来解决这一矛盾是相当困难。

美国作为发达国家把先进的燃气轮机技术、煤气化技术以及热煤气净化技术组合成整体煤气化联合循环发电技术推向市场是正合时宜，必定会引起广大发展中国家的兴趣。

9. 中国电力工业的迅速发展将是美国 IGCC 技术的一个潜在市场

中国在今后相当长时间里将以煤作为最主要的一次能源，当然电力工业也将以燃煤的火电为主。予计到 2000 年，发电总容量将达到 290GW，从 1996 年到 2000 年间每年新增容量约为 16GW，而从 2000 年到 2020 年间每年新增容量约为 25GW，这些新增容量中火电约占 80%。如果 IGCC 能从中争取到 15%，那么每年就有 2-3GW 的市场。

对于中国来讲既要保持国民经济的持续发展，又要承诺对全球环境保护

作出贡献，那么她一定要找到一个低投资、高效率、低污染的燃煤发电新技术，作为一种在电网内能承担基本负荷的大型机组来加以推广使用。经过中美双方专家两年多的分析、研究和考察认为 IGCC 技术是最适于入选，因为它是具有燃煤电站的最佳供电热效率，而且能达到最佳的环保指标，从发展角度看， IGCC 在这两方面还有很大潜力可以发掘。但对于初投资和运行成本对 IGCC 有不少非议，下面我们来作一详细分析。

10. 利用美国技术在中国建立 IGCC 示范电站，将对中国产生经济效益和社会效益

通过上述分析可以看出，对于燃煤电站来说从技术上看 IGCC 是具有明显的竞争力，而对于初投资和运行成本 IGCC 是不是也具有优势，特别对于中国建立示范电站有没有发展前途这也是大家关心的问题。

经过两年多来的讨论分析，中美以及欧盟专家一致认为经济性的比较应在同一基础上来进行，都应以美国的条件来相比。根据 1991 年记载，对美国来讲 IGCC 的比投资较 PC+FGD 电站贵 10-20%，而两者运行成本就非常接近。但随着 IGCC 进入商业化后，其比投资和运行成本还会大幅度下降，其比投资会低于 PC+FGD 电站 20%。这是 IGCC 电站在经济上的发展趋势。

对于中国政府来讲除关心 IGCC 发展趋势外，更关心的是第一座具有规模经济等级（200-400MW）的示范电站，在经济上的可行性。详细的示范电站预可行性报告已由中国 IGCC 示范项目技术可行性研究课题组于 1994 年底提出，其中结论是：

	新建 IGCC 电　站	老厂改建 IGCC 电站
在美国的造价 USD/kW	～1500	～1350
在中国的造价 USD/kW（主要设备国外引进）	～1200	～1000

中国准备认真执行“中国 21 世纪议程”并要对洁净全球环境作出贡献，那么从上面的造价来看建立第一座 IGCC 电站是完全适合中国国情。因为通过

“主要设备引进—吸收消化—充分利用本国制造能力”的模式来开发这一新技术，还能进一步降低 IGCC 电站的造价。估计进入商业化生产后的 IGCC 机组其造价会低于 PC+FGD 的同容量机组的造价，而且从发展角度看 IGCC 无论在性能和造价上都还具有很大的潜力有待发掘。所以建立第一座 IGCC 示范电站对中国是具有很明显的经济效益，同时对本国和全球环境都会显示出深远的社会效益。

当然，对于美国来讲，在将 IGCC 推入中国电力工业的同时，实际上是进入了世界上最大的燃煤电力市场。21 世纪后，最大的洁净煤竞争市场是在中国，如果中美能在 IGCC 技术上进行充分和有效的合作，并在中国进行推广，那么未来的最大洁净煤市场将为美国所占有，这也正是美国政府和商界在十年前开拓洁净煤技术的本意—在为美国新技术开拓市场的同时为全球环境作出贡献。

希望本报告能为中国政府对 IGCC 技术的进一步了解和决策提供一个有意义的评估依据。

Ⅱ. 引　言

背景

1985 年 4 月美国能源部和中国煤炭工业部签订了化石能源研究与发展议定书。作为该议定书的一个附件－附件九：洁净煤技术利用－是在 1994 年 4 月由美国能源部与中国国家科学技术委员会签订。

由中国和美国签订的附件九讨论了发电中共同关心的问题和因烧煤形成的排污问题。在合作解决这些问题中，双方认为都能获益。譬如，中国力求找到具有商业化价值的洁净煤技术，而美国可以提供从洁净煤计划中获得的经验，并帮助中国实施。

中国要求更高效和更清洁地利用煤炭能源，这就给洁净煤技术提供一个市场。这一市场随着今后中国的经济发展将会继续扩大。近期内 (2000 年以前) 感兴趣的技术是那些能使常规燃煤电站在使用低成本的降低 SO_2 和 NO_X 排放系统的同时又能提高效率的措施。2000 年以后计划利用的新技术将是整体煤气化联合循环 (IGCC) 电站以及其他。IGCC 作为一种新的为改进效率和降低排污的燃煤发电技术已趋于成熟。IGCC 在欧洲和美国都已进入全尺寸商业化时代。目前可提供的 IGCC 技术已具有比常规发电系统更高的效率。通过进一步对煤气化和高温燃气轮机的改进，在下一世纪 IGCC 的效率可望达到 50%。

为在 21 世纪发展高效和洁净的燃煤发电技术，中国电力工业部已把 IGCC 列入中、长期发展计划，力求建设一座大型 (200–400MW) 先进的 IGCC 示范电站。这一示范电站将作为 21 世纪在中国 IGCC 技术商业化应用的基础。中国在 21 世纪议程中已把建设一座 IGCC 示范电站列为优先项目。这一示范电站是基于进口技术，它可以作为在中国大型化应用和发展 IGCC 技术的一个坚实基础。

IGCC 专家报告的目的

建立 IGCC 的资料库可为进一步研究和发展设备提供信息，并为在中国继续建新装置提供基础数据。由国家科学技术委员会、国家计划委员会、国家经济贸易委员会、电力工业部、机械工业部和煤炭工业部的中国高级官员组成了一个 IGCC 示范项目领导小组。

根据予测的国民经济增长速率，在不久的将来，中国的能源需求将会增长。在今后长时期里煤在能源供应中仍将占主导地位。解决高效和低污染的燃煤措施是极其重要，因为它不仅影响中国能源的合理利用而且对全球环境能起到保护。示范项目的工程预可行性研究已经完成。

由中美 IGCC 方面的著名专家准备的本报告的目的是为了提供给高层决策者，为加速 IGCC 示范项目在中国获得更快实施。IGCC 在中国的潜在市场以及它与其他洁净煤技术的竟争性在本报告中也有所分析。这些信息将不仅对中国政府而且对美国厂商都有用。本报告对美国技术发展商和设备供应商为联系到设备和系统的采购和供应方面对 IGCC 在中国的潜在市场作出评估也是有用的。为了对美国洁净煤技术转让到中国的可行性作出公正和合理的评估，报告着重分析了中国的能源供应结构，中国的能源和环保需求以及中国的潜在能源市场。本报告是由中美专家合作撰写而成，并将由中国科学院领导呈送国家计划委员会以便对 IGCC 在今后中国电力生产中的重要性进行考虑。

本报告的目的是要回答中国关心的 IGCC 技术在中国用于生产电力的可接受程度以及其商业化前途。报告将集中于下列各点来考虑：

1. 对于不同煤种 IGCC 目前在成熟性、可靠性、灵活性和适应性上处于何种程度？

2. 第一座 IGCC 示范电站和其商业化后在投资成本和运行费用的差价是多少？

3. 美国已有成功的 IGCC 示范电站，为何没有广泛使用？

4. 中国有大量的低硫煤矿 (<1%S), 为何煤的含硫量仍是选择 IGCC 的一项关键指标？

5. 影响燃气轮机寿命的是什么；为了烧好中热值煤气对燃气轮机应作哪些改造？

IGCC 专家会议

作为继续促使 IGCC 技术在中国实施大型化发电 (250-600MW) 示范论证工作的一部分，由中美两国在 IGCC 技术发展和商业化方面有关的不同集团的代表组成了一个 IGCC 专家组。参加 IGCC 专家会议的代表来自在 IGCC 及其有关技术领域里的政府、工业和科技界的有声望人物。1995 年 11 月 29 日到 12 月 6 日，专家会议在北京举行，并对 10 个专题进行了讨论。专题讨论中所反映的技术素材中美双方一致建议作为 IGCC 专家报告联合准备的内容。专家会议讨论了关于 IGCC 技术的发展现状及其在中国用于电力生产示范和应用的潜在趋势。对提出的素材在会议上进行了广泛评论，并提出不同观点和问题，以及 IGCC 在应用和商业化方面的成熟程度。同时也讨论了 IGCC 在中国用于电力生产时会遇到的障碍以及选用 IGCC 对中国目前和今后电力需求上的优点。中美专家最后确定了报告的格式和纲要内容，同时对双方成员要为这份共同开发的合作性报告进一步提供的专门技术素材达成协议。

Ⅲ. 中方专家的论述

1. 中国能源及电力的现状和展望

周凤起 研究员

2. 中国的煤炭及煤炭洁净利用技术

陈家仁 研究员

3. 中国电力工业简况及对 IGCC 发电技术的展望

霍宏先 高级工程师、肖云汉 博士

4. 煤气化工艺在中国发展的情况及已达到的水平

方德巍 教授、于遵宏 教授

5. IGCC 是中国发展高效率、低污染、少用水燃煤电站的一项高新技术

蔡睿贤 院士、林汝谋 研究员

1. 中国能源及电力的现状和展望

周凤起　所长　研究员

中国国家计委　中国科学院　能源研究所

中　国　　北　京

能源资源与能源生产

中国有丰富的煤炭资源和水能资源。

已探明的煤炭储量为 1 万亿吨左右，占常规能源储量的 90% 以上，其中烟煤占 75%，无烟煤占 12%，褐煤占 13%。煤炭资源的 80% 集中在中国的华北和西北地区。

中国可开发的水能资源达 3.79 亿 kW，居世界第一位，主要集中在中国的西南、西北和华中地区。

据 1993 年完成的全国油气主要评价，中国石油总资源量为 940 亿吨，天然气资源为 38 万亿立方米。目前，我国油气资源勘探还处在初期阶段，已探明的油气储量只是其中一部分，而且大部分都集中在长江以北的东部地区。

中国的生物质能资源主要包括三部分，即农作物秸秆中可作为燃料使用的部分；人们生活活动范围内各类树木合理采伐可作为薪柴使用部分；人畜粪便及有机废水。目前每年消耗的生物质能资源约 3 亿吨标煤。

综上，中国的能源资源丰富，品种比较齐全，但分布并不均衡；而且，由于人口众多，人均占有量低，必须节约使用。

中国的能源生产发展迅速，在 1949 － 1993 年期间，原煤产量由 32Mt 增长

到 1149.7Mt；原油从 120kt 增长到 145.2Mt；天然气从 $7Mm^3$ 增长到 $16.95Gm^3$; 发电量由 4.3TWh 增长到 839.5TWh，其中水电由 0.7TWh 增长到 151.8TWh。1993 年一次商品能源总产量为 1112.63Mtce，列世界第 3 位。

历年能源生产情况见表 1，由表可计算出年平均年增长速度为 9.1%。

能源消费现状及特点

表 2 表示了有选择年份的中国能源消费总量及结构。

由表可见，从 1949 年以来，随着能源消费数量的增长，一次能源消费结构也发生了很大的变化，由单一的煤炭结构变为煤、油、气和水电的多种能源结构。但是可以预见，在短时期内，以煤为主的能源结构尚难改变。

表 3 是中国一次能源分部门的消费量及结构，由表可见，中国的部门能源消费结构以工业为主。80 年代以来，工业生产用能的比例不仅没有降低，反而不断增长。1992 年工业生产用能占 70%，在工业中，化工、冶金和建材所消耗的能源占工业能耗的 45.8%。

中国生产的能源主要用于本身消费。1993 年出口的煤炭不足年产量的 2%，中国曾一度出口过大量原油，但 93 年已成为石油净进口国。

表 4 是中国 80 年代以来的能源进出口量，用于加工转换为二次能源的煤炭比重不高，1992 年全国消费煤炭 11.4 亿吨，用于转换二次能源的煤炭占煤炭消费总量的 43%，其中用于发电量占 29.3%；其余 57% 用于各种工业锅炉、工业窑炉和人民生活所用燃料，大量的煤炭直接燃烧带来严重的大气污染。

农村生活用能以生物质能为主。1992 年中国农村生活用能 70% 仍依靠生物质能，但 1980 － 1992 年 12 年间商品能源消费量年均增长率超过 10%，1992 年商品能源消费量已超过生物质能。

中国未来能源需求预测

能源需求预测方法

采用 LEAP(Long-range energy alternatives planning system) 模型进行预测， 1990 年为基准年， 2000 、 2010 、 2020 年为规划目标年，划分为 6 个主部门、 17 个子部门， 11 个终端能源品种。

规划指标的设定：经济增长指标设定： GNP 年均增长率 1990 年－ 2000 年为 9%；2000 － 2010 年为 7.5%；2010 － 2020 年为 6%。一、二、三产业及各部门经济增长速度见表 5。人口增长指标设定为：人口年均增长率 1990 － 2000 年为 12.5 ‰；2000 － 2010 年 7.2 ‰；2010 － 2020 年为 4.2 ‰。届时人口数到 2000 年为 12.94 亿人，2010 年为 13.9 亿人；2020 年为 14.5 亿人。详见表 6。节能率：1990 － 2000 年全国平均节能率为 4.49%，2000 － 2010 年为 4.42%；2010 － 2020 年为 3.35%。

能源需求预测的结果

根据 1990 年终端能源消费情况和上述假定，采用 LEAP 模型对规划年的能源需求进行预测，结果见表 7。表 8 是中国各种终端能源需求在各个预测年的年增长率。表 9 －表 12 是中国各部门在各个预测年的终端能源需求。由终端能源需求预测结果可见： (1) 中国终端能源需求中煤的比例将由 1990 年的 33% 下降至 2020 年的 20% 左右； (2) 对电力的需求增长很快，电力在终端能源中的比重将由 1990 年的 17.7% 升至 35.3%； (3) 对油、气需求也有较大增长，将从 1990 年的 13% 增长至 2020 年的 22.4%。

中国未来电力生产预测

1990 年中国电力装机容量 137.89GW，其中水利发电容量为 36.05GW，占 26.1%；发电量 621.62TWh，其中水电发电量 126.47TWh，占 20.34%。

1990 年中国的火力发电消耗燃料 202.18Mtce，其中煤炭占 94.4%，燃料油和气体仅占 5.6%。平均发电能耗为 392gce/kWh，发电效率 31.4%。平均供电能

耗为 427gce/kWh，供电效率为 28.8%。中国电力生产能耗高的主要原因是：中国的火力发电以燃煤为主，而大部分燃煤电厂都是五、六十年代的技术和设备；中国大型高效发电机组的比重低。1990 年末，125MW 以上高参数大容量的发电机组只占全国火电总装机容量的 47%，而目前在运行的中低压小容量发电机组占全国火电总装机容量的 26%；中国大型火力机组设计水平较低，设计能耗指标比国外先进水平高 10%，而发电机组的实际运行水平又达不到设计要求；中国火力发电厂的辅助设备效率普遍较低，因而电厂的自用电率高，1990 年平均为 8.22%，比发达国家高 30 － 50%。

根据专家预测，中国电力工业发展趋势列于表 13 和表 14。应该说明的这是低速增长的预测，1990 － 2020 年的 30 年间，火力发电的装机容量年均增长率为 5.55%，而九十年代，年均增长率为 8%。

一次能源供应预测

根据终端能源需求预测结果，考虑到能源生产、运输和分配过程中的损失，可求得一次能源需求，在考虑了国内的生产能力和进口量后，即可获得一次能源的供应方案，见表 15。

由表可见在 2000、2010、2020 年的一次商品能源需求大致是 15、20、25 亿吨标煤；煤炭分别是 15、20、23 亿吨；原油是 2、2.8、3.5 亿吨；天然气是 300、600、1200 亿立方米。煤炭在一次能源中的比重于 30 年中下降了 10 个百分点、天然气、水电和核电的比重逐步有所上升。

中国能源发展面临的挑战

中国的现代化面临人口、资源和环境的巨大压力。能源和这三个制约因素密切相关。

首先是人口过多，1995 年 2 月我国人口已达 12 亿人，小学以下文化程度者占半数以上，人口过多和人口素质低下，是解决我国能源问题的一个长期的首要制约因素。目前我国一次能源消费量已居世界第二位，但人均能源水

平很低。1994 年人均商品能源消费量为 1024kgce，仅为世界平均值的 50%，居民家庭人均用电为 73kWh，只有美国的 2.2%，而且迄今还有 1 亿人未用上电。

第二是人均能源资源不足。我国拥有比较丰富而多样的能源资源，但人均拥有量相对不足。全国 1500 米深度内煤炭总资源量达 4 万亿吨，但在现有技术经济条件下可采出的储量为 1145 亿吨，人均值仅为世界平均水平的二分之一。据英国石油公司“1995 世界能源统计评论”数据，中国 1994 年末石油探明剩余可采储量为 33 亿吨，人均只有 2.75 吨，仅为世界平均值的 11%。人均能源资源相对不足，是我国社会经济发展的重要制约因素，特别是石油。

第三是生态环境恶化。我国的能源环境问题主要是大量烧煤造成的城市大气污染和农村过度消耗生物质能引起的生态破坏。

我国是世界上少数几个能源以煤为主的国家之一，也是世界最大煤炭消费国，1994 年煤炭消费量占世界的 26.6%。全国(不含乡镇工业)SO_2 排放量达 18.25Mt，烟尘排放量 14.14Mt，分别比 1990 年增加 12.2% 和 6.8%，其中烧煤排放者估计分别占 90% 和 70%。由于对 SO_2 排放控制不力，目前据专家估计已有三分之一国土形成了酸雨区，一些城市燃用 1 吨煤产生的 SO_2 和酸雨污染造成的经济损失达 50 － 70 元。

另外，中国排放的温室气体已占世界第三位，也必须采取措施控制 CO_2 排放的迅速增长。

可持续发展的能源政策

综合能源规划与管理

建立与经济发展相适应、有益于环境的能源供应体系和消费模式，必须进行能源、环境、经济发展综合规划，作为制订计划与政策措施和进行管理的依据。它有利于综合分析、研究和解决能源、环境和经济领域内的交叉问题，协调相互关系，以达到能源、环境、经济发展的综合协调与平衡。

综合能源规划与管理的目标是建立一套适应中国国情和社会主义市场经济体制要求的能源、环境、经济综合规划方法，并推广应用到各级能源管理部门。2000 年前制订国家和地区级的能源、环境、经济综合规划及相应的实施方案。

本世纪末以前，中国的能源与环境发展的战略和政策可以主要归纳为：能源开发与节约并举，节能放在优先的地位；改善能源结构与布局；能源工业的发展要以电力为中心，煤炭为基础，大力发展水电，积极开发石油天然气，适当发展核电，因地制宜地开发新能源和可再生能源，依靠科技进步，提高能源效率，合理利用能源资源，减少环境污染。

提高能源效率和节能

随着经济的快速发展和人口的增长，能源供不应求的矛盾将会长期存在，优质能源供需缺口将会日益扩大，所以中国的经济发展必须由过去的粗放经营逐步转向集约经营，走资源节约型道路。另一方面节能也是防止污染、抑制温室效应的经济、有效措施。

目前中国单位产值能耗是发达国家的 3 － 4 倍，主要工业产品能源单耗比国外平均高 40%，平均能源利用率只有 30% 左右，而工业发达国家均在 40% 以上。所以中国具有很大的直接节能潜力。

中国的产业结构不尽合理，低能耗的服务业比例低，高能耗的工业比例较大占 51.8%，达到规模生产的企业数目少。随着产业结构、产品结构、能源结构的调整和优化，能源配置将趋于合理，间接节能比直接节能的潜力更大。节能的目标是 2000 年前节能率要高于 4%，能源消费弹性系数低于 0.5，即一半以上的能源需求增长量通过节能来满足。为达到上述目标，必须将节能工作纳入国民经济和社会发展计划，制定和实施“节能法”，逐步取消对能源的不合理的财政补贴，进一步改革能源价格。

推广清洁煤技术

推广清洁煤技术是促进以煤为主的能源系统向环境无害的可持续的模式转变的战略组成部分。中国政府拟制定清洁煤技术发展规划，纳入国民经济和社会发展计划之中，同时要制订一系列的政策法规和利用经济手段促进煤炭的清洁利用。

要研究高硫煤的洗选脱硫技术，干法选煤技术，扩大原煤入洗比例；扩大民用和工业型煤生产，提高动力配煤的比例，要研究和开发高效、低污染的生物质型煤；开发或引进大型循环硫化床燃烧技术；开发或引进水煤浆制备的燃烧技术；开发引进煤炭气化和煤气化联合循环发电技术；研究开发煤泥、无烟煤和褐煤的高效燃烧和利用技术。

要提高煤炭转化成电力、热力和煤气等洁净的二次能源的比例，减少直接和分散燃烧原煤的终端用途。

开发引进先进高效的烟气净化技术，重点发展适合中国国情的烟气除尘、脱硫、脱硝、废物资源化的技术与装备。

开发利用新能源和可再生能源。

只有可再生能源才能不产生或很少产生污染物，所以可再生能源是未来可持续能源结构的基础。

中国具有丰富的可再生能源资源，进一步开发利用的潜力极大。到 1993 年仅开发了水能资源的 11.8%，风能资源的十万分之二，地热资源的万分之一，至于太阳能、生物质能的资源利用前景也十分广阔。

为了更大规模地集中利用可再生能源，使之能与化石燃料相竞争，一定要增加投入，政策扶植、开发技术、降低成本。目标是 2000 年可再生能源的利用总量要达到 2.98 亿 tce， 2010 年达到 3.9 亿 tce 。

表 1　1949 — 1993 年能源生产量

年	能源总产量 (Mtce)	原煤 (Mt)	原油 (Mt)	天然气 (Gm^3)	发电量 (TWh)	
					总量	其中水电
1949	23.71	32.0	0.12	0.007	4.3	0.7
1952	48.71	66.0	0.44	0.008	7.3	1.3
1957	98.61	131.0	1.46	0.07	19.3	4.8
1962	171.85	220.0	5.75	1.21	45.8	9.0
1965	188.24	232.0	11.31	1.10	67.6	10.4
1970	309.90	354.0	30.65	2.87	115.9	20.5
1975	487.54	482.0	77.06	8.85	195.8	47.6
1980	637.35	620.0	105.95	14.27	300.6	58.2
1985	855.46	872.0	124.90	12.93	410.7	92.4
1990	1039.22	1080.0	138.31	15.30	621.2	126.7
1993	1112.63	1149.7	145.20	16.95	839.5	151.8

资料来源：中国统计年鉴 1994

表 2　能源消费结构

年	国内总消费量 (Mtce)	消费结构 (%)			
		煤	油	天然气	水电
1953	54.11	94.33	3.81	0.02	1.84
1957	96.11	92.32	4.59	0.08	3.01
1962	165.40	89.23	6.61	0.93	3.23
1965	189.01	86.45	10.27	0.63	2.65
1970	292.91	80.89	14.67	0.92	3.52
1975	454.25	71.85	21.07	2.51	4.57
1980	602.75	72.15	20.76	3.10	3.99
1985	770.20	75.92	17.02	2.23	4.83
1990	987.03	76.20	16.60	2.10	5.10
1993	1117.68	72.80	19.60	2.00	5.60

资料来源：中国统计年鉴 1994

表 3 一次能源分部门消费量及其结构

	1980		1990		1992	
	消费量 (Mtce)	%	消费量 (Mtce)	%	消费量 (Mtce)	%
总的终端消费	602.75	100	987.03	100	1091.70	100
1. 物质生产部门	480.55	79.7	794.30	80.47	891.73	81.6
A. 农业	46.92	7.8	48.52	4.92	50.20	4.6
B. 工业	389.86	64.7	675.78	68.47	762.79	69.8
a. 重工业	322.14	53.4	538.60	54.57	606.28	55.53
b. 轻工业	67.72	11.2	137.19	13.90	156.51	14.34
C. 建筑业	9.57	1.6	12.13	1.23	13.92	1.28
D. 交通运输邮电业	29.02	4.8	45.41	4.60	50.58	4.63
E. 商业	5.18	0.9	12.47	1.26	14.24	1.30
2. 非物质生产部门	12.05	2.0	34.73	3.52	43.61	4.00
3. 人民生活	110.15	18.3	158.00	16.01	156.36	14.32

资料来源：中国统计年鉴 1994 、 1991

表 4 中国 1980 － 1993 年能源进出口

单位：百万吨

	1980	1985	1990	1991	1992	1993
原油						
出口	13.31	30.03	23.99	22.60	21.51	19.43
进口	0.37		2.92	5.97	11.36	15.65
石油制品						
出口	4.20	6.21	6.33	6.82	5.98	4.56
进口	0.46	0.90	3.94	5.91	7.78	17.54
煤炭						
出口	6.32	7.77	17.29	20.10	20.19	19.81
进口	1.99	2.31	2.00	1.37	2.00	

资料来源：中国能源年评 1994

表 5 中国未来经济部门发展方案

	1990 年		2000 年			2010 年			2020 年		
	产值(亿元)	比例%	产值(亿元)	比例%	增长率%	产值(亿元)	比例%	增长率%	产值(亿元)	比例%	增长率%
全国	17676	100	41846	100	9	86246	100	7.5	154453	100	6
一产	5024	28.4	7700	18.4	4.36	10522	12.2	3.17	13437	8.70	2.48
二产	7829	44.3	18878	45.16	9.2	37394	43.36	7.07	63324	41.0	5.41
三产	4818	27.3	15170	36.3	12.15	38385	44.44	9.73	77711	50.3	7.31
农业	5024	28.4	7700	18.4	4.6	10522	12.20	3.17	13437	8.70	2.48
工业	6981	39.5	16679	39.90	9.10	32859	38.10	7.0	55140	35.70	5.3
建筑	848	4.80	2199	5.26	10.00	4534	5.26	7.5	8124	5.26	6.0
交通	956	5.41	2480	5.93	10.00	5114	5.93	7.5	9174	5.94	6.0
商业	944	5.34	2958	7.07	12.10	7596	8.81	10	15560	10.10	7.4
非物质	2918	16.5	9732	23.30	12.80	25678	29.80	10	52977	34.30	7.5

表 6 中国未来人口增长方案

	1990 年		2000 年			2010 年			2020 年		
	人口数(亿)	比例%	人口数(亿)	比例%	增长率‰	人口数(亿)	比例%	增长率‰	人口数(亿)	比例%	增长率‰
全国	11.43	100.0	12.94	100.0	12.5	13.90	100.0	7.2	14.5	100.0	4.2
城镇	3.02	26.4	4.06	31.4		5.20	37.4		6.5	44.8	
乡镇	8.41	73.6	8.88	68.6		8.70	62.6		8.0	55.2	
人／户	4.20		3.86			3.61			3.37		

表 7 终端能源需求量及构成预测结果

		1990		2000		2010		2020	
能源品种	单位	需求量	构成 (%)	需求量	构成 (%)	需求量	构成 (%)	需求量	构成 (%)
煤炭	Mt	530.98	33.04	632.76	27.85	771.59	24.00	715.71	19.97
原油	Mt	3.87	0.48	2.32	0.20	2.81	0.19	3.09	0.17
天然气	亿 m^3	147.89	1.71	268.20	2.20	537.74	3.38	995.19	5.17
电力	亿 kWh	5182.40	17.70	11232.50	24.92	19413.94	30.26	28246.88	35.30
石油制品	Mt	88.11	11.29	157.16	14.25	229.67	15.95	299.84	17.23
生物质能	Mtce	264.97	23.08	264.40	16.29	254.32	12.01	220.76	8.62
其它	Mtce	145.74	12.70	231.64	14.28	300.72	14.20	346.51	13.53
总量	Mtce	1147.98	100.00	1622.63	100.00	2117.46	100.00	2560.36	100.00

表 8 终端能源需求的年增长率 %

	1990 — 2000	2000 — 2010	2010 — 2020
煤炭	1.77	1.18	0.06
原油	– 4.97	1.93	0.95
天然气	6.13	7.20	6.35
电力	7.13	4.71	3.50
石油制品	5.96	3.87	2.70
生物质能	– 0.02	– 0.38	–1.40
其它	4.74	2.64	1.43
总量	3.52	2.70	1.92

表 9　1990 年中国各部门终端能源需求分析表

部门		民用		农业		工业		交通		建筑		服务业		总计	
需求量及比例		Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%
能源品种	煤炭	93.13	24.56	14.93	3.94	237.35	62.58	10.01	2.64	3.40	0.90	20.45	5.39	379.27	100
	原油	0	0	0	0	4.75	86.00	0	0	0.77	14.00	0	0	5.53	100
	天然气	2.47	12.58	0	0	15.63	79.45	0	0	1.41	7.16	0.16	0.81	19.67	100
	电力	18.87	9.29	16.68	8.21	152.33	74.98	2.09	1.03	2.26	1.11	10.92	5.38	203.15	100
	石油制品	4.26	3.28	11.83	9.12	59.78	46.11	49.36	38.07	1.96	1.51	2.47	1.91	129.65	100
	生物质能	264.97	100	0	0	0	0	0	0	0	0	0	0	264.97	100
	其它	32.51	22.31	0	0	111.69	76.64	0	0	0	0	1.54	1.06	145.74	100
总计		416.21	36.26	43.44	3.78	581.53	50.66	61.46	5.35	9.80	0.85	35.54	3.10	1147.98	100

表 10　2000 年中国各部门终端能源需求分析表

部门		民用		农业		工业		交通		建筑		服务业		总计	
需求量及比例		Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%
能源品种	煤炭	89.28	19.75	16.29	3.61	308.29	68.21	7.28	1.61	3.54	0.78	27.29	6.04	451.97	100
	原油	0	0	0	0	3.32	100	0	0	0	0	0	0	3.32	100
	天然气	9.45	26.49	0	0	24.0	67.27	0	0	1.64	4.59	0.59	1.65	35.67	100
	电力	50.45	12.48	20.68	5.11	288.62	71.38	5.71	1.41	5.07	1.25	33.83	8.37	404.37	100
	石油制品	9.40	4.07	14.42	6.24	98.53	42.61	99.69	43.11	3.04	1.30	6.18	2.67	231.64	100
	生物质能	264.40	100	0	0	0	0	0	0	0	0	0	0	264.40	100
	其它	64.89	28.01	0	0	162.50	70.15	0	0	0	0	4.25	1.83	231.64	100
总计		487.88	30.07	51.39	3.17	885.26	54.56	112.68	6.94	13.29	0.82	72.13	4.45	1622.63	100

表 11　2010 年中国各部门终端能源需求分析表

部门		民用		农业		工业		交通		建筑		服务业		总计	
需求量及比例		Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%
能源品种	煤炭	93.27	18.35	17.27	3.40	351.85	69.22	4.15	0.82	4.03	0.79	37.72	7.42	508.28	100
	原油	0	0	0	0	4.02	100	0	0	0	0	0	0	4.02	100
	天然气	32.15	44.96	0	0	35.11	49.09	0	0	2.58	3.60	1.68	2.35	71.52	100
	电力	90.55	14.13	25.41	3.97	421.36	65.77	11.69	1.82	8.84	1.38	82.81	12.93	640.44	100
	石油制品	13.91	4.12	19.80	5.86	117.78	34.85	172.87	51.15	3.75	1.11	9.83	2.91	237.94	100
	生物质能	254.32	100	0	0	0	0	0	0	0	0	0	0	254.32	100
	其它	87.09	28.96	0	0	203.99	67.84	0	0	0	0	9.63	3.20	300.72	100
总计		571.30	26.98	62.49	2.95	1134.11	53.56	188.71	8.91	19.19	0.91	141.67	6.69	2117.46	100

表 12　2020 年中国各部门终端能源需求分析表

部门		民用		农业		工业		交通		建筑		服务业		总计	
需求量及比例		Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%
能源品种	煤炭	99.82	19.53	18.07	3.53	336.91	65.90	0	0	4.13	0.81	52.31	10.23	511.22	100
	原油	0	0	0	0	4.42	100	0	0	0	0	0	0	4.42	100
	天然气	84.38	63.75	0	0	40.48	30.58	0	0	3.85	2.91	3.66	2.76	132.36	100
	电力	128.74	14.24	31.61	3.50	543.35	60.11	21.83	2.42	13.73	1.52	164.64	18.21	903.90	100
	石油制品	18.72	4.24	24.54	5.56	123.91	28.09	255.21	57.85	3.84	0.87	14.95	3.39	441.18	100
	生物质能	220.76	100	0	0	0	0	0	0	0	0	0	0	220.76	100
	其它	108.79	31.40	0	0	222.65	64.25	0	0	0	0	15.07	4.35	346.51	100
总计		661.21	25.83	74.22	2.90	1271.72	49.67	277.05	10.82	25.54	1.00	250.62	9.79	2560.36	100

表 13 中国电力工业发电装机容量的发展趋势

发电方式	1990		2000		2010		2020	
	MW	%	MW	%	MW	%	MW	%
火力发电	101820	73.86	220200	75.79	374650	76.39	514850	73.55
水力发电	36040	26.14	66500	22.89	100000	20.39	138000	19.71
核电	0	–	2700	0.93	10700	2.18	32000	4.57
风力发电	10	–	1000	0.34	4000	0.82	10000	1.43
地热发电	21	–	60	0.02	100	0.02	150	0.02
太阳能发电	0.26	–	80	0.03	1000	0.20	5000	0.71
合计	137891	100.00	290540	100.00	490450	100.00	700000	100.00

表 14 中国电力工业发电量预测

发电方式	1990		2000		2010		2020	
	TWh	%	TWh	%	TWh	%	TWh	%
火力发电	495.05	79.64	1044.53	78.48	1788.72	78.81	2447.56	75.51
水力发电	126.47	20.34	266.36	20.01	400.54	17.65	552.75	17.05
核电	–	–	17.56	1.32	69.59	3.07	208.11	6.42
风力发电	–	–	2.00	0.15	7.99	0.35	19.98	0.62
地热发电	0.1	0.02	0.23	0.02	0.38	0.02	0.56	0.02
太阳能发电	–	–	0.20	0.02	2.50	0.10	12.49	0.38
合计	621.62	100.00	1330.88	100.00	2269.72	100.00	3241.45	100.00

表 15 一次能源供应 (1990 － 2020 年)

		单位	1990 量	1990 比例 %	2000 量	2000 比例 %	2010 量	2010 比例 %	2020 量	2020 比例 %
商品能源		Mtce	1041.92	79.54	1505.45	84.79	2045.58	88.62	2544.86	91.61
煤炭		亿吨	10.82		15.00		19.63		22.77	
		Mtce	773.58	74.25	1072.45	71.23	1401.84	68.53	1626.32	63.91
石油	生产量	亿吨	1.38		1.65		2.00		2.21	
		Mtce	197.69		235.79		285.80		314.38	
	进口量	亿吨	0		0.38		0.84		1.34	
		Mtce	0		54.14		119.47		191.59	
	供应量	亿吨	1.38		2.03		2.84		3.55	
		Mtce	197.69	18.97	289.93	19.26	405.27	19.81	505.97	19.88
天然气	生产量	亿 m^3	157.74		300.15		499.25		798.80	
		Mtce	20.98		39.92		66.40		106.24	
	进口量	亿 m^3	0		0		99.55		393.76	
		Mtce	0		0		13.24		52.37	
	供应量	亿 m^3	157.74		300.15		598.80		1192.56	
		Mtce	20.98	2.01	39.92	2.65	79.64	3.89	158.61	6.23
水电		亿 kWh	1266.00		2665.28		4007.88		5525.63	
		Mtce	49.63	4.76	95.95	6.37	132.26	6.47	176.82	6.95
核电		亿 kWh	0		175.83		696.36		2080.31	
		Mtce	0		6.33	0.42	22.98	1.12	66.57	2.61
风能 地热能 太阳能		亿 kWh	1.02		24.17		108.79		330.31	
		Mtce	0.04		0.87	0.06	3.59	0.18	10.57	0.42
小计		Mtce	1041.92	100.00	1505.45	100.00	2045.58	100.00	2544.86	100.00
非商品能源 (生物质能)		Mtce	268.07	20.46	270.09	15.21	262.57	11.38	233.01	8.39
总计		Mtce	1309.99	100.00	1775.54	100.00	2308.15	100.00	2777.87	100.00

2. 中国的煤炭及煤炭洁净利用技术

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摘 要

中国煤的储量、产量在一次能源中都占主导地位。分布集中在北部和西北部，中国的煤品种多，高硫难洗煤多，应用面广，涉及国民经济各个领域。列举了中国洁净煤利用技术各领域的情况与现状，指出目前与先进国家之间的主要差距是在规模与成熟程度上。建议从实际出发“因煤制宜”“因用户制宜”发展中国的洁净煤技术，在今后发展中应注意加强国际合作，重点在抓住主要用户、关键技术及成熟技术三方面。

中国的煤炭

中国煤的探明储量及分布情况

根据1992年能源统计表明，中国煤的保有储量为9863亿吨，（探明储量按国际能源委员会定义的是其30%）约占常规能源储量的90%[1]。中国煤的成煤年代与世界各地成煤年代大致相同，聚煤作用主要是在早寒武纪，早石炭纪，晚石炭纪一早二叠纪，晚二叠纪，晚三叠纪，早、中侏罗纪，早白垩纪，第三纪。即从古生代，中生代到早新生代。由于条件和气候的关系，中国南方主要是以古生代及部分新生代成煤，北方主要是以晚古生代及中生代为主，在东北及内蒙也有新生代成煤。从成煤情况看，我国主要是石炭二叠纪，早、中侏罗纪的煤，这就决定了中国的北部、西北部为主要储煤区，而相对来说南部，特别是东南部煤的储量较少。近年来我国开采的主要是石炭二叠纪煤，今后主要是早、中侏罗纪煤，煤炭生产将由北方向西北方向转移。根据最近出版的地质资料[2]对中国煤资源的远景预测成果，截止1990年底，

在 <2000m 以浅的煤炭资源为 5328.7Gt，而华北石炭一二叠纪和北方早、中侏罗纪分别占 28% 和 63.1% 。从这些数字可以清楚地看出，中国的煤资源是丰富的，分布也是广泛的。但是，在数量上看，中国煤的资源分布是很不均衡的，大部分集中在北方，尤其是西北部将来必然成为中国煤的主要产区。中国煤的具体分布见图 1 。

中国煤的煤种特点及其分布地域

煤的煤种特性是与成煤条件、年代有关的。成煤条件包括成煤物质、成煤环境（地点、空间、温度、压力等）。煤中灰分高低从成煤环境方面主要取决于成煤泥炭沼泽距陆源区及海岸线的远近。泥炭沼泽受海水影响程度是导致煤中全硫及各种硫变化的主要原因。

在构成不同变质程度煤（从褐煤→烟煤→无烟煤→天然石墨）的煤化过程中，热源又是主要因素。在中国大陆由北到南有三个巨型变质带，这些带中又可分为约 20 个变质区，每个变质区围绕其中心依次形成环带状的不同煤种。总体上看中国煤的变质程度从北向南变质程度加深。而在中国的大陆东部及东南部由于受火成岩活动的影响，一般都只有变质程度较深的无烟煤和新生代形成的褐煤。在中国从褐煤到无烟煤都有。按予测资源结果对煤类的数量统计：褐煤只占 2.7%, 低变质烟煤占 54.1%，烟煤占 26.8%，无烟煤占 9.3% 。从埋藏深度来说， < 600m 的只占 18.7%, 这就决定了中国的煤矿生产大部分要用深井采煤，只有少数可以露天开采。

根据成煤情况，中国煤的灰分一般都较高，原煤中灰分大部分在 25% 以上，且高硫难洗煤比重较大。中国煤的平均硫分在 1995 年为 0.77% 。中国高硫煤在西南部，但不少北方煤中硫含量随着开采往深部发展而在提高，这是由于成煤泥炭受海水影响的结果。表 1 列出晋城等煤矿上部煤层与下部煤层平均硫含量的数据，从数据看，这些煤矿的上部均为低硫煤，但到下部硫含量大部为 2 - 4% 的高硫煤，这说明今后煤利用中脱硫也将越来越重要。

表 1　一些煤矿中硫（St,d%）与深度的关系

煤矿	晋城	石圪节	安太堡	新汶 (协庄)	柴里	南屯	钱家营 (开滦)
上部	0.34	0.26	0.51	0.55	0.81	0.66	0.57
下部	3.09	3.28	2.57	4.1	2.79	3.17	1.67

中国煤在能源中的地位

中国煤的贮量占能源的 90%，石油、天然气相对较少。为了满足国民经济高速发展的要求，能源中煤的比重在将来的 30 - 50 年内不会有大的变化。煤在一次能源生产中的比重会长期保持在约 70% 的水平上。表 2 列出我国能源生产总量及原煤占能源生产总量的比例。从表 2 可见中国煤炭在能源中的主导作用。煤炭的主导作用还表现在它应用于各个领域。在电力工业中，火电发电量占总发电量的 80%，其中燃煤的电站占总发电量的 76%，所耗煤占煤炭生产量的 30%。在其他工业的燃料与动力所用的能源中，有 75% 是从煤炭获得，其消费量占煤产量的 33%。其中化肥工业 60% 的原料来自煤。民用燃料中 80% 是煤，占煤炭生产量的 20%。冶金工业占用煤炭生产量的 8%，主要用于焦炭生产和动力供应。

表 2　1949–1994 年一次能源产量及原煤占能源生产总量的百分数

年份	(Mtce)	(%)	年份	(Mtce)	(%)
1949	23.74	96.3	1950	31.74	96.7
1955	72.95	95.9	1960	296.37	95.6
1965	188.24	88.0	1970	309.90	81.6
1975	487.54	70.6	1980	637.35	69.4
1985	855.46	72.8	1990	1039.22	74.2
1991	1048.44	74.2	1992	1072.56	74.3
1993	1112.63	73.8	1994	1120.20	77.3

由于中国煤的储量大，产量高，以煤为原料、燃料的事业可靠性、稳定性好。以化肥工业为例，前些年，中国从国外引进大量以油、气为原料的大合成氨厂，建厂不久就碰到原料不足的困扰，以后随着原料油、气价格的调整又面临经济上的亏损，有的要进行改用煤的改造工作。而用煤为原料的化肥则在不断发展。

中国煤的生产和利用中存在的问题

煤炭毕竟是固体的化石能源，中国的煤中灰分又较高，硫含量也有逐步增多的趋势。在生产和利用中，由于量大，已经给中国的环境造成较大的影响。

在煤炭生产中造成大面积地表塌陷，固体、水、气等废弃物的排放对环境造成不良影响。中国煤炭埋藏深，这就使中国采煤 96% 采用井工开采。据不完全统计，平均每采百万吨原煤就沉陷破环 0.2ha 土地。至 1990 年底，全国因土地下沉破坏的面积已达 30 万 ha，相当于 375 万人的耕地(中国人均耕地为 0.08ha，即 1.2 市亩)。予计到 2000 年沉陷破环土地将达 50 万 ha。中国煤矸石的积存量已达 3.04Gt，占地 1.2 万 ha 每年仍以 130Mt 量外排。煤矸石的自燃也带来空气的污染。每年矿井水外排 1.75Gt，煤层气 $6.0Gm^3$ 这不仅浪费了宝贵的水资源和燃气资源，而且对环境造成危害。

在煤的加工利用中产生的问题如下：

a. 目前，原煤入洗率只 22%，尤其是动力煤的入洗率只占火电用煤量的 11.28%。而中国的煤大部分在北部、西部、“北煤南运”，“西煤东运”是必然的，不洗选的煤中的矸石占去大量的运力，而且在用户的地区又造成矸石等废物的处理问题。灰分的增加也会造成效率的下降。

b. 中国型煤和煤层气利用在近年开始逐步发展，但型煤工业还只是起步阶段，煤层气目前大都还没有利用，规模也很小，不少技术也尚不成熟。

c. 中国煤的利用效率与发达国家相比还低。工业窑炉效率平均低 10% 以上，工业锅炉热效率低 15 - 20%，火电厂效率全国平均只 30% 比发达国家耗

煤高 30% 。

d. 燃煤环保治理刚开始重视，燃煤电站对烟尘治理较好， 1990 年除尘效率就达 93.9%, 全行业 TSP 合格率在 90%，但对烟气中硫化物基本上没有处理，目前全国燃煤排放的 SO_2 占 90%，烟尘占 70%， 1992 年分别为 14.72Mt/a 和 9.9Mt/a 。在联合国几年前的一项报告中列举空气中含 SO_2 最高的 10 大城市中中国占有其三，沈阳、西安、北京分别为第二、第七、第八位。

综上所述，中国的煤是主要的一次能源，其主导地位在今后一段时间不会改变。燃煤和煤的生产本身给环境产生较大的危害，为了今后中国的发展，必须把大力发展洁净煤利用技术作为一项重大的国策，以保证中国的能源与环境协调发展。

中国的洁净煤利用技术

洁净煤利用技术涉及面很广泛，贯穿煤炭生产、运输、加工、利用的全过程，在煤生产中的环境污染控制技术有矸石、废水、煤层气的处理和利用，有塌陷控制，塌陷区的综合治理等；在加工过程中有选煤工艺开发，选煤产品如中煤、尾煤、煤泥的处理及利用，煤的干燥、粉煤成型或磨粉，水煤浆的制备及利用技术；在利用方面有各类燃烧技术，烟气净化技术，煤的转化技术如气化、热解、液化及其他非燃料的特殊加工利用技术等。中国是世界上除南非和印度以外少数的一直以煤为主要能源的国家，一贯关注着煤的洁净利用技术。政府各有关部门和地方机构都大力支持洁净煤技术的发展。在国内有一批具有实力的研究院所、大专院校，有一大批相关的专家技术力量，并建起一批洁净煤示范项目，有些成果已在工业上应用。

中国洁净煤利用技术的发展及现状

煤的洗选加工

中国具备各种洗煤工艺技术，包括干洗，湿洗，磁选等，有的技术有相当规模的成套设备， 1994 年所建的两座重介质洗煤厂的生产能力分别为 8Mt/a

和 15Mt/a 。中国煤中约 80% 属于难选煤，选煤厂技术也逐步由过去的一般跳汰法转为新的浮选、重介质技术工艺。情况如表 3 所列[3] 。

表 3　选煤方法比较

年份	跳汰法	浮选法	重介质法	其他
1978	～ 70%	14%	～ 14%	2%
1985	～ 59%	16%	23%	
1994	～ 58%	17%	24%	

型煤比烧散煤可减少 60 – 90% 的烟尘，节约用煤约 20%，中国有长期研究开发的技术，各类有机、无机及复合粘结剂的型煤在中国的工业、民用上大量使用，联合国东北亚项目将中国的型煤技术介绍到亚洲其他国家。鉴于机械化采煤的发展，粉煤产率均在 70%，而中国中、小型的锅炉大都为层燃式，气化炉亦大都为移动床，这就促使中国在型煤的制造和使用都积累有丰富的经验。

在水煤浆的制备及应用中，近年来中国也进行了大量的工作，目前已建成 6 个制浆厂， 2 个添加剂厂及一批示范项目。水煤浆气化的 Texaco 气化工艺已在山东鲁南等化肥厂投产，并将有一批化肥厂将应用同样的工艺。

煤的燃烧

中国煤的 80% 用于直接燃烧，一般大电厂都采用高效的烧粉煤的锅炉，中小型锅炉一般都用层燃锅炉，热效率可达 60 – 70% 。以燃用低热值煤及矸石为其特点的沸腾锅炉在中国早在文革前就已开发应用，鼓泡式流化床锅炉（ BFBB ）如今已成系列，近年开始兴起的循环流化床锅炉（ CFBB ）以其较高的效率和脱硫率而发展很快，已发展到 20 多家制造厂，生产 < 130t/h 的 CFBB，已有 300 多台投运。加压流化床燃烧（ PFBC ）在多年研究的基础上，东南大学等单位在贾汪（江苏）建了一个中试电站（ 15MW ）。

煤的转化技术

煤炭气化：煤气化往往是洁净煤利用技术的第一步，氨、甲醇合成气生产用它，间接液化技术中合成原料气用它，煤气化联合循环发电、燃料电池，甚至第二代的加压流化床燃烧联合循环发电技术也先用干馏器产一部分燃气。虽然中国的绝大多数工业气化炉还是常压移动床气化炉为主，但从 60 年代初开始，加压、流化床、气流床和熔渣池等新的气化工艺都在不少试验装置上运行过。较成功的有水煤浆下喷式气化炉，灰熔聚气化炉和加压气化炉。

煤的地下气化近年来在长通道、大断面、二阶段气化上有较大的进展，为废旧矿井残留煤的利用开创了新的途径。近年来采用反燃式的气化炉将煤气中的高烃化合物都裂解掉，从而使煤气化本身更洁净的技术，正在中国广泛推广应用。

煤的液化：煤的直接液化目前有两段加氢和煤油共炼等工艺的效果较好，一般可以从 4 吨原煤生产 1 吨液化油，其转化效率接近 50% ，正在准备建较大规模的示范工程，该工艺对年轻的烟煤褐煤较合适，如果煤中灰低些效果会更好。煤的间接液化主要在合成上，目前中国发展的新催化剂可使单位原料气的液化油收率增加较大。在原 100t/a 中试的基础上，建设的 2000t/a 的工业试验厂正在运转试验，该厂结合副产城市煤气。

煤的干馏：在中国常规炼焦厂担负着城市煤气的生产任务，近年来在焦化产品开发方面有较大的进展。在煤的低温干馏（即所谓的温和气化技术）方面中国有固体热载体直接加热法和多段回转窑式（Multi － stage Rotary Furnaces, 产品 MRF）两种工艺都已建了工业示范厂。该项技术不论在第二代加压流化床燃烧联合循环发电 PFBC － CC 或循环流化床固体热载体气化三联产（热、电、煤气）项目中都有用。其主要核心问题是经济问题，而关键在于主产品半焦的合理利用及市场。

煤气、烟气的净化：低温的除尘和脱硫在中国的化工等工厂中是成熟的技术，高温下的气体净化现正在开发。在国家科委和 UNDP 等的支持下，近年来配合 IGCC 技术和 PFBC － CC 技术的发展，热煤气（或烟气）的净化（

Hot − Gas Clean Up, HGCU）研究开发工作进展顺利。这项工作对 PFBC − CC 及湿法加料煤气化（如 Texaco 及 Destec 等）IGCC 的效率提高是至关重要的。

其他：针对其他中国煤生产和利用中存在的问题如地表塌陷，煤矸石、煤矿井下水处理，煤层气抽放利用等也有许多技术的开发工作，有些已成功地应用于实际。

中国洁净煤利用技术与先进国家的主要差距

中国煤炭产量和消费量均居世界第一位。国家的领导人和部门负责都对洁净煤利用技术十分重视。近年还特别重视从环保立法着手，广泛开展与国际合作来发展中国的洁净煤技术。由于中国是发展中国家，在经济实力上比发达国家尚有差距。洁净煤技术的发展上主要差距是在某些领域尚处于起步阶段如 PFBC − CC， IGCC， CFBC 等，都还只在小规模，试验规模，而其他发达国家已发展到示范甚至大工业应用阶段。如循环流化床锅炉（CFBB）中国一般最大的也就是 220t/h，而国外已达 700t/h。加压流化床联合循环发电技术中国还在 15MW 试验而瑞典 ABB 已完成 P200 项目（~75MW）长期运转转入 350MW 示范。IGCC 方面 250MW 的示范装置在荷兰、美国均已投入运行，而中国还在示范厂技术预可行性研究的论证阶段。在煤气化技术上国外如荷兰 Shell 已成功运行 2000 - 3000t/d 的气化炉，中国目前最大引进 Texaco 的气化炉生产能力也只 500t/d，从气化效率比较，鲁南化肥厂 Texaco 只 69% 而荷兰 Shell 炉的气化效率可达 83% 以上。煤的间接液化在南非已一直运行了数十年，而中国还是在 2000t/a 的试验水平。总之差距是客观存在的，主要是在规模及技术的成熟程度上。造成这些差距的原因是中国的环保立法建立较晚，在技术开发的投入上资金尚少。

关于中国洁净煤利用技术的发展方面几点看法与建议

中国是一个煤储量较多而石油天然气相对较少的经济正高速发展的国家。客观的现实决定了中国未来几十年能源还必须以煤为主。社会主义体制和作为地球重要成员的中国在快速发展的同时必须万分关心自己生存的环境。因此发展洁净煤利用技术是中国今后一段时期内的一项重大国策，在洁净煤

技术上中国应重点把握的主要方面是：加强洗选，发展型煤，开发高效率、低污染、成本少的煤转化技术即高效、经济、实用的中国特色洁净煤利用技术。

中国煤品种多，质量也不一致，而某项洁净煤的技术都有其一定的局限性，在选择开发洁净煤技术时，应从实际分析出发，要“因煤制宜”“因使用对象制宜”的选择合适的技术。例如对灰份高的劣质煤就应选流化床的气化、燃烧工艺，用发电宜采用 PFBC－CC 工艺，对灰较低而硫含量较高的煤则采用 IGCC 较好；对合成氨用原料煤气生产用高温熔渣气化炉。如在煤炭液化方面如果原料煤是无烟煤，就只好走间接液化，而如果是低灰的年轻烟煤则直接液化较有利。

洁净煤利用技术的应用范围广泛，开发工作既要分工协作，也要重点突出。重点应在煤的重要用户，抓住关键技术，大力推广成熟技术。对长远有战略意义的技术亦应跟踪研究，如煤的液化，煤的燃料电池发电等。

几点看法与建议

1. 鉴于中国煤的储量、产量在能源中处主要地位且近期内不会变化的现实，从中国煤的灰份含量较高，硫分也在逐步提高的现实情况出发，洁净煤利用技术的发展在中国有特殊重要性。

2. 中国在几十年的发展中， 煤的洁净利用技术在各方面均有良好的开端。 目前与发达国家间的差距主要在技术的可用规模及技术的成熟程度方面。

3. 中国煤数量及品种上分布不均匀，工业基础差的西部、气候干旱的北方和西北地区煤的储量多、产量大，南部、东南部发达地区是煤的主要消费区，西煤东运、北煤南运是一种必然结果。要缓和这种情况应加强选煤，减少运输，就地加工利用，变原煤运输为煤产品（如：焦、电等）输出。加工技术应注重节水的工艺。

4. 针对中国煤的品种多，质量差别大及应用于各类工业用户的特点，在

发展洁净技术上应从具体实际出发，“因煤制宜”，“因用途制宜”采用适宜的洁净煤技术。

5. 建议在今后应加强国际合作以加速中国洁净煤技术的发展，在某些国外较先进的领域，可择优引进成熟技术。在发展洁净煤技术中应分工协作，重点放在用煤大户、关键技术和成熟技术三方面。

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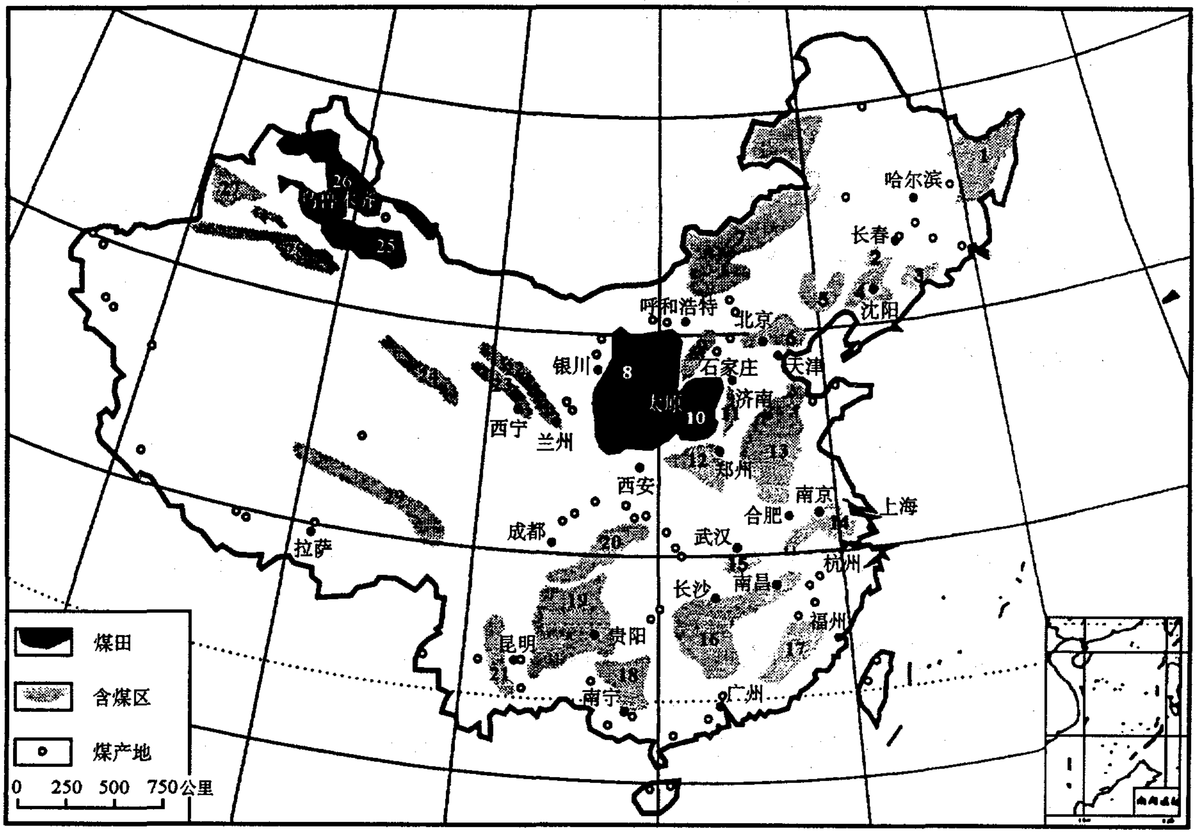

图 1　中国煤炭资源分布图

1— 三江穆棱区； 2— 辽北区； 3— 浑江区； 4— 辽河太子河区； 5— 辽西区； 6— 京唐区； 7— 内蒙东部区； 8— 鄂尔多斯煤田； 9— 大宁煤田； 10— 沁水煤田； 11— 太行山东麓区； 12— 豫西区； 13— 苏鲁豫皖区； 14— 浙苏皖 (南) 区； 15— 鄂东南区； 16— 湘赣粤区； 17— 闽粤区； 18— 桂中区； 19— 黔滇川区； 20— 华莹山区； 21— 滇中区； 22— 河西走廊区； 23— 大通河区； 24— 柴北区； 25— 吐鲁番哈密煤田； 26— 准噶尔煤田； 27— 伊犁区； 28— 塔里木北缘区； 29— 藏北区。

3．中国电力工业简况及对IGCC发电技术的展望

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摘　要

整体煤气化联合循环(Integrated Coal Gasification Combined Cycle，简称IGCC)发电技术是目前清洁煤技术中最清洁、效率最高、技术最成熟的发电技术，也是中国用得起的技术。工业发达国家以强化能源供应的安全性和多样化为战略目标，继续投入充足的人力和物力发展、改进和完善IGCC。为实现可持续发展的战略目标，根据我国的资源储备和油（气）与煤的比价高于国外的国情，我国目前确已达到必须加速试点发展IGCC技术的时候了。IGCC很可能是必须首先在中国大量发展使用，随后由我国自己在大量使用的过程中发扬光大的清洁煤高新技术。

全国发电设备总容量及发电量概况

改革开放以来，我国电力工业取得了极为可喜的成绩。1980年全国发电装机总容量仅为6587万kW，年发电量为3006亿kWh。到1995年底，装机总容量已达到21000万kW，年发电量达到9000亿kWh。从1996年到2000年的“九五”计划期间，预计每年新增发电设备容量，约为1600万kW；到2000年底，总容量可达到29000万kW，为1980年总装机容量的4.4倍；年发电量达到14000亿kWh，为1980年发电量的4.6倍。因此，2000年的发电装机总容

量和发电量两项指标均将比1980年翻两番以上。

在我国已探明的一次能源储量中，以煤炭储量最为丰富。我国发电能源，一向也是以煤炭为主要燃料，燃煤火力发电机组容量所占比例最大。其次为水力发电机组，也占相当大的比例。表1为1980－1992年期间我国历年发电设备总容量、总发电量以及水火电比例情况[1]。从表1可以看出，从1990年开始，在每年的发电设备总容量中，火电机组大致要占75%左右，水电占25%左右；在每年的发电量中，火电大致占80%左右，水电占20%左右。据专家预测，在今后较长时期的发展过程中，无论是装机容量或年发电量，火电比例还会升高一些，水电比例会降低一些。预计到2000年底，火电机组总容量将约为22000万kW，水电机组容量约为7000万kW，合计为29000万kW；2000年火力发电机组年发电量将约为11200亿kWh，水力发电机组年发电量约为2800亿kWh，合计为14000亿kWh。

表1　1980－1992年发电设备容量与发电量

年份	发电设备			发电量		
	总计 MW	水力 %	火力 %	总计 TWh	水力 %	火力 %
1980	65869.1	30.8	69.2	300.6	19.4	80.6
1981	69132.6	31.7	68.3	309.3	21.2	78.8
1982	72359.6	31.7	68.3	327.7	22.7	77.3
1983	76444.9	31.6	68.4	351.4	24.6	75.4
1984	80116.9	31.9	68.1	377.0	23.0	77.0
1985	87053.2	30.3	69.7	410.7	22.5	77.5
1986	93818.5	29.4	70.6	449.6	21.0	79.0
1987	102897.0	29.3	70.7	497.3	20.2	79.8
1988	115497.1	28.3	71.7	545.1	20.0	80.0
1989	126638.6	27.0	73.0	584.7	20.2	79.8
1990	137890.0	26.1	73.9	621.3	20.2	79.8
1991	151473.1	25.0	75.0	677.5	18.4	81.6
1992	166532.4	24.4	75.6	754.2	17.4	82.6

目前火力发电机组中，常规燃油火电机组所占比例不大，燃用石油或天然气的联合循环发电机组约 150 万 kW，所占比例也小；此外核电以及其他新能源发电机组在总装机容量中约占 1%，因此上述的“火力发电机”均系以煤炭为燃料的火力发电机组。

据专家对中国 2000 － 2050 年能源战略的研究表明，2010 、2020 和 2050 年煤电装机容量将分别达到 369GW 、500GW 和 820GW 。基于调峰和环境考虑，燃油、气的机组将占一定比例，2010 、2020 和 2050 年的装机容量将可能分别达到 45GW 、75GW 和 150GW 。

煤电机组耗煤量与 SO_2 排放

我国燃煤火力发电机组，平均净热效率较低，目前仅为 30% (LHV) 左右，折合供电煤耗率，约为 410 克 (标煤) /kWh 。在“九五”计划期间新投产的燃煤火力发电机组，一般将采用高参数、高效率、高容量（300MW 以上）的机组，到 2000 年，平均净热效率，可望提高到 32%(LHV) 左右，折合供电煤耗率为 380 克 (标煤) /kWh 。因此，到 2000 年全国燃煤机组年消耗标准煤量将约为 4.3 亿吨，届时，如果不采用专门脱硫措施，燃煤火电机组全年排放的 SO_2 量可采用以下公式做一简单估算：

$$M_{SO_2} = 2B_g(1-\eta_{SO_2})(1-q_4)S^y k = 0.0625\text{亿吨} / \text{年} = 625\text{万吨} / \text{年}$$

式中，

M_{SO_2} = SO_2 排放量，吨 / 年；
B_g = 燃煤量， 4.3 亿吨 / 年；
η_{SO_2} = 除尘器脱硫效率， 15% ；
q_4 = 未完全燃烧损失， 5% ；
S^y = 燃煤的应用基硫份， 1% ；
k = 燃烧后氧化成 SO_2 的份额， 0.9 。

清洁、高效的火力发电

为了迅速减少燃煤火力发电机组排向大气的 SO_2 数量，我国正在加紧研究并准备采用诸多有效的脱硫措施，有的已经采用。例如，在常规烟气脱硫技术方面：

- 重庆珞璜电厂，已采用烟气湿法脱硫措施。

- 山东黄岛和山西太原电厂，正准备采用简易烟气脱硫措施。

- 南京下关电厂，准备采用芬兰 Lifac 脱硫措施。

此外还有若干电厂正在积极研究选用合适的脱硫技术，如磷铵肥脱硫技术、石灰洗涤法、旋转喷雾吸收干燥法和炉内喷钙脱硫措施等，准备在工程中正式采用。

清洁煤是我国能源的未来。根据我国的能源资源条件、技术和经济发展水平，以及世界能源形势，到 21 世纪中期，以煤为主的能源结构不会改变，更不可能减少煤炭消耗。大量煤炭的低效使用严重损害了可持续发展的资源和环境基础，唯一可行的选择是发展清洁煤技术，减少污染物排放，提高利用效率和经济效益。我国正在积极发展清洁煤燃烧技术：

- 我国已建成一座 100MW 循环流化床（AFBC）锅炉，目前正在引进技术基础上加紧开发 200MW 以及 300MW AFBC 锅炉。

- 我国第一台 15MW 增压流化床（PFBC）锅炉试验电站，已于 194 年三季度在徐州贾旺电厂动工修建。

- 我国正在大力准备，争取在 2000 年前后，在国内建成一座 200 － 400MW 整体煤气化联合循环示范电站（IGCC 示范电站），为下一世纪初推广使用，做好充分准备。

从当前国际上各种高效清洁煤发电技术的研制、开发、示范、使用等情况来看， IGCC 具有以下特点：

- IGCC 技术成熟性最好。已建成 2 座 250MW 级商业性示范电站，另外两座 250 － 300MW 商业性示范电站正在建造，计划将于本年度建成，投入示范运行。 IGCC 是目前上述三种清洁煤燃烧技术中容量最大，成熟性最好的机组。

- IGCC 技术效率最高。已建成的荷兰 250MW IGCC 机组，净效率能达到 43%（LHV）。正在建设的西班牙 300MW 机组，净效率将能达到 45%（LHV），是当前燃煤机组中效率最高的机型。

- IGCC 造价并不太高。美国能源部直属的能源技术中心（METC）的预测如表 2 所示[2]， 1995 － 2000 年期间建造的 IGCC 电站，不仅热效率可达到 45%（LHV），造价也可以比常规燃煤带烟气脱硫机组低 20%，达到 $1200/kW 。

- IGCC 技术最清洁。 IGCC 机组是目前公认的最清洁的燃煤发电机组，环保性能极好。除硫可达 99%，除氮可达 90%， CO_2 排放量可减少 30%，因此使用 IGCC 技术，对当代人以及子孙后代的生存及身体健康都是十分有益的。

表 2　METC 对 IGCC 技术的估计

IGCC 技术	年　限	效　率 (%)	造　价 ($/kW)	与 PC 造价相比 (%)
第一代	1985 － 1994	32 － 42	3000 － 1500	高 15
第二代	1995 － 2000	45	1200	低 20
第三代	2000 － 2010	52	1050	低 25

本文将在下面进一步讨论 IGCC 的上述特点。

IGCC 发展中有关技术、经济问题的初步评估

能源效率和节能是实现可持续发展战略的最有效和最经济的途径，为形成可持续的发电系统，我国寄厚望于对 IGCC 发电技术。为了使 IGCC 电站能早日在国内建成示范，确实还存在一些急待进一步澄清的问题，热诚盼望关心 IGCC 技术发展的有关领导和专家，多提宝贵批评和促进意见。

IGCC 技术成熟度的评估

能不能仅靠几座已经建成和正在建造的 300MW 级 IGCC 示范电站，就认为 IGCC 技术已是国际上较成熟的技术？例如，人们经常提到的高温除尘和高温脱硫技术，都还是未成熟技术。除尘脱硫技术尚不成熟，能否说 IGCC 已是成熟技术？

这一问题，准确地说出了当前高温除尘、高温脱硫技术的真实情况，但这两项技术不成熟，绝不等于 IGCC 技术就是不成熟技术。上面提到的 IGCC 机组的高技术性能，均是指未使用高温除尘、高温脱硫技术时即已可能获得的性能。不使用高温净化技术，IGCC 电站净效率已经可以达到 43-45%（LHV），已是当今燃煤火电机组中，没有其它任何一种机型能够达到的效率水平。将来使用高温净化技术后，当然还可以达到比 43-45%（LHV）更高的效率。对 IGCC 而言，高温净化是“锦上添花”的技术改进，而不是“雪中送碳”的技术要求，这与增压流化床燃煤联合循环必须依赖高温净化技术的情形是完全不同的。

事实上，当前 IGCC 电站主要也只由两大部类技术集成。一类是以天然气或油做燃料的常规联合循环发电技术，目前世界上，包括我国在内，已有上千台这类机组在正常运行。另一类是煤炭气化与净化技术，目前世界上包括中国在内，总共也有上百台装置在正常运行。目前国际上用气流床气化炉组成的 IGCC 电站，除了新开发的一些必要的协调控制装置和少数配套设备外，主要就是集成了这两类技术，基本上没有太多的新开发技术项目。因此，如果我国选定开发基于气流床气化炉的这一类 IGCC 电站，技术上不存在太大风险，不但可以借鉴国外成熟的经验，而且也能借鉴和使用国内的成熟经验。后者包括国内发电行业常规联合循环电站的运行经验及国内化工行业气

流床气化炉、煤气生产和低温除尘低温脱硫的成熟经验。不妨认为，IGCC 技术可能是在我国发展清洁煤技术中潜在成熟性最高而风险性最小的技术，是我国最应该积极研究和开发的一项技术。

IGCC 造价的评估

根据 METC 的预测，在 1995-2000 年期间，国外新建 IGCC 电站造价仅为 $1200/kW，比国外常规带烟气脱硫脱硝装置火电站的造价还低 20%，真会有此可能？

从国外一些初步公布的数字来看，METC 预测的可信度是比较高的：

第一，METC 本世纪初对 1985-1994 年期间有关情况的预测，相当准确；因此，有理由相信其对 1995-2000 年期间的预测和实际值也不会相差太大。例如，1995 年建成的美国 Wabash River 262MW 老厂改造 IGCC 示范电站，公布的造价为 $1511/kW，净效率为 40% (LHV)；如果扣除留作三年示范使用的 5200 万美元费用，则仅含 $1366/kW[3]。即将于今年建成的美国 Tampa 260MW 新建 IGCC 示范电站，公布的造价为 $1460/kW，净效率为 42%（LHV），以上两工程的造价都比 METC 预测的同时期最低值 $1500/kW 还要稍低一些。

第二，欧洲一些专家也持有和 METC 相类似的观点。例如，1995 年 6 月在北京举办的中荷洁净技术研讨会上，荷方的一篇论文[4]就曾认为，IGCC 电站的造价当前与常规带烟气脱硫脱硝装置火电站的造价已非常接近，而且具有较大的降低潜力，将越来越具有更高的竞争能力。

第三，欧洲已建成和正在建造的 IGCC 电站，公布的造价为什么比美国高很多？例如，已于 1993 年建成的荷兰 Demkolec 250MW IGCC 电站，为 $1858/kW；计划即将于今年建成的西班牙 Elugas 300MW IGCC 电站，为 $2303/kW；难道能说这也和目前火电机组造价相接近？

以上两座电站造价高，很可能与所使用的气化炉，都是第一次在 IGCC 电站进行示范有关，再加上这两座电站都使用干粉进料工艺，比水煤浆进料

工艺的造价可能也要稍高一些，其它方面差距并不太大。例如，上述两电站用的都是德国 Siemens 公司的燃气轮机，售价并不比美国高；据 1993 − 1994 年《燃气轮机世界》报导， Siemens 94.3 型 220,000kW 机组售价为 \$178/kW ，而美国 GE PG9331FA 型 226,500 kW 机组，却为 \$192/kW ，前者比后者还低 \$14/kW 。另据其它资料 [5] 报导，美国 Tampa 电站所用的废热锅炉（ Syngas Cooler ）以及碎渣机等，还是分别向德国 MAN GHH 公司和荷兰 GEHO 公司购买的。美国用了欧洲的产品，在第二座 IGCC 电站中造价还能大幅度降低下来，可见欧洲用自己的产品在他们的第二座示范电站中，造价也有可能大幅度降低。

目前造价高，很可能主要是由于第一次示范。其实美国用水煤浆的第一座煤气化联合循环示范电站（ Cool Water ），造价更高，为 \$3000/kW ，比欧洲第一座 IGCC 示范电站造价还要高，但在仍使用水煤浆的第二座示范电站（ Tampa, 更好集成的 IGCC ），就已降到 \$1460/kW 。文献 [4] 所说的 IGCC 电站造价，应该是指第二座的电站造价，因此上述论文中说已达到和常规火电机组很接近的造价，是可信的。

值得注意的是，造价不是小问题，很可能是关系到 IGCC 技术何时才能在我国推广使用的大问题。IGCC 技术性能再好，如果造价太高，也用不起，至少要和国内常规火电机组造价相当，或高得不多，才有推广使用的基础，什么时候才能达到这一要求呢？国内没有 IGCC 机组制造和运行经验，不好直接比较，国外市场经济经验丰富，又有比较长时期的制造使用经验，比较结果，可信度高。因此，认真关心了解国外发展动态，非常重要。如果国外已发展到 IGCC 的造价和常规火电机组的相当或稍高一些，国内立即上马示范，就绝不会犯大错误。国内第一座示范电站，同国外一样，造价肯定也会略高一些，并且大型燃气轮机国产化难度也相对要大一些，但不会用太长时间，也能做到相当甚至略低于常规火电机组的水平。当然造价应在同一基础上作比较，要脱硫就都按脱硫要求比，要不脱硫就都按不脱硫比；示范的与示范的比，规模化商业生产的与规模商业生产的比。重要的是，如果国外很快就能达到比常规火电机组还低 20% 的造价水平，这样好的技术，我们不积极开发使用，也是潜在的浪费行为。

IGCC 干法与湿法进料对效率影响的评估

国内对采用干粉进料的 IGCC 电站的净效率，没有不同意见，认为当前达到 43-45%（LHV），没有问题。但是，对采用水煤浆进料的 IGCC 电站，净效率能否达到 42%（LHV），看法有较大的分歧，如有的认为“美国冷水电站净效率才 32%（LHV），经过完善之后，能到 36%（LHV）就不错了！”

由于效率问题是涉及到技术途径选择并影响决策的大问题，而多次辩论均无结果，未形成统一看法，因此深入研究是十分必要的。在 1994 年上半年，国内专家先在国内做了深入细致的分析研究，借助能量系统分析和综合的成果，对采用水煤浆的 IGCC 发电系统进行了“系统集成”，表明可以达到 42%（LHV）的净效率。接着又到国外进行调访，搜集了大量资料，终于查明，用水煤浆进料的 IGCC 电站，在用相类似的低温除尘、低温脱硫工艺和相同效率的燃气轮机的条件下，比用干粉进料工艺的电站，净效率大致只低 1 个百分点左右，而且将来高温净化技术成熟之后，两者的差距可能还要缩小，大致只差 0.5 个百分点左右。因此，现在基本上都已认为两者都可以达到很高的净效率。

如果以上分析和理解没有太大误差，就可以看出，我国如要发展 IGCC 技术，首先就应该发展使用国外已成熟的 IGCC 电站技术，先建成一座或几座 IGCC 电站，至于先上干粉进料工艺或先上水煤浆进料工艺，由于都已是成熟工艺，不是原则问题。水煤浆进料工艺，电站净效率稍低一些，但低得不多，同时造价可能也会略低一些，很适合在煤价低的地区使用。干粉进料工艺，电站净效率高，更适合在煤价较高的地区使用。可以预料，在今后相当长时期内，不管在中国还是在全世界，都不会形成一种工艺“独占天下”的局面；就气化炉技术而言，也决不会只使用气流床一种技术，随后流化床、移动床技术，也将会逐步得到使用。只要我国近期及不远的将来，还迫切需要大量建造净效率为 35 – 37%（LHV）（甚至为 42%（LHV））但环保条件还较差的常规燃煤火电机组，而用不同气化炉技术组成的 IGCC 电站，包括其它清洁煤技术电站，净效率能达到 45%（LHV）左右，造价也不高，环保性能又极好，就均有对电力工业发展作出大贡献的机会和条件。

IGCC 应用缓慢的原因评估

IGCC 电站技术性能好，造价又不高，为什么国际上发展使用不很快？美国 Cool Water 示范电站，在 1989 年就已试验完毕，示范取得很大成功。但从 1989 年到现在，时间又过了"七年"，国际上到今年年底之前能够建成的 300MW 级 IGCC 示范电站，总计也只有 4 座。因此，一个很自然的问题就是："IGCC 这一先进技术，在国际上都没有大量推广使用，在中国就能有大量发展使用的动力和条件吗？"这是一个国内专家很关心的问题，也是一个无法回避而必须做出明确回答的大问题。

过去国内有些专家倾向于认为，是由于八十年代美国 Cool Water 示范电站尽管是当时世界上最清洁的燃煤电站，但实际净效率太低，只有 32%(LHV)*，把 IGCC 技术的名声搞坏了，所以在国外长期得不到推广使用。不过，答案并非如此这么简单。荷兰 Demkolec 电站的净效率为 43%（LHV），不算低了，为什么至今，尚末见到第二座 IGCC 电站的建造计划？与此相反，荷兰用天燃气为燃料的常规联合循环电站，却早已作好安排，要在 1995 － 1996 年期间投入 1,700MW 之多[5]。可见国外 IGCC 电站没有大量发展使用，必然还存在其它方面更为重要的原因，不可能仅是建成的示范电站净效率 的问题。

国外不少专家认为 IGCC 电站技术没有大量发展使用的主要原因可能和国外天然气（包括石油）的售价相对较低，而国外煤炭售价又相对稍高，有着密切的联系。这一看法比较符合当前实际情况，很值得认真分析。燃用天然气的联合循环机组（NGCC 机组）造价低，天然气（NG）售价又低，IGCC 自然就竞争不过 NGCC，不只是 IGCC 技术，常规的燃煤带烟气脱硫装置的火电机组也竞争不过 NGCC 机组。所以，国外近年来，不仅 IGCC 电站建造得少，常规火电机组建造得也不多，道理可能就在这里。

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* 低效率的主要原因是当时该电站以考验技术的可行性为示范目的，而对效率影响极大的系统集成没有重视。仅把各关键技术积木式地组合在一起，而未对各子系统间的物质和能量进行集成，导致效率低，因此将其称为煤气化联合循环（GCC）更合适。受当时燃气轮机的入口温度所限，顶循环和底循环效率都不高，是低效率的又一重要原因。

表 3　IGCC 与 NGCC 和常规燃煤机组的费用比较

	电站类别	NGCC	IGCC	常规燃煤机组
美国数据 [6]	电站造价 ($/kW)	680	1700	1650
	净效率 (%HHV)	47.50	37.95	34.45
	燃料种类	天然气	煤	煤
	燃料售价 1 ($/$10^6$Btu)	2.65	1.5	1.5
推导数据	燃料售价	0.105 $\$/Nm^3$	0.041 $/kg	0.041 $/kg
	燃料消耗量	0.181 Nm^3/ kWh	0.322 kg/kWh	0.345 kg/kWh
	燃料费 ($/kWh)	0.0190	0.0132	0.0141
	折旧费 2($/kWh)	0.0146	0.0364	0.0354
	燃料费加折旧费 3 ($/ kWh)	0.0336	0.0496	0.0495

说明：

1. 按照原始 (实际运行) 数据，
   天然气售价 / 煤炭售价 =2.65/1.5=1.77
2. 年折旧率取 15%，年运行时间取 7000 小时
3. 燃料费加折旧费 = 不计燃料以外的运行和维护费用的发电成本
4. 如果 NGCC 的发电成本等于 IGCC 的发电成本，
   则天然气的售价应为 $0.193/$Nm^3$，相当于 $5/$10^6$Btu
5. IGCC 与 NGCC 竞争的必要条件为：
   天然气售价 / 煤炭售价 =5/1.5=3.33

从美国的数据中 [6]，可以清楚地推导出这一重要关系。表 3 是按该文献 [6] 的数据换算或推导得出的一些主要数据。美国当时天然气和煤炭的价格比为 2.65/1.5，等于 1.77， IGCC 技术在美国具有和 NGCC 技术相竞争的必要条件是美国天然气售价必须从 $2.65/$10^6$Btu 上涨到 $5/$10^6$Btu，从而使价格比达到 5/1.5=3.3，对美国常规燃煤火电机组来说，还需要上涨得更高一些，否则可能会无利可图。因此，当前国外 IGCC 电站建设台数不多，可能不是它的技术性

能不好，或不成熟，主要是国外天然气，包括石油，售价相对较低的原故。近来 IGCC 电站造价已降到 $1,400/kW 左右，电站净效率已高到 42%（LHV）以上，都是发展 IGCC 技术的有利条件；但天然气价格近来也有下降趋势，因而国外有些专家认为价格比达到 4 以上，才是 IGCC 技术得到发展的重要条件[7]。

“国外近期不大量使用 IGCC 这一技术，为什么还要化大力气开发、完善这一技术？”这方面的原因比较难以推测，可能有如下一些原因：

- 世界上油和天然气的储量没有煤炭储量丰富，而要高效利用煤炭资源又要保护环境，IGCC 是现实有效和经济的选择；
- 能源供应的安全性和多样化要求减少对石油和天然气的依赖，IGCC 是能够实现此目的的技术；
- IGCC 技术的发展，对抑止天然气和石油售价猛涨，可能有相当重要的作用；
- IGCC 技术的发展，对随后更先进的整体煤气化燃料电池（IGFC）联合循环发电技术的开发能起一定的先行作用。

不管如何，上述对国外 IGCC 技术发展情况的分析和认识，如果没有太大偏差，对我国研究 IGCC 技术的开发和使用问题肯定会有极大的启发和决策参考作用。我国天然气和石油售价相对要高，例如轻柴油一般是￥1500－2000/吨，煤炭售价相对要低一些，如暂按￥300/吨（标煤）估计，相同发热量的价格比大致在 3－4 以上，所以不存在经济上竞争不过 NGCC 技术的问题。我国在 2010 年甚至更远一些的年代，必然还是以煤炭作为火力发电机组的主要燃料，国外 IGCC 电站造价目前已经达到和常规火电机组造价相当，并且很快将低于常规火电机组造价，按照市场经济法则，国外的这一情况，必然也可能很快在国内得到验证。因此，无论从那一方面考虑，我国目前确已达到必须加速试点发展 IGCC 技术的阶段了，除非我国天然气和石油售价也象国际市场一样暴跌下来。目前有人持“等国外大量使用 IGCC 机组后再引进开发”的想法，可能很不现实的，只要国外天然气和石油售价不暴涨，近期在国外就不存在大量使用 IGCC 机组的市场动力。根据我国自己的国情

（资源储备和特色）， IGCC 很可能会是必须首先在中国大量发展使用，随后由我国自己在大量使用 IGCC 技术过程中进一步发扬光大。

结　论

- 在目前直至2050年的长时间内，煤电仍是我国最主要的电力供应保障。

- 为实现可持续发展的战略目标，清洁煤发电技术是煤电唯一可行的选择，是煤电的未来。

- IGCC 发电技术是目前清洁煤技术中最清洁、效率最高、技术最成熟的发电技术。

- IGCC 发电技术是中国用得起的技术，新建 IGCC 电站的造价可以比带烟气脱硫的常规煤粉电站的造价低 20%，还存在继续降低造价的较大技术潜力。

- 如果国际市场上油和天然气的售价不暴涨，国外就不存在大量使用 IGCC 的市场动力。国外电力首先选择的是常规燃油、气的联合循环，近期不会大量使用 IGCC 。“等国外大量使用 IGCC 机组后再引进开发”的想法几乎是异想天开。

- 工业发达国家以强化能源供应的安全性和多样化为战略目标，继续投入充足的人力和物力发展、改进和完善 IGCC 。根据我国的资源储备和油（气）与煤的比价高于国外的国情，我国目前确已达到必须加速试点发展 IGCC 技术的时候了。IGCC 很可能是必须首先在中国大量发展使用的清洁煤高新技术，随后由我国自己在大量使用的过程中发扬光大。

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4．煤气化工艺在中国发展的情况及已达到的水平

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煤气化工艺（特别是气流床气化工艺）在中国化学工业中已积累的经验介绍

概　论

1995年中国生产合成氨2760万吨，甲醇110万吨，其中煤为原料约占65%。80年代以前中国以煤为原料生产合成氨与甲醇原料气的工艺主要是间歇式固定床气化。众所周知，这种工艺效率低，环境污染大，且要求无烟煤或焦炭为原料。中国的无烟煤大型矿区仅有阳泉与晋城，1994年两地产量约为2060万吨。煤价与运输费为1比1，这就在产量与运输两方面进一步限制了传统气化工艺在合成气工艺中的发展。

为了发展煤化工，生产更多的化肥，支援农业，中国在有发展前途的煤气化技术中有选择地引进了鲁奇与德士古煤气化技术。经验表明后者更适合于合成氨工业。继引进鲁南、吴泾、渭河之后，中国正在论证建设金陵、洞庭、湖北等九套装置，到1995年底引进技术的态势示于表1。

表 1　引进状况

地点	装置能力 吨煤 / 天	技术来源	备　注
山西	1200	鲁奇专利并承包	1987.7 投产
鲁南	350	德士古许可证及工艺软件包，中国设计	1993.4 投产
吴泾	1500	德士古许可证及工艺软件包，中国设计	1995.5 投产
渭河	1500	德士古许可证，中国设计。承包商：宇部（日本）	1996.2 试运行
首钢	1000	德士古许可证。承包商： CTIP(意大利)	1989 全套引进
金陵、洞庭、湖北	1500×3	德士古许可证及工艺软件包，中国设计	1996 起动工程
长山、衢化、浩良河 淮南、刘家峡、鲁南	1000×6	德士古许可证及工艺软件包	目前进行 可行性研究

山西化肥厂鲁奇煤气化

鲁奇干底固定床气化炉是目前广泛使用的加压气化炉。主要工厂有：南非的萨索厂（能力为每年处理 3 千万吨烟煤）生产制造液体燃料和其它化学品的合成气；美国的 DGC 工厂每年处理 4 百万吨褐煤，每小时生产 16 万标准立方米的合成天然气。

鲁奇干底加压气化炉以固定床方式进行。煤和气化剂以及产品气是逆流进行的，从而在所有气化系统中具有较低的氧耗和较高的冷煤气效率（大约 90% 以上的煤的热值转化为产品气的化学热），但煤气会携带煤尘、焦油和其它有机物。

鲁奇提供了山西化肥厂全部气化工程设备，4 台气化炉（3 开 1 备），直径 3848/4100mm，气化压力 3.1MPa（A），每台炉加煤量 16.69t/h，产气 36000Nm^3/h·台，碳转化率 98%。建设始于 1983 年 7 月， 1987 年 7 月气化装置投产，运

行结果如下：

1. 典型煤气成分（v%）为：CO_2=27.28，CO=23.23，H_2=39.08，CH_4=7.93，H_2S=0.08，C_2H_4=0.03，C_2H_6=0.44，N_2=1.31，Ar=0.62。

2. 气化炉出口煤气典型携带物质（kg/h）为：氨=516，氯=20，脂肪酸=35，萘=26，石脑油=68，油=211，焦油=358，尘=672。

3. 运行6年后，到1993年底最高生产能力仅为设计值的90%，因堵塞经常停车，堵塞单元有：煤气化、灰处理、从煤气中分离水、氨回收、煤气冷却、一氧化碳变换、气体净化（甲醇洗、液氮洗）以及甲烷转化。结垢物质为煤粉尘、焦油、碳酸铵、萘、硅酸盐、炭黑等。

经过八年的实践，人们普遍认为：

1. 鲁奇干底固定床气化工艺不适合半无烟煤，该技术有特定煤种与尺寸要求。

2. 主要问题是堵塞，迄今还没有有效的方法分离煤粉尘、焦油、烃、碳酸铵、碳黑等。

3. 废水处理十分复杂。

鲁南德士古水煤浆气化

装置设计

鉴于我国无烟煤短缺，运输价格高，十分需要经济、有效的非无烟煤气化方法。国家计委、国家科委、化工部重视新气化方法开发，决定建立示范装置，以改变原料煤种。与此同时，我国制订了引进规划。

1984年鲁南与美国德士古开发公司签订合同，购买许可证和工艺设计软

件包（PDP）。由化工部第一设计院完成工程基础设计和详细设计，并负责采购进口设备、阀门和仪表，成为国际上继美国贝克特尔、德国伍德和日本宇部之后第四个完成该工程设计的单位。鲁南化肥厂日处理 350 吨煤，年生产 8 万吨合成氨。通过设计积累了如下经验：

1. 开发了“七五”煤助熔剂（碳酸钙）添加技术和橡胶衬里球磨机。

2. 设计了气化炉、排渣锁斗、带搅拌器的煤浆槽、文氏管洗涤器和煤气洗涤塔、捞渣机、洗涤塔循环泵、锁斗循环泵、换热器、闪蒸塔，国产化率达到总设备的 90%。

3. 改进了德士古真空蒸发器液位调节技术，开发了防止闪蒸系统管道磨蚀技术。

4. 开发了利用煤气成份控制炉温技术。

运行状况

1993 年 2 月完成预试车，1993 年 4 月第一次投料并生产合成气，1994 年 2 月全负荷生产，1995 年 7 月负荷达到设计能力的 120%。设计与运行值比较见表 2。

表 2　设计与运行值比较

项　　目	单　位	设计值	运行值
气化压力	MPa	4.0	2.7 – 3.0
氧加料速率	Nm^3/h	10000	11500
氧气成份	%	99.5	99.8
煤浆浓度	固体 %	63 ± 1	65 ± 1
气化炉负荷 (单炉水煤浆加料速率)	m^3/h t/h	18.6 14.6	22.0 17.6
合成气组成	v%	CO　45.03 H_2　35.1 CO_2　18.53 N_2+Ar　0.14	CO　45.1 H_2　35.42 CO_2　18.54 N_2+Ar　0.11
合成气流率	Nm^3/h	27262.5	33234
气化炉开工率	%	85	96.89
碳转化率	%	—	~96

运行过程中气化系统作了如下改进：

1. 堵塞

1993 年 5 月，当气化炉工作 600 小时后，黑水与灰水系统发生严重堵塞，导致文氏管内径减小、降低热交换效率并使激冷环流道截面减小。针对产生的问题，经过分析研究，采取了下列措施：

- 文丘利洗涤器中的垢主要是煤灰、碳酸钙和硅酸盐，通过在灰水中加入新型抗结垢剂与分散剂以及改变文氏管内的流动分布，结垢已大为缓解。

- 通过在灰水中加抗结垢剂与分散剂，灰水换热器和激冷环的结垢问题已基本解决。灰水换热器工作 4000 小时再行清洗，灰水泵的操作周期也相应延长。

2. 耐火砖

鲁南气化炉已经使用法国 ZIRCHROM 80 和 ZIRCHROM 90 以及国产洛耐砖。运行情况载于表 3 。

表 3 耐火砖运行情况

项目	运行时间 (小时)	烧蚀率 (mm/h)	价格比
洛耐	1877.1	0.0317	0.5
ZIRCHROM 80	4679.6	0.0412	1
ZIRCHROM 90	1499	0.016	1

3. 工艺喷嘴

鲁南化学工业（集团）公司开工之前，已经从美国引进 4 台工艺喷嘴和 6 个喷嘴头，自 1994 年后采用鲁南自制的喷嘴头，表 4 给出运行情况。

表 4 工艺喷嘴运行情况

项　目	工作寿命
引进喷嘴	66 天
鲁南喷嘴	62 天

4. 原料煤

气化装置设计时采用原料煤为“七五”煤，其灰熔点较高，流动点温度约 1510°C 。为了降低气化温度、氧耗以及助溶剂（$CaCO_3$），采用“七五”煤与“北宿”煤按 1 比 1 (重量比) 混合，其灰熔点温度降低，流动点温度约 1280°C 。

上海焦化厂三联供（吴泾）气化装置

德士古水煤浆气化

该装置4台气化炉（3开一备），壳体内径为2800mm，耐火砖内径为1676mm，设计气化压力为3.92MPa，日处理“神府”煤1500吨，生产甲醇和醋酸。购买专利许可证和工艺设计软件包（PDP）由化工部第一设计院设计。1995年5月投产，经过一年运转，生产能力、气体成份、碳转化率均达到设计指标。

U-Gas 煤气化

U-Gas为美国煤气技术研究所（IGT）技术。上海焦化厂购买专利，由上海化工设计院完成工程设计，共8台炉，直径2600mm，压力为0.6MPa，每台日处理120吨煤，1994年11月投入生产，问题很多，诸如出渣口堵塞、粉尘分离不良、碳转化率低等，迄今最长的运转周期为7天。

渭河德士古水煤浆气化

该装置由日本宇部总承包，化工部第六设计院参加工程设计，3台气化炉（2开一备），壳体内径为2794mm，气化压力为6.5MPa，单炉日处理黄陵煤820吨。该装置于1996年2月23日投产，目前处于试运转阶段。

迄今中国煤气化（气流床）已经达到如下水平

1. 一旦引进许可证、工艺设计软件包以及煤浆泵、破渣阀和少量关键阀门、仪表和材料，中国就可以设计、安装与运行气化装置。

2. 已经成功地设计、建设、安装与运行了鲁南、吴泾、渭河三套装置，就每年运行时间、工艺指标、安全、稳定诸方面而论，已经达到德士古技术的水平，而且在防止堵塞、水煤浆添加剂、开工措施等方面有新发展。

为发展 IGCC 中国有条件可以将化工中积累的发展气化工艺的经验应用过来（包括运行经验和制造经验）

概述

整体煤气化联合循环发电是一种先进的发电技术，具有发电效率高，保护环境的优点，是中国优先发展的燃煤发电技术之一。该系统由若干子系统组成，包括空分、气化与煤渣处理、合成气净化、热回收、燃气与蒸汽联合循环发电六个技术单元，其中煤气化是关键技术。目前世界上已经示范的大容量 IGCC 电站都采用气流床煤气化技术，举例如下。

采用德士古水煤浆气化技术的 IGCC 电站

冷水（Cool Water）电站采用德士古水煤浆气化技术，一台炉容积 16.98m^3（600ft^3），耐火砖内径 1828mm，气化压力为 3.0MPa，日处理煤 700t，另一台炉容积为 25.48m^3（900ft^3），耐火砖内径 2430mm，气化压力为 3.0MPa，日处理煤 1000t。电站净功率为 100MW。1984 年投运，1989 年完成示范任务。Tampa（Polk 电站）也采用德士古水煤浆气化技术，气化炉容积为 51m^3（1800ft^3），日处理 2300 吨，电站净功率为 257.8MW。预计 1996 年投运。

采用 Dow 水煤浆气化技术的 IGCC 电站

LGTI 采用 Dow 水煤浆气化技术，气化压力为 2.8MPa，单炉日处理煤 2400t，1987 年投入运行，净功率为 160MW。Wabash River 电站，二台气化炉（一开一备），日处理煤 2500t，2.8MPa 气化，净功率 262MW，1995 年 11 月投运。

Buggenum 电站

Buggenum 基于 Shell 气化技术，净功率 253MW，1993 年开工，1994 - 1996 年为验证运行期。

上述气流床气化的IGCC发电项目在商业规模的尺度上证实了IGCC发电的经济和环境特征，显示了良好前景。中国在化学工业中已经积累了水煤浆气化研究、设计、制造和操作经验，将其应用于IGCC发电，将有利于降低投资，有助于提高装置安全性与可靠性，推动IGCC在中国的发展。

中国水煤浆气化的研究与开发

70年代末，西北化工研究院在研究粉煤气流床气化的基础上开始研究水煤浆气化技术，80年代中期由化工部第一设计院设计了中试装置。日处理煤24－35吨。气化压力范围2.6－3.4MPa；煤浆浓度为55%、60%、65%；气化温度是1350°C、1450°C及1550°C三种状况。试验了冷壁炉和热壁炉（内直径770mm，直筒高2400mm），辐射废热锅炉（内直径1900mm，高9070mm），五种喷嘴结构、六种煤，为鲁南、吴泾水煤浆气化装置成功打下了基础。

德士古公司参观了中试装置后，与西北化工研究院签订合同，确认该装置的试烧数据可作为该公司编制PDP的依据。

操作经验

以鲁南气化装置为例，已经安全稳定地运行三年，1995年装置能力达到设计值的120%，开工率达到96.89%。

水煤浆制备与煤种

中国已经成功地在工业装置上使用“七五”、“北宿”、“落陵”、“黄陵”、“神府”五个煤种，水煤浆浓度约为65%，每吨煤使用添加剂的费用约10元人民币，开发的助熔添加剂技术可使灰渣熔点温度低于1300°C，有助于降低氧耗和延长耐火砖寿命。

开工率与更换喷嘴

如前所述，开工率已经达到96.89%，1995年投料成功率为100%，1994年

12 月 13 日成功地实现了不换喷嘴直接投料，又于 1995 年 5 月 28 日成功地进行了不置换连续投料。这些经验极大地缩短了开车时间，最短的一次从停车到开车仅用 32 分钟。

上述经验有利于气流床煤气化技术与发电工业特征（安全、稳定、调峰）相匹配。

负荷与技术指标

业经证实，鲁南气化装置负荷已经达到设计值的 120%，每吨煤的氧耗由设计值的 684.9Nm³ 降为 653Nm³，每吨煤的产气量由设计值的 1867.3Nm³ 增加为 1882Nm³。这些经验有利于降低电价成本。

设计与制造经验

气化炉

由化工部第一设计院设计，金州重型机械厂为鲁南、吴泾制造了壳体内直径 2800mm 气化炉 6 台，耐压 4.0MPa，日处理煤 500 吨（鲁南操作压力为 2.8MPa，日处理煤 350 吨）；哈尔滨锅炉厂为渭河制造了直径 2794mm 气化炉 3 台，耐压 6.5MPa，单炉日处理煤约 820 吨。我国还将制造已经进入工程起动阶段的金陵、湖北、洞庭等 9 台直径 3200mm 气化炉，压力为 4.1MPa，单炉日处理煤约 1200 吨。

耐火砖

国产洛耐砖使用寿命介于法国 ZIRCHROM80 与 ZIRCHROM90 之间，价格仅为其二分之一。

其他设备

中国已设计并已制造了磨煤机、锁渣斗、激冷环、捞渣机、文氏管洗涤

器、洗涤塔、闪蒸塔、换热器、灰水泵、沉淀槽等。换言之，除高压正位移煤浆泵、破渣阀、工艺喷嘴外，其他设备国内都积累了丰富的生产经验。

应用煤气化工艺经验发展 IGCC 技术

1. 中国在化学工业中已经积累的德士古气化经验，可直接用于发电容量为 200MW 的 IGCC 气化单元。

2. 按已有经验，中国有能力建设与 400MW IGCC 相匹配的气化装置。

3. 积累的操作准备、维修、安全以及培训方法等经验，都将应用于 IGCC 电站。

4. 水煤浆气化由于其技术特征决定：存在冷煤气效率低（～ 70%），调峰能力差等缺点，但在安全、稳定、环境保护、大的生产强度方面与其他煤气化技术相比具有良好的竞争能力。

5．IGCC 是中国发展高效率、低污染、少用水燃煤电站的一项高新技术

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整体煤气化联合循环 (Integrated Gasification Combined Cycle，简称 IGCC) 是把高效的联合循环和洁净的燃煤技术结合起来的先进发电技术，为当今世界能源动力界关注的一个热点。它将成为跨世纪火电动力发展的主要方向之一，也正是中国开拓高效率、低污染、少用水的火电发展新模式所需的高新技术，对中国 21 世纪乃至未来国民经济持续发展和环境生态保护都是至关重要的。

中国需要 IGCC

中国为世界最大的煤炭生产国和消费国。1995 年全国煤炭消费总量 1.298 Gt，约占一次能源消费的 3/4，为世界煤炭总消费量的 1/4。煤炭是中国主要一次能源，丰富而价廉，且煤炭为主的格局在相当长时期内不会改变。困扰中国持续发展的一个难题是：现有煤炭利用技术多为低效率和高污染的。特别是电力，以火电为主 (约占 81%)、火电能源以煤为主 (约占 92.7%)、火电动力以常规的汽轮机为主 (约 95%)，由此产生三大问题：煤耗高 (1994 年为 413gce/kWh)；有害物排放量大，致使环境生态污染严重；耗水量大，在多数缺水地区与其它行业争水。随着国民经济的发展，现有约 210GW 庞大火电网还将成倍扩大，若不采用先进技术改造现有电站和建设新电站，则能源浪费和环境污染的问题势必更为严峻。

显然，中国电力只能走洁净煤发电的道路，必须在大幅度提高能源利用率的同时，解决烧煤造成的日益严重的污染问题。世界正在开发的洁净煤发电技术类型很多，但越来越多的人相信： IGCC 是最有发展前景的洁净煤发

电技术。我们重视 IGCC，是基于其下列突出优点：

1. 具有提高发电系统热效率的最大潜在能力。目前其供电效率可达 40－46%，下世纪有望突破 50%；

2. 易大型化，装机容量已能做到规模经济等级 (300－600MW)；

3. 优良环保性能：污染问题解决得最彻底，即使燃用高硫煤，也能满足严格的环保标准的要求，脱硫率 ≥98%，废物处理量最少，副产品有用；

4. 能充分综合利用煤炭资源，适用煤种广。把它和煤化工结合成多联产系统，能同时生产电、热、燃料气和化工产品；

5. 耗水量比较少，比常规汽轮机电站少 30－50%，这对许多缺水地区有利，也适于矿区建设坑口电站；

6. 能最大程度沿用烧油气联合循环和化工部门煤气化的现有技术，基本集成技术已趋成熟。示范装置运行可用率达到 80% 以上，能满足商业化运行的要求；

7. 能广泛共享相关科技成果，有广阔的高新科技产业发展前景：亚临界或超临界蒸汽参数的 IGCC，整体煤气化湿空气透平循环 (IGHAT)，整体煤气化燃料电池联合循环 (IGFC–CC) 等。

IGCC 在中国商业化的关键因素

近十多年来，世界上几乎所有主要石油煤炭公司和动力制造厂商都加入到 IGCC 开发行列，投入大量人力物力，取得重大进展：建成一批示范工程，跨进商业验证阶段。IGCC 在中国推广应用的竞争对手是传统的烧煤粉汽轮机机组 (PC) 及其超临界机组 (PC–SC) 和增压流化床燃煤联合循环装置 (PFBC–CC)。鉴于中国要求多样的广阔火电市场，三种发电技术都会占有自己一席之地，会在不同层次上发展、相互补充与促进。至于 IGCC 在中国电网中占有

份额，则在很大程度上取决于其热力性能和经济性，这也是 IGCC 在中国商业化的两个关键因素。

相当长时期， IGCC 的发展是围绕提高热力性能为主要目标进行：研制高性能燃气轮机及其联合循环装置；开发不同形式气化炉和常温、高温的煤气净化技术；研究系统整体优化，包括空分制氧系统和蒸汽流程等。IGCC 热力系统的核心是联合循环动力块，故燃气轮机性能的提高是发展 IGCC 的前提。表 1 列出燃气轮机及其 IGCC 性能参数的典型值。显然，八十年代，初温 1100°C 燃气轮机组成的 IGCC 还难以和汽轮机发电机组相匹敌；而九十年代后，研制出一批高性能燃气轮机，可建造供电效率 40 - 46% 的大型 IGCC 装置，在热力性能上就足以和传统的燃煤电站相竞争。所以，当前 IGCC 商业化的更大制约因素是经济性。

表 1　燃气轮机及其 IGCC 热力性能参数与预测

	燃气轮机初温 (°C)	简单循环		烧油气联合循环		IGCC	
		单机功率 (MW)	供电效率 (%)	单机功率 (MW)	供电效率 (%)	单机功率 (MW)	供电效率 (%)
八十年代	1100	100	32 - 34	150	45	180	36
九十年代	1250 - 1288	230	34 - 38	350	55	400	40 - 46
2000 年	1430	280	38 - 40	480	60	600	≥50

早期 IGCC 示范工程的单位造价高达 $2500/kW 以上，目前计划筹建的项目也多介于 $1500 - 2500/kW 之间。降低 IGCC 比投资费用和发电成本的途径很多，值得特别重视的是：

1. 继续改进关键设备，优化和简化系统，不断提高系统性能。如应用新一代燃气轮机 (G 型或 H 型系列产品) 和高温干法净化技术，优化整体空分方案以及发展 IGHAT 和多联供 IGCC 等。技术进步和性能提高将使 IGCC 投资成本迅速下降。表 2 列出 GE 公司 （GER － 3650C） 对 IGCC 技术性能和成本关系的分析结果。

表 2 IGCC 技术性能和成本的联系

	IGCC 系统类型	燃气轮机初温 (°C)	IGCC 热效率 % (LHV)	装置比投资成本 ($/kW)
九十年代初期	常规 PC 机组		36 - 37	1200
	常规 IGCC 低温净化、独立空分	1260 (F 型)	38 - 42	1400 - 1600
九十年代中期	低温净化、整体空分	1260 (F 型)	43 - 46	1350 - 1550
	高温净化、整体空分	1260 (F 型)	45 - 48	1180 - 1380
九十年代后期	高温净化、整体空分	1370 (G 、 H 型)	46 - 50	1130 - 1330

2. 继续增大 IGCC 电站的装机容量，使之达到规模经济的水平，并尽可能采用单台大容量的气化炉和燃气轮机，取消备用炉。许多研究都表明，装机容量对初投资的影响很大：若机组功率每翻一番，单位造价将会下降 10 - 20% 。

3. 争取早日转入批量生产。不言而喻，若干台（第 N 台）后装置的造价将明显低于首台。如美国 CRSS 公司曾对 500MW 级 IGCC 批量生产对价格影响进行详细计算分析，其结论为：若干台后造价将比第一台下降 40% 。在进行经济性分析时，多采用下列的成本减小系数 R ：第一台， R=1.1 ；第二台， R=0.9 ；第三台， R=0.8 ；第四台， R=0.7 。

4. 由于劳动力价廉等许多因素影响，在中国建电站的造价要比在美国的造价低许多。如 PC 电站，国产机组为 $500 - 700/kW ，当主要设备国外引进时为 $800 - 1000/kW ，比在美国建造同类电站造价分别低 50% 和 20% 。对于 IGCC 电站，相关的研究分析也得出相近的结果，如在美国新建 IGCC 电站单位造价为 $1500/kW 时，则在中国的造价 (主要设备国外引进) 可降低到 $1200/kW 。

5. 燃用廉价的高硫煤。 IGCC 的优势还在于能燃用高硫煤，若燃用比常规 PC 电站者便宜 10 - 25% 的煤，则会使发电成本降低 10% 左右。再很好利用销售副产品 (包括元素硫，玻璃状渣等) ，则经济性还会进一步改善。

许多中外专家都曾对 IGCC 、 PC 、 PFBC-CC 三种发电方案的技术经济性指标进行全面分析比较，表 3 列出有代表性的数据。虽然因比较条件的不

同，计算结果有所差异，但从这些大量分析研究归纳得出的下列结论却是相当明确的：

1. IGCC 在环保性能和耗水量等方面的优势无可争议。其有害物排放量远低于其它两者，PC 机组加上 FGD 措施时只和 PFBC-CC 相当，还是比 IGCC 逊色。

2. IGCC 供电效率已超过常规 PC 和 PFBC-CC 机组（高 10% 左右），与超临界的 PC-SC 相当，但 IGCC 在热力性能上的优势，将继续扩大，而且 IGCC 也可以采用超临界参数，可进一步提高效率。

3. IGCC 商业化的关键在于经济性，现在其比投资费用比其它两者平均高 10 - 20%，发电成本高 6 - 10%。随着 IGCC 技术进一步发展，特别是达到规模经济容量水平和批量生产后，其单位造价会大幅度下降，预计下世纪初就可降到 PC+FGD 的水平。

表 3　几种不同发电方案的技术经济指标比较

		PC		PFBC-CC	IGCC
		常规	带 FGD		
电站规模（MW）	目前	300 - 1300	300 - 1300	80 - 350	200 - 600
	2010 年			500	1000
供电效率（%）	目前	36 - 38 (SC:40 - 42)	34.5 - 36.5	36 - 39	40 - 46
	2010 年			45 - 50 (第二代)	50 - 54
用水量比		100	100	70 - 80	50 - 70
环保性能（排放量比）	SOx	100	6 - 12	5 - 10	1 - 5
	NOx	100	18 - 90	17 - 48	17 - 32
	粉尘	100	2 - 5	2 - 4	2
	固态废料	100	120 - 200	95 - 600	50 - 95
	CO_2	100	107	98	95
单位造价 $/kW		1160	1400	1300 - 1400	1400 - 1700
发电成本 * mills/kWh		48 - 57	56 - 66	54 - 66	49 - 63

* 摘自美国吉尔帕特公司的经济分析报告（以 1991 年美元价为计算基准）

中国在积极地发展 IGCC

早在十多年前，中国曾两次考虑建立 IGCC 示范电站，均因技术和资金困难，未能实现。但相关的技术研究和应用开发工作一直在进行。八十年代初，著名科学家吴仲华教授就提出一个发展联合循环的“双管齐下”方针：一方面在能够烧油气的地方先发展，以取得实际经验，也为使用者节能；另一方面要大力研究有关的燃煤技术，然后把两者结合起来。中国科学院工程热物理研究所、清华大学、电力部热工研究所等都一直在进行燃气轮机总能系统（包括 IGCC ）的应用基础研究和工程开发工作，包括燃煤联合循环系统方案、优化分析以及推广应用等方面。

中国已在大庆、新疆等油田和深圳、珠海、汕头等沿海城市建成数十套燃油气的联合循环发电机组（多为进口的），积累了丰富的运行使用经验。

南京汽轮电机厂和美国 GE 公司合作，已生产出 MS6000 系列燃气轮机及联合循环；哈尔滨汽轮机厂、东方汽轮机厂和上海汽轮机厂等过去研制过几种型号的燃气轮机，现正寻求国际合作、生产大型高性能的产品；航空部许多发动机厂都在开展航机陆用工作；中国科学院沈阳金属所研制出用于 1100°C 透平初温部件的 M38 高温合金；中国早就在哈尔滨、上海和四川建立三大电站动力设备生产基地，可设计制造各种型号的汽轮机和锅炉；哈尔滨锅炉厂和杭州锅炉厂通过引进技术，已能制造用于联合循环的余热锅炉。

中科院山西煤炭化学研究所自八十年代以来，开发研究空气气化的流化床团聚排渣气化炉；化工部西北研究院进行 Texaco 炉烧多种煤种的气化试验研究；煤炭部煤科总院北京煤化学研究所进行不同气化工艺的试验研究。

中国还进口了多套不同用途的煤气化装置，如鲁南化肥工程的 350t/d 、首钢的 1000t/d 和渭河合成氨厂的 2x820t/d 的 Texaco 炉等。哈尔滨锅炉厂和金州重型机械厂等曾通过国际合作方式生产不同形式的气化炉。

煤气常温湿法净化技术在中国化工部门比较成熟，已能自行设计制造，也有丰富使用经验；高温净化技术研究也已起步，并在气固两相流、脱硫剂

制备以及净化流程等方面取得一定进展。

经过十多年的努力，中国已具备相当好的发展 IGCC 的基础。中国很重视与美国、欧洲各国、日本等同行的国际交流和合作，正积极争取国际合作，加紧开展 IGCC 关键技术研究和筹建大型 IGCC 示范装置。

1994 年在国家科委和电力部领导下成立中国 IGCC 领导小组，集中国内各方面技术力量，对拟建的 200 － 400MW 级 IGCC 示范工程进行了可行性研究。大家都希望它能尽早建成，并成为中国高效率、低污染、少用水燃煤电站的示范样板和先进发电设备技术人员的培训基地。此外，有些地方部门也在考虑建设 50 － 100MW 级 IGCC 电站，相关的技术经济可行性研究正在进行。

总之，中国已认识到洁净煤发电技术的重要性，把它列为国家能源政策和能源发展规划的重要内容，列为电力工业中长期科技发展规划的重要领域，列入 21 世纪议程行动计划的优先项目。

中国有较大的 IGCC 应用市场

IGCC 可以不同形式在中国许多部门得到应用，例如：

1. 大电网中基本负荷机组：预计，2000 年中国装机总容量将达到 290GW，年发电量将为 1400TWh 。2000 － 2020 年间每年新增的装机容量可能达到 25GW 左右，其中大部分仍将由火电承担。而跨进 21 世纪后， IGCC 的性能更高、技术更成熟、成本进一步较低，将具有更强的竞争力。若按新增装机容量 15% 计，则 IGCC 每年有 3000MW 市场。

2. 现有电站的 IGCC 技术更新改造：中国现有火电网在很长时期内都将面临着把煤耗和污染降下来的双重压力，特别是技术落后、性能差的数千万 kW 中小型汽轮机机组急需更新改造。研究表明，对许多旧电站的更新改造，IGCC 技术常是有效手段。它在现有汽轮机电站加装燃气轮机和煤气化装置，组成 IGCC 电站。现有厂房设备大部分还能利用，改造投资小，扩容降耗效果明显，有害物排放量大为降低，并能大大延长老机组的技术经济寿命和缓解

对新建电站巨额投资的压力。

3. 在沿海地区分阶段建设 IGCC 电站：中国南方沿海地区经济发展快，电力需求的增长也快。据统计，仅珠江三角洲，近期就需建 20 套 600MW 级燃煤机组。对不同类型电站方案分析比较表明，分阶段建立的 IGCC 电站方案（燃气轮机发电机组－烧油气的联合循环发电装置－ IGCC ）具有建设周期短、初投资少、效率高以及污染小等优点，很值得试点和逐步推广应用。

4. 多联产的 IGCC ：煤通过气化的途径，不仅可供燃料气给联合循环来发电供热，还能生产甲醇、汽油、尿素等化工产品和城市煤气。这不仅使煤炭得以充分综合利用，还能明显降低生产成本。因而多联供的 IGCC 在中国也有实用的前景，上海吴泾焦化厂筹建中 IGCC ，就是一个工程实例。

Ⅳ. 美方专家的论述

1. 美国的洁净煤技术概览

Dr. Benjamin C. B. Hsieh

2. IGCC 在中国的近期和远期市场潜力

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3. IGCC 在中国：市场定义及需求基础

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4. 美国 IGCC 技术在中国使用对全球环境的潜在影响与益处

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5. 从美国电业看 IGCC 技术

Charles R. Black 和 Stephen D. Jenkins

1. 美国的洁净煤技术概览

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洁净煤技术 (CCT) 示范计划是由美国能源部 (DOE) 和美国企业共同合作来展示将煤转化成电力的新一代技术。具有提高能源利用效率和改善环境质量的前景，这些技术将进入国内及国际市场。

美国洁净煤技术示范的现状

全世界对电力的需求每年都在增加，同时对于一个更为清洁的环境的要求也在提高。由于意识到煤炭已经，并且还将继续成为电力生产的一个主要燃料来源，美国能源部在 1985 年就开始了洁净煤计划，以期这种技术能够令煤炭利用符合上述两个要求。洁净煤技术正在商业领域得到示范，所有项目中至少由企业合伙人出资百分之五十。

经过长达九年，在五轮竞争性的论证后，目前有 43 个项目被挑选出来。前三轮主要集中在能减轻酸雨的潜在影响的技术上。后两轮主要针对下个世纪的能源需求，即那些既能保证高效率，又能保证低排放量的技术。这些项目中有 18 个已经完成了，有 8 个正在运行， 14 个正在施工或设计， 2 个被取消了，还有 1 个项目在经过最后一轮论证后正在洽谈中。项目的资本投资超过七十亿美元，平均企业成本份额占总额的 67% 。

这些项目可划分为四个市场领域：先进的发电系统，环保控制装置，煤炭加工为清洁燃料，和工业应用。

属于先进发电系统领域的 14 个项目正在把燃煤电站带入二十一世纪。

这些项目新发电能力超过 1,000MW, 老厂改造发电能力超过 800MW, 总价值超过 46 亿美元。这些项目会大大提高改善电站的以下方面：热力效率，电力成本，对二氧化硫 (SO_2) 和氮氧化物 (NO_x) 的整体控制，缓解或消除固体废料管理的问题，燃料的可变性并能将老厂改造发电的电力生产能力提高 150%。在这一领域的主要技术是整体煤气化联合循环 (IGCC), 有 5 个项目，以及流化床燃烧，有 6 个项目。

针对当前的环保标准对燃煤电站的要求，价值超过 6.86 亿美元的 19 个项目已被挑选出来，它们属于环保控制装置这一领域。该领域技术的特点是高效率地控制 SO_2 和 NO_x, 低成本消耗以及减低固体废料的问题，这些技术旨在达到 1990 年清洁空气法修正案的要求。

在煤炭加工为清洁燃料这一领域的 5 个项目价值超过 5.19 亿美元，它们涉及广泛的技术用以将煤加工成更清洁，更有价值的燃料。

另一个方向的技术由工业应用项目来完成。总价值超过 13 亿的这五个项目涉及在工业和生产中煤的应用，如在炼铁高炉中以煤炭代替焦炭及在水泥窑中减少煤炭燃烧的排放物。

美国洁净煤技术中 IGCC 项目

IGCC 技术无论在项目数量及总的美元价值上都是最大的洁净煤技术之一。这是因为 IGCC 技术不仅在煤炭利用效率上有竞争力，它还表现出出色的环保成绩并显示出不久的将来它还会进一步提高效率并降低电力成本。五个 IGCC 项目是 Wabash River 煤气化老厂改造发电项目， Tampa 电力公司 IGCC 项目， Pinon Pine IGCC 电力项目，燃烧工程公司 IGCC 老厂改造发电项目及清洁能源示范项目。

Wabash River 煤气化老厂改造发电项目 – 在五个 IGCC 洁净煤项目中该项目是发展最完善的一个。 1995 年 11 月 30 日它开始正式投产，并将继续由能源部共同合作运行直到 1998 年。该项目于 1991 年获选，总耗资 4.38 亿美元，是 PSI 电力公司和 Destec 能源公司的合资企业。该项目老厂改造发电能力为

262MW, 位于印地安那州的 West Terre Haute, 是目前美国最大的单机煤气化联合循环电站。气化炉技术是 Destec 公司的二段式氧气气化的气流床水煤浆进料气化工艺，而联合循环系统使用的是 GE 公司的 7FA 以煤气作燃料的燃气轮机来使六个蒸汽轮机 / 发电机中的一个老厂改造发电。一个常温湿法煤气脱硫系统将 SO_2 的排放量减少 98% 以上，降低 NO_x 的排放量达 90%, 同时一个高温除尘过滤器除去尘粒。预计这一发电系统在应用高硫烟煤时的净热耗率大约为 2,150 kcal/kWh, 或 40% LHV 的发电效率。1996 年的运行结果显示电力产量及热耗率达到和超过了设计值。这项技术的商业建议是建立在一个 300MW 的单机机组上用于一个新电站，与传统的采用烟气湿法脱硫装置的粉煤电站相比，这种技术将使效率至少提高 20% 。

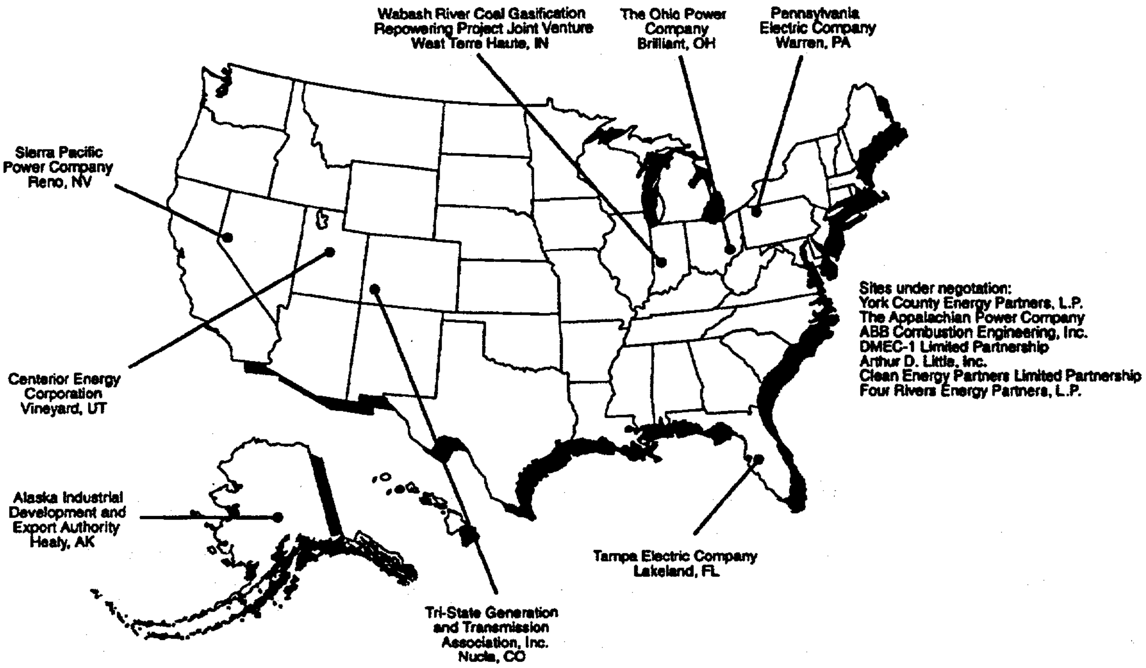

图 1　美国洁净煤项目地点

Tampa 电力公司整体煤气化联合循环项目 – 该工程位于佛罗里达州的 Lakeland 附近，目前近于完工，计划于 1996 年 9 月投产。该项目总价值为 5.5 亿美元，作为新建立的发电量为 1,150MW 的 Polk 电站的第一机组，它将产生 250MW 的电力。此项目使用 Texaco 公司的水煤浆进料氧气气化的气流床气化炉技术，并把传统的常温湿法煤气脱硫和新的高温煤气脱硫系统同时用于中

热值煤气。发电摸块域包括 GE 的 7FA 燃气轮机，蒸汽轮机和 Henry Vogt 的余热锅炉。煤中的硫和灰分的约 98% 将被控制并加工为副产品 - 硫酸及能在商业上销售的熔渣。这个项目的净热耗率预计约为 2,050 kcal/kWh, 或 42% 的 LHV 发电效率。这个联邦政府合资的项目将运行到 1998 年底，然后该电厂将投入商业运行。

Pinon Pine 整体煤气化联合循环项目 – 位于内华达州的 Reno, Sierra Pacific 电力公司，已经选择安装一套 IGCC 系统来实现发电量的预期增长，这是由于他们考虑到这项技术的灵活性，多样性和可靠性等优点。 Pinon Pine IGCC 电力项目在 1991 年获选，也将近完工，计划 1997 年 2 月投产。这项价值 3.09 亿美元的项目使用 KRW 的干粉进料空气气化流化床煤气化系统配以 GE 的 6FA 燃气轮机来生产预计的 99MW 电力。KRW 气化炉是在能源部研究与开发计划中发展的，它是最有效的气化炉之一，产生电力的净热耗率为 2,000 kcal/kWh, 或约 43% LHV 发电效率。煤气净化系统包括：通过注入碎石灰石在流化床内截获硫，用高温陶瓷过滤器除去尘粒，以及可再生的金属氧化物高温煤气脱硫系统。如在使用美国西部烟煤 (含硫 0.5–0.9%) 的项目中，该系统可将 NO_x 的排放量降低 94%, SO_2 排放量降低 90%, 同时几乎除去所有尘粒。与其它燃煤发电系统相比，完整的 KRW 气化系统设计减少了对用地的要求，流化床气化炉能气化各种煤种，以及生物质能及垃圾废料。电站唯一的固体废料是气化炉产生的灰及硫酸钙的混合物，这是一种无危险的废料，宜于填埋。

IGCC 状况 – 过去，现在和将来

煤及其它含炭物质的气化并不是一个新名词，实际上在含炭物质分解时，这一过程在一定条件下几千年来一直发生。二十世纪早期，人们开始煤气化尝试，通过最早的一种固定床装置向很多用户提供城市煤气，在三，四十年代德国人使用气化炉来降低全国的石油用量。早期的方法演化为各种固定床装置如加压 Lurgi 气化炉，而后是常压气流床 (Koppers Totzek) 气化炉及流化床 (Winkler) 气化炉，这些在五，六十年代在欧洲及南非广泛使用。

在 1973 年 10 月以后，由于政治上的矛盾和油价的上涨， IGCC 被建议作为燃煤电站的一种选择。那时候，联合循环电站的净效率开始超过传统蒸汽

电站的 38%LHV 的净效率。七十年代的传统蒸汽循环电站达到了技术极限。另外 1970 年清洁空气法修正案使发电效率进一步降低，如要求增加烟气脱硫 (FGD) 系统。

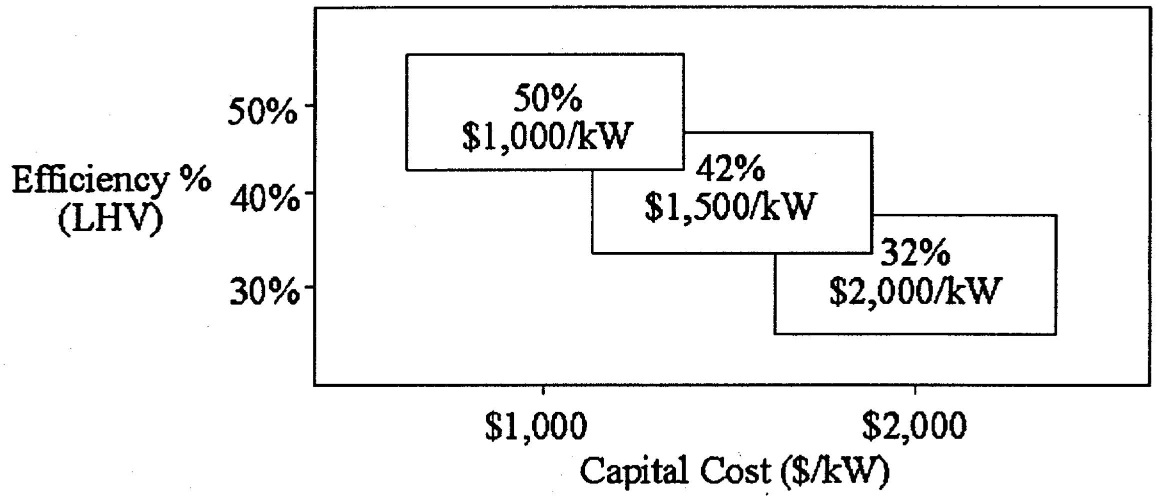

图 2 IGCC 的 LHV 效率 ~ 投资

燃气轮机是联合循环系统，也是 IGCC 系统的重要部分。所谓的工业燃气轮机是在飞机发动机的基础上发展起来的，第一台燃气轮机是 1949 年在美国使用的。在五十年代燃气轮机得到了迅速发展。在六十年代以前，燃气轮机技术的大部分应用都是以单循环装置满足用电高峰负荷，因为燃气轮机可迅速安装运行，不会影响工厂基本负荷的正常运行。在六十年代，燃气轮机技术效率更高而且运转灵活，可满足中间负荷及高峰负荷。

在七十年代石油禁运期间，当依赖进口外国石油成为美国面临的问题时，用天然气和燃料油的大型燃气轮机成功地以联合循环模式运转。在这一时期燃气轮机联合循环效率也得到了提高，到八十年代，总的联合循环的净效率达到 45%LHV, 比燃烧煤粉电站约高 10% 。

IGCC 发展的第一阶段的标志是冷水电站项目，它使用一个 Texaco 的气化炉，常温湿法煤气除尘和脱硫系统，加上 GE 公司的 7E 燃气轮机和蒸汽轮机的 IGCC 系统。冷水电站从 1984 年运行至 1989 年，规模为 100MW, 它显示出

IGCC 的生存力和极好的环保效果。这带动了几个煤气化系统的发展，几个不同的项目现在处于商业使用中。冷水工程中使用的 Texaco 气化炉，常温煤气洁净系统以及联合循环系统现在得到进一步改进，在 Tampa 电力公司的 IGCC 洁净煤项目中正在更大规模上得到示范。

当前，在九十年代，联合循环的净效率已近 55%LHV, 在满足基本负荷和高峰用电方面，燃气轮机联合循环技术已起到主导作用，它的成本低，可靠性高，保养要求低。通过现今进一步的发展和提高，先进的燃气轮机技术预计将使联合循环的净 LHV 效率达到 60% 以上。 IGCC 电站的效率约是使用于 IGCC 系统中的联合循环系统效率的 80% 。因此，今后 IGCC 系统的净效率可接近 50%LHV(图 2) 。

与传统的燃煤电站排放的污染物相比，目前商业运用中的 IGCC 显示出在高效下的特别环保效果。在降低 SO_2, NO_x 和粉尘的排放量方面，它获得了无以伦比的成功， SO_2 和 NO_x 的排放量是目前美国环保标准允许范围的十分之一弱。这种程度的环保效果目前已超过全世界市场的要求，在所有领域的趋势是今后会有更严格的环境限制，因此， IGCC 技术是对付未来不定因素的一个安全对策。

今天，成熟的 IGCC 技术的净效率超过 42%LHV 。作为比较传统的燃煤蒸汽电站从五十年前 27%LHV 的净效率提高到现在最好的 36%HHV, 而超临界燃煤蒸汽电站为了满足 1990 年清洁空气法修正案的要求，其净效率只能达到 38%HHV 。传统的煤粉电站和超临界电站受限于 Rankine(蒸汽) 循环的效率，而 IGCC 电站通过将 Rankine(蒸汽) 循环和 Brayton(燃气) 循环结合进一步提高了效率。

今天在使用 F 级燃气轮机技术的新电站中，已经论证的 IGCC 的单位投资为每 kW 1,400 美元到 1,600 美元。使用目前常温净化系统和 G 级燃气轮机技术的常规 IGCC 将产生 45% 的效率 (LHV), 投资比使用 F 级燃气轮机的情况要低 200 美元。使用 H 级燃气轮机技术的同样系统将产生 50% 的效率，与使用 F 级燃气轮机技术相比，每 kW 投资要低 400 美元。

比较先进的 IGCC 系统，包括目前的气化技术和正在发展和示范的 G 级燃气轮机将于 2000 年后商业化，它的目标是使净效率水平达到 45%LHV, 同时建厂成本将减少到每 kW 1,200 美元。这些先进的 IGCC 系统将有别于今天使用于商业的机组，它们可能会使用 800-1,200°F 的热煤气净化装置，和在 1,800°F 温度下运行的空气气化的气化炉。低投资和高效率将降低发电成本，同时保持非常好的环保效果。

进一步提高燃气轮机技术加上先进的气化炉装置将是IGCC 发展的标志，到 2010 年或之前，它的净系统效率将超过 50%LHV, 正确的实现时间要取决于天然气的价格及供应。DOE 的先进燃气轮机系统计划的创新内容将被用于煤气发电，从而效率会更高，到 2010 年投资可能会更低达到每 kW 1,050 美元。考虑到其它化石能源燃料，如天然气今后的涨价因素，未来的 IGCC 系统不仅比传统燃煤电站在成本上有优越性，而且在清洁环境方面还具有与天然气联合循环电站竞争的能力。

IGCC 对电力工业的益处

除了优越的环保效果，高效率，潜在的低投资以及低电力费用，IGCC 还有几个其它好处，它们对于电力公司有关机构在新发电能力方面的决策很重要。

在几个洁净煤项目中已可发现，IGCC 技术适用于老厂改造。在老电厂的蒸汽轮机和其它各种装置上加上一个气化炉和燃气轮机就可大大提高电厂效率，它不需要一个新电厂的投资费用。老厂改造发电可大大降低电厂的污物排放并把发电能力提高到 250% 。

很多气化炉具有燃料灵活性，即它们可以气化高质或低质煤以及很多其它的碳化物。IGCC 也可通过分阶段建设实现燃料灵活性。例如，第一阶段的安装可以只包括一台燃气轮机，通过燃烧天然气以适用于高峰负荷 (间歇使用) 。加上一个蒸汽轮机就建立了一个联合循环系统，这将在需要时提高电厂的产量及效率。第三步的安装是将气化炉和煤气净化系统结合进去，条件是煤价低，或缺乏天然气，或需要将电厂转向基本负荷 (连续使用) 时采用。将

煤气化系统做成模块装置，并分成几步来实施，这样就可使它们理想地应用于实际。

IGCC 的其它环保优势包括节水和低二氧化碳 (CO_2) 排放。IGCC 电站运行所需的水量只有使用完全烟气脱硫系统粉煤电站用水量的 50-70%。更高的效率带来单位发电用煤量的减少，这样 IGCC 系统可大大降低 CO_2 排放量。

成熟的 IGCC 也具有高产量的优点，通过单机组生产更多的电力。循环流化床燃烧系统因在大气压下运行，单机组发电低于 100MW, 而 IGCC 系统现在单机组发电能力达 300MW。尽管加压流化床燃烧系统通过在高压下运行克服了这种限制，今天尚未能在商业上使用。到 2000 年后可预计 CFBC 的单机组发电可在 250-300MW 之间，然而，IGCC 系统单机组发电应能在 450-550MW 之间。

目前可以使用的 IGCC 在可靠性，可用性和维护性方面都有进一步的提高，这使它们在基本负荷发电方面具有吸引力。当今，煤粉电站的可用率为 60-80%, 而 IGCC 电站的可用率则高于 90%。

另一个优点即在几种洁净煤的产品中由于产生了可销售的副产品，废料排放被降到最低限度。灰和微量元素在 IGCC 系统里溶化，当冷却时，它们形成于环保安全的似玻璃的熔渣，可用于建筑 (如造路和制砖) 和水泥工业。煤中的硫可被煤气净化工艺截获并转化为可销售的元素硫或硫酸。由于煤气净化系统是通过可再生用的吸收剂除去煤气中的硫，废料排放就被减到最少。相反，传统燃煤电站的烟气脱硫所使用的硫吸收剂需要进行大量的固体废料处理。

IGCC 将不只是一个发电系统，其煤气化工艺还可同时生产下列产品，如甲烷或液态燃料，化肥，钢铁加热，及化学产品。在 IGCC 系统中存在着大量的可使用的低位热，可用于需要蒸汽的生产工艺，如造纸厂或地区供热。

2. IGCC 在中国的近期和远期市场潜力

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前言

全球发电市场不断地引进用燃油和燃气发电的燃气轮机 / 联合循环 (GT/CC) 技术。这主要是由于燃气轮机技术已达到越来越高的功率密度，具有很高的效率和可靠性。目前 GT/CC 的技术水平也可以通过使用清洁煤技术用煤，重油，石油焦炭等燃料和废料来降低发电成本并达到环保效果。

在不同的发展过程阶段对应地有四种不同的技术，这包括熔渣燃烧器，压力流化床燃烧 (PFBC), 外燃联合循环 (EFCC) 和整体煤气化联合循环 (IGCC) 。目前，唯一可以作为商业使用的技术就是 IGCC 。

广泛的研究和发展一直集中于把迅速发展的联合循环发电技术和使用低价燃料的气化技术结合起来。IGCC 技术通过试点企业和示范设备已经得到证明。在八十年代，它在技术和环保上的特性及对发电站的适用性就已得到展示。然而在 1990 年新一代燃气轮机技术投入商业使用之前经济性令人失望。当一些 IGCC 项目在九十年代中期投入商业使用后，其中某些仍然得到美国洁净煤技术 (CCT) 计划的支持，目前正处于示范商业上的经济实用性分界线上。有十个以上的工程正处于不同的建设阶段中，它们将在 1996 到 2000 年之间开始投入商业使用。

下面主要讨论一下 IGCC 技术进入中国的电力系统的潜力。目前的 GT/CC 技术将用于近期内，包括全面的 IGCC 示范设施。远期的应用将以下一代 GT/CC 技术为基础，这种技术可能会在 2000 年左右应用于商业运行中。这里所用的电力系统数据来自中国电力工业部信息研究所编辑， 1994 年出版的“电力工业在中国， 1994” 。

发电市场情况

从世界范围看，重油和煤的电站市场很大，预计在今后十年内需求量约为 350GW 。这一市场的特性因地区和国家而异。这些差异一般由以下因素造成：地区或国家的成本特点，人口分配，环保标准及特性，燃料的成本及可用性，以及水力和其它再生能源的可用性。特别是在对环保有较强关注的地方，即使目前的 IGCC 技术也具有与其它发电技术竞争的优势。

即使在环境敏感地区，效率和建厂成本是决定使用 IGCC 的最重要因素，因为它们是确定发电成本的要素。

目前水平的 GT/CC 技术在以下领域具有竞争力：环境要求高而又需使用劣质燃料的地方以及可利用 IGCC 的优势来同时生产除蒸汽和电力以外的化学产品，如氢和甲烷。

下一步的 GT/CC 技术将使 IGCC 电站具有经济上的特点，如建厂成本及效率在市场多方面都优于传统的燃煤电站。下面的表 1 显示的是当前和下一代 GT/CC 术的电站规模，效率以及预计的建厂成本水平。

表 1　IGCC 技术的参考数据

GT/CC 技术	功率 MW	建厂投资 $/kW	效率 % (LHV)
当前的	120-390	1400-900	40-46
下一代	460-550	1000-800	49-51

世界上一些地区和国家目前的建厂和燃料成本可能与上述的基本结论不符。大型电站的建厂成本，如传统蒸汽电站和 IGCC 电站受到下列因素影响：当地劳动力，可由当地生产的部件和机组价格以及建设费用。譬如在中国，全部使用国产机器的燃煤蒸汽轮机电站的建厂成本水平一直低于国际上同类电站的平均成本。烟气洁净脱硫装置还未在中国广泛使用，这也是建厂成本相对较低的一个原因。这使得 IGCC 技术在近期内将以较慢速度进入中国

市场。在中国， IGCC 和传统蒸汽电站建厂成本间的关系还受到这样一个因素的影响，即目前缺乏主要的国内燃气轮机生产能力。如果中国今后进一步使用降低空气污染的设施，同时提高国内燃气轮机的生产水平，那么总体成本之间差距会缩小。经过一段时间，有关的电站之间的成本关系就会接近典型的国际平均水平，这将使 IGCC 技术能更有利地与传统燃煤蒸汽电站竞争。

在中国增加发电能力的选择

中国的装机发电能力在 1993 年大约为 183GW 。热力发电约占总量的 75%，水力发电占 25% 。大部分热力发电都由燃煤蒸汽电站来完成。为了能在 2000 年左右使发电能力达到 300GW，预计每年需增加超过 15GW 的发电量。总体目标是保持热力和水力发电 75%/25% 的比例。核电将继续增加，但新增热力发电的绝大部分将是燃煤发电。

据此，无论从近期还是远期来看，每年中国的电力系统燃煤功率增加都要在 10GW 以上。IGCC 技术加入中国电力系统将自 2000 年左右开始。首先，目前的 GT/CC 技术应被采用，但当下一代 GT/CC 技术在天然气方面积累了运行经验且 CC 产量的提高带来的经济效益得到证明后，从本世纪末起，使用这种 GT/CC 技术的 IGCC 电站将会经历一个平稳的过渡。用于试验和肯定下一代 GT/CC 技术中煤气良好的燃烧性能的技术规划已经到位，并将在这种技术用于 IGCC 电站之前得以完成。

IGCC 技术的长期进入市场在很大程度上要取决于发电的经济状况。在下一代 GT/CC 技术引进之后， IGCC 电站的成本将与传统的使用烟气脱硫装置 (FGD) 设备的燃煤蒸汽电站相同或更低。IGCC 的效率 (LHV) 将达到 50% 左右，而燃煤蒸汽电站效率约为 38%，且由于效率的差别， IGCC 的用煤量也要低于后者 80% 。这两代电站的运行及维护费用将大致相同。这些经济效益使 IGCC 在任何时候都具有优势。

除了经济状况外，电站的重要特性是可靠性和运行上的特性。在一个适当的示范规划实行之前，这些特性通常不能被完全接受。对中国而言，尽可能及早安装运行一套完整的 IGCC 示范设备是必要的。并且中国应尽可能地

多了解目前商业运行的IGCC电站以缩短时间来了解和熟悉IGCC技术运行情况。有利的是，目前的IGCC设备使用的是几种不同的气化炉技术和不同的燃料，因此仔细观察这些设施的状况会使中国从第一套IGCC设备中尽可能学到更多的经验。在中国的第一个IGCC项目将成为其它对IGCC技术感兴趣的国家学习过程中的重要一步。中国最初的IGCC设备的成功需得到认可，然后才能够进行以IGCC技术为基础的大规模增加发电计划。

另一个重要问题是电力企业对IGCC技术能接受的程度。这不仅对中国是这样，对其它很多国家也是如此。一个用惯了蒸汽锅炉技术的电站运行人员不会自动接受把气化炉作为他的电站运行的一部分。通过全面的示范过程教育和讲解IGCC的运行及维护，是中国区域性电网接受IGCC技术的重要一步。

在IGCC技术不断被接受的同时，有必要将国内生产能力转向生产适用于联合循环的燃气轮机，余热锅炉及蒸汽轮机。如前面所讲，这个转化过程是影响IGCC技术进入中国的另一因素。最初， IGCC电站的进口设备占相对较高比例是可以接受的，但是，要使IGCC以最好的方式进入中国电力系统，电站设备的主要部分则需由国内生产。

近期和远期IGCC在中国推广的预计

在前面的讨论中曾提到过，如经济状况是唯一决定IGCC推广的因素，那麽在下世纪初的头几年内，这种IGCC推广将100%用于新增加的燃煤基本负荷电站。实际上，在2010年之前， IGCC在每年的发电增加部分中所占比例不太可能超过25%。随着GT/CC技术不断提高效率并降低建厂成本，（与传统燃煤蒸汽电站相比），从2010年到2020年， IGCC在新增加的燃煤基本负荷电站中会占高于50%的比例。但是由于现在对2020年的任何估计都不太可能完全正确，上述讨论应被看作从我们目前知道和理解的角度看到的一种可能图景。

发电经济状况举例

下面举一简单例子说明有关发电经济状况。由于建厂成本和燃料成本因国家和地区而异，下面的计算仅作示范。建厂成本和燃料成本作了可以更改的处理，读者可以用自己的成本数据得到有关传统的燃煤蒸汽电站和使用 IGCC 技术的电站两者之间相对的经济比较。假定 FGD 系统的影响被列入传统燃煤蒸汽电站的建厂成本和效率评估中，那么环境效益就不另算了。两种电站的运行和维护费用假定相等，这是由于保守评估把潜在的销售元素硫和对环保无害的熔渣的收入列入净运行和维护费用中。

本例中所列的经济指标如表 2 所示。为了便于对比，假定传统燃煤蒸汽电站的建厂成本为 $1,000/kW 。与之相比的两个 IGCC 技术的建厂成本为可变成本。每个电站的效率是以热耗率 (kcal/kWh) 来显示。假定燃煤蒸汽电站的净效率为 38%(LHV), 用 F 级技术的 IGCC 电站为 42.7%(LHV), 使用 H 级技术的电站为 50%(LHV) 。假定它们的其它成本都相同。

因为在这些计算里的建厂成本是唯一的可变成本，结果显示的 IGCC 允许的建厂成本与传统燃煤蒸汽电站的比较是以 25 年为周期，建立在平均发电成本上的。数据是以每年运行 5,000 到 8,000 小时来计算的。计算结果见图 1 。

表 2　经济指标参考数据

发电形式	建厂投资 $/kW	热　耗 LHV kcal/kWh	燃料费 LHV $/Gcal	运行与维护的固定费用 $/kW/yr.	运行与维护的可变费用 mills/kWh
燃煤蒸汽轮机电站	1,000	2,250	6.00	10.00	4.00
IGCC(F 系列燃气轮机)	可变	2,000	6.00	10.00	4.00
IGCC(H 系列燃气轮机)	可变	1,700	6.00	10.00	4.00

所有费用计算中的通货膨胀率 =4%/ 年

利率 =12%/ 年

参考周期 =25 年

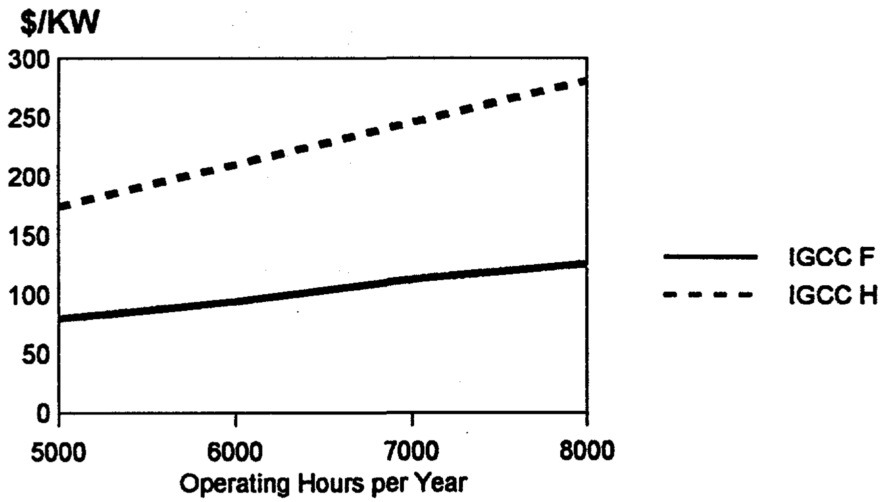

图 1　对 IGCC 容许的补贴费

举例说，假定一个使用目前的 GT/CC 技术的 IGCC 电站每年运行 7,000 小时， IGCC 的相当建厂成本是 $1,110/kW, 可比燃煤蒸汽电站高出 $110/kW 。而使用下一代 GT/CC 技术的 IGCC, 其相当建厂成本将为 $1,243/kW, 可高于燃煤蒸汽电站 $243/kW 。这些建厂成本的差别只是由于 IGCC 电站的效率提高了。

结论

总体来说， IGCC 技术有足够的经济及环保方面的理由来积极参与中国的区域电力系统。 IGCC 推广的程度由很多因素决定，但一个可能的推广图景是到 2010 年约 25% 的新燃煤电站将是 IGCC 电站，在那之后，这一比例还可能升高。

除了可能获得的经济利益以外，更重要的是明显的环保利益。 SO_2, CO_2, NO_x 以及粉尘排放将会得到更有效的控制，并且燃煤量也会较大减少，从而减少了对煤炭运输的需求。

3. IGCC 在中国：市场定义及需求基础

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前言

发展日程

IGCC 在中国的市场潜力取决于中国控制电站污染物排放和提高发电效率这两个目标。这两个目标对中国都很重要。由于中国希望尽可能缩小其在全球排放预算中的份额，因此需降低排放量。提高燃料转化效率是为了把浪费减至最少，这对于他们规划基础设施越来越重要。

这些目标影响着中国电力工业的以下领域：

1. 新电站建设－新建电站需要更多地考虑运用更有效的技术来控制污染排放 –IGCC 将逐渐成为这方面的主要选择，特别对于一些大型电站，如果它们所处的地方易于使用成分合适的煤。

2. 改造 / 更新发电与污染排放标准无关的电站 –IGCC 不太可能在这方面发挥作用。

3. 关闭大体上与污染排放标准无关的电站－这涉及电站中的小发电机组(低于 100MW), 它们无法被改造或更新发电，也不能改造为其它热－电循环。不再使用这些设备是为了适应燃料利用效率和环保方面的要求。这些做法会影响到中国电网对发电能力的要求，也会随之建一些新电站， IGCC 也许会或不会在其中发挥作用。

4. 根据上述情况，IGCC 在中国的市场潜力 (定义为在电站中实际运行的 IGCC 机组) 可被看作是长期的，而不是短期的发展。

电力集团和煤炭质量

中国的电网可以分为下列电力集团、省级电力公司和自治区电力公司：

1) 华北电力集团	6) 山东省电力公司	11) 四川省电力公司
2) 华中电力集团	7) 福建省电力公司	12) 云南省电力公司
3) 华东电力集团	8) 广东省电力公司	13) 海南省电力公司
4) 东北电力集团	9) 广西自治区电力公司	14) 新疆自治区电力公司
5) 西北电力集团	10) 贵州省电力公司	15) 西藏自治区电力公司

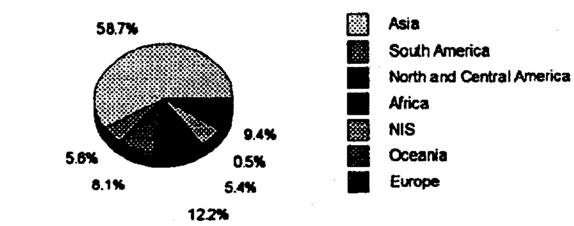
山西煤田的煤矿 (如山西省大同), 四川煤田，以及在华东电力集团 (如淮北), 在山东省，在华北电力集团 (如开滦) 及在东北电力集团 (如阜新，抚顺，鸡西和鹤岗) 的煤矿生产中国大部分的高质煤。IGCC 的市场准备在这些地区开始发展。

与此相关，若想了解 IGCC 在中国的市场潜力，就要分析一下亚洲的能源情况，中国在这一地区的作用以及在中国进行的能源转化技术对世界范围的影响。

中国能源需求的增长与亚洲及世界的关系

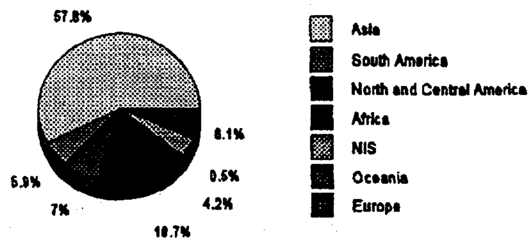
人口增长

亚洲地区 (经济合作与发展组织 (OECD) 及非 OECD 亚洲国家和地区) 人口在 1990 年占世界总人口的 58.7% 。预计到 2025 年该地区人口将占世界的 57.8% 。图 1 和图 2 表示 1990 年和预计 2025 年世界人口的分布情况。



Reference: World Resources, WRI, 1990

图 1 1990 年世界人口分布



Reference: World Resources, WRI, 1990

图 2 2025 年世界人口预计分布

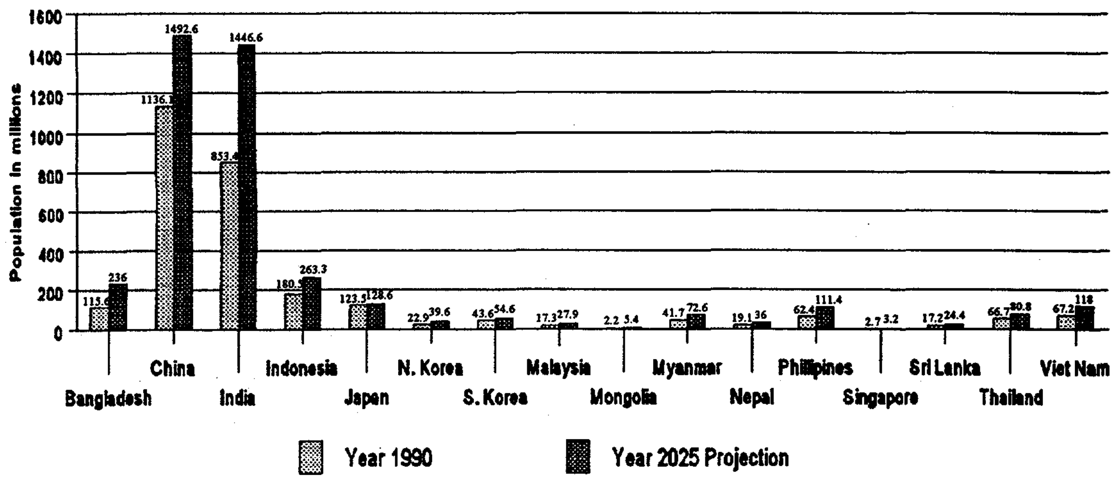
据估计，1990 年至 2010 年期间，世界人口将增加 20 亿以上。图 3 代表的是 16 个亚洲国家的人口分布。中国和印度是图中人口最多的国家。预计到 2025 年，中国和印度的人口将分别增加 23.9% 和 40.9% 。对于增长的人口而言，提高能源的可用性和消费会全面提高人们的生活水平，随着环保和能源效率的提高，也会产生相应的影响。

亚洲的能源消费

世界能源消费根据能源来源和使用方式而一直在发展和变化。世界能源消费预计将从 1990 年的 346 quadrillion Btu 增加到 2010 年的 472 quadrillion Btu 。一些地区的增长比其它地区快，平均来讲，这表明在世界范围内每年的增长率将超过 1.6% 。

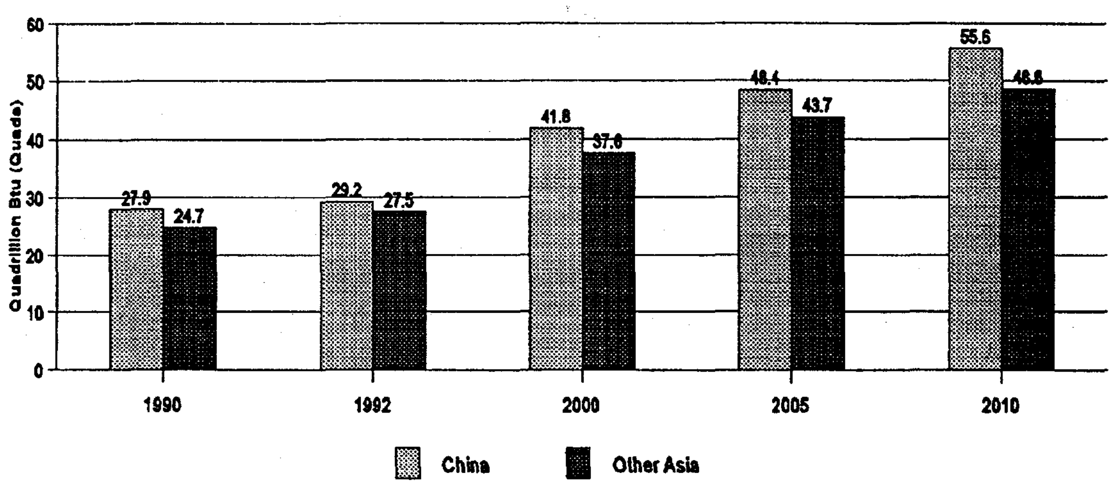
国家的能源消费

亚洲国家由于经济的快速增长将成为能源的最大用户。在这一地区的大国中，中国和印度作为最大的两个国家都采取了鼓励经济发展的积极政策并且到 2010 年也会一直实行这样的政策。据此，图 4 表明中国的能源消费到 2010 年将达到 55.6 quadrillion Btu 。



Reference: World Resources, WRI, 1990

图 3　某些亚洲国家人口分布



Asia (Non-OECD) Includes Countries with 53% of World Population
Reference: International Energy Outlook 1995, U.S. DOE

图 4 1990–2010 年非 OECD 亚洲国家和地区预计的能源消费总量

非 OECD 地区的能源消费预计在 1990-2025 年期间年增长率为 1.8% 。自从 1970 年以来，非 OECD 的能源消费比 OECD 增长得快。因此，到 2010 年，非 OECD 将占世界能源总消费的约 50% 。

在亚洲地区，工业和民用所用能源仍占能源消费的主体。图 5 显示的是在 1990 年的工业能源消费中，中国和印度处于领先地位，分别达 3.54 和 0.676 亿 TOE 。在 1990 年，中国，韩国，印度和印度尼西亚成为最大的民用 / 商业能源消费者。

交通方面的能源消耗将有显著增长，虽然目前它的发展相对落后。在民用方面，当这些国家使用更先进的加热和炊事用具时，非商品燃料如植物及动物粪便会被常规燃料如丙烷及其它燃料所代替，这种能源使用的转换将使民用能源消费进一步增长。中国和这个地区的其它几个国家的经济还会继续快速发展，随之而来的是能源消费的迅速增长。

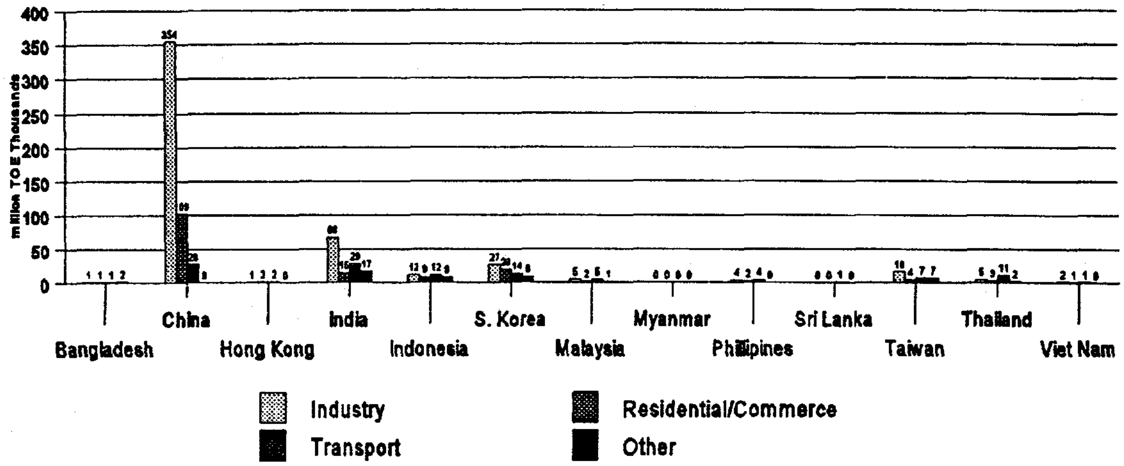
燃料的能源消费

从 1970 年到 1990 年，世界的能源消费增长了近 140 quadrillion Btu, 年均增长率为 2.6% 。在这期间，石油在能源供给中占最大份额，但它在整个能源中的比例已在下降。在化石燃料中，天然气使用增长最快。非化石燃料的使用增长显著，从 1970–1990 年，其所占比重由 6% 提高到 13% 。

如图 6 所示，在非 OECD 的亚洲国家和地区中，煤炭和石油在能源供给中的比例是最大的。到 2010 年，这一地区总的煤炭消耗量预计达 52.8 quadrillion Btu, 石油消耗将达 34.6 quadrillion Btu 。 2010 年的预计数字几乎是 1990 年能源消耗的两倍。

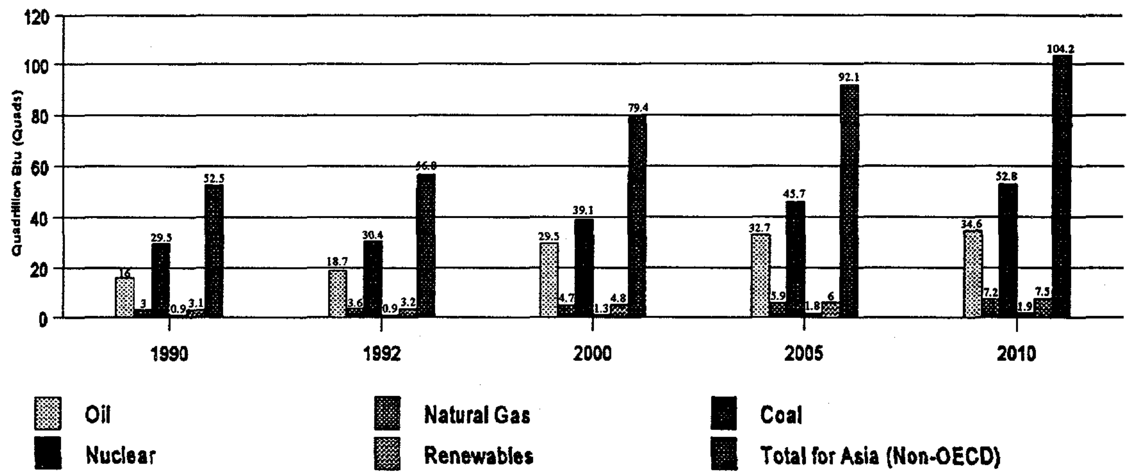
煤炭 – 如图 7 所示，从一次能源消费看，煤炭一直是世界上的主要能源之一。从 1990–2010 年，亚洲的用煤量将有大幅度增长。中国用煤量的增长将占整个增长量的四分之三以上。到 2010 年，全世界的用煤量可高达 7,379Mt 。

图 8 显示的是一些亚洲国家和地区自产能源和能源进口的分布情况。在这一地区中，突出的经济发展将使这些国家和地区大量进口煤炭。



Reference: World Resource, WRI, 1990

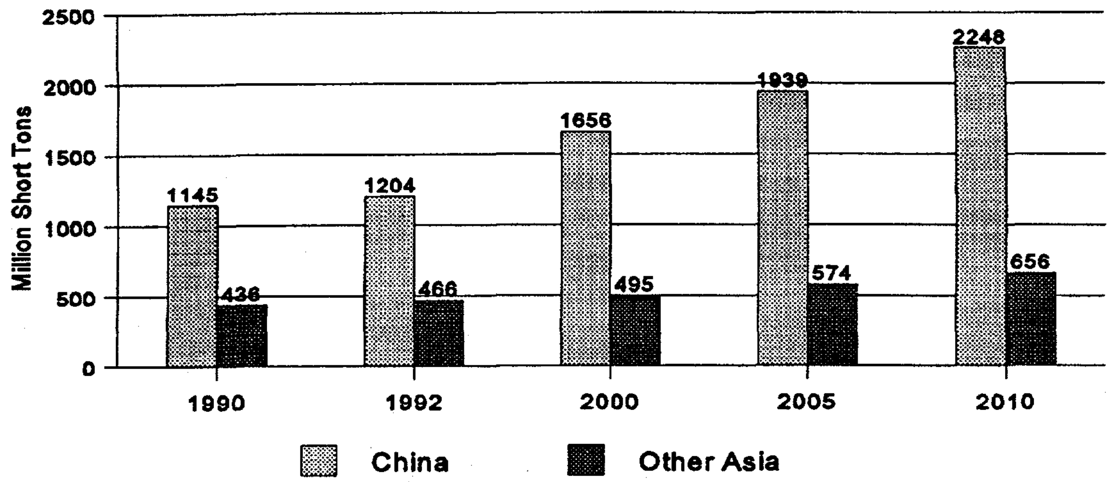
图 5 1990 年亚洲地区各终端能源的消费量



Asia (Non-OECD) Includes Countries with 53% of World Population
Reference: International Energy Outlook 1995, U.S. DOE

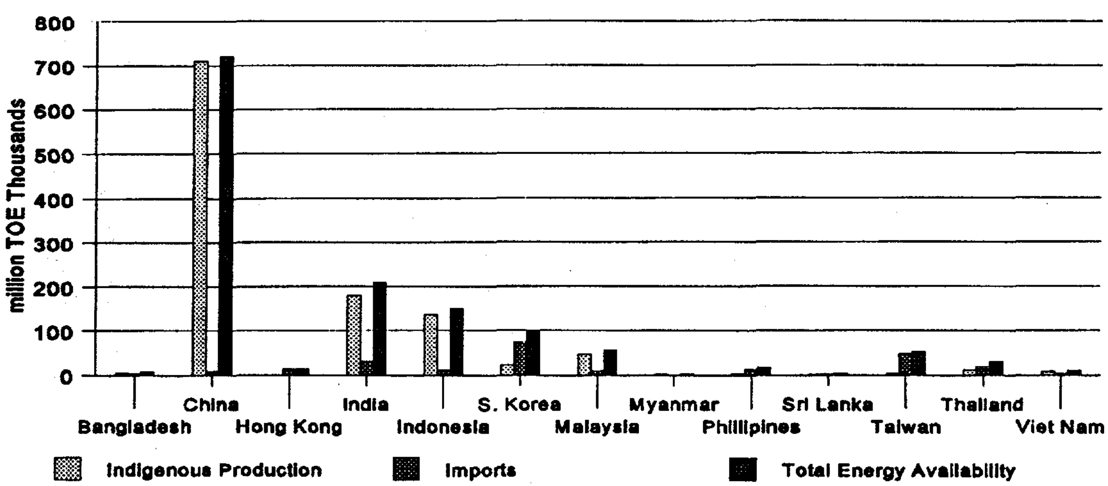
图 6 1990–2010 年非 OECD 亚洲国家和地区预计的

由燃料供应的能源消费总量



Asia (Non-OECD) Includes Countries with 53% of World Population
Reference: International Energy Outlook 1995, U.S. DOE

图 7 1990-2010 年非 OECD 亚洲国家和地区预计的煤消费总量



Reference: ADB, 1992

图 8 1990 年亚洲地区可利用的 (包括自产和进口的) 能源

中国在这一地区的增长中占 80% 以上。印度和中国都准备在今后大规模建设新电站。

中国可能在一些地区使用进口煤，因为与自己开矿并把煤运输到新电站相比，这样做更经济一些。作为亚洲的煤出口国，印度尼西亚和中国在出口

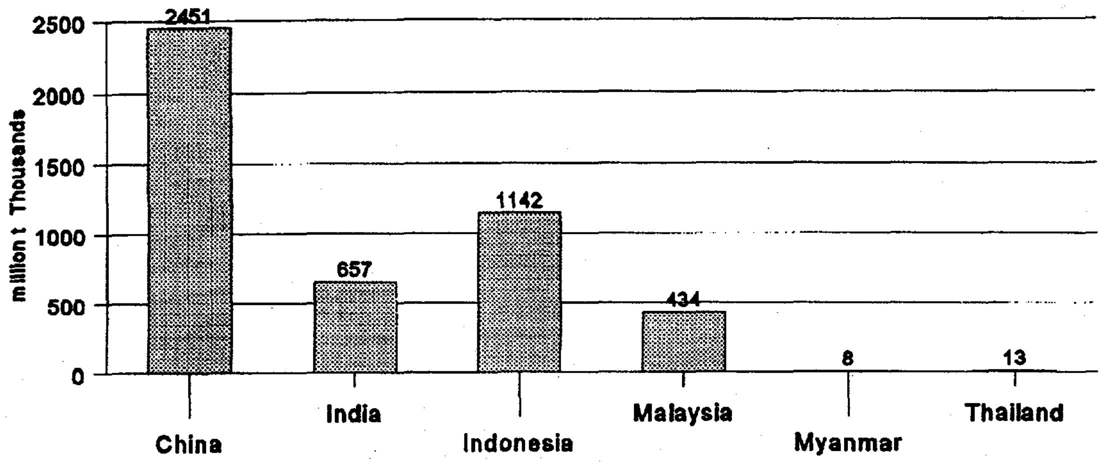
市场方面正在取得显著的进展，它们已从亚洲市场不断扩大的煤炭消耗计划中获益。

由于这个地区快速的经济发展，煤炭用量在非 OECD 亚洲国家和地区中将以最快速度增长，预计到 2010 年，将占世界用煤量的 44%, 而 1990 年它只占 31% 。从 1990 年到 2010 年，亚洲地区的用煤量预计将增长 84%, 即从 1,581Mt 提高到 2,904Mt 。中国的煤炭用量预计将增加 1,103Mt, 几乎是目前国内煤耗的两倍。如果中国的燃料使用政策不变，那麽到 2010 年，煤炭还将继续占所有能源消费的近四分之三。在整个亚洲，煤炭进口在未来二十年内将进一步增长，预计将从 1990 年的 184Mt 增加到 2010 年的 385Mt 。

石油 –1991 年世界石油资源情况如下表所示：

地　　点	10^9 桶
波斯湾	483–620
北美 (包括墨西哥)	139–281
俄罗斯和东欧	130–274
远东 (包括中国)	81–198
南美和中美	75-136
西欧	45–78
澳大利亚和新西兰	4–13

预计从 1990-2010 年，非 OECD 亚洲国家和地区的石油用量将以每年平均 3.9% 的速度增长。中国的石油用量预计每年增长 2.8%, 即从每天使用 230 万桶增加到 400 万桶。图 9 详细统计了亚洲原油的可开采的储量。



Source: World Resources, WRI, 1990-91

图 9 1987 年某些亚洲国家可开采的原油储量

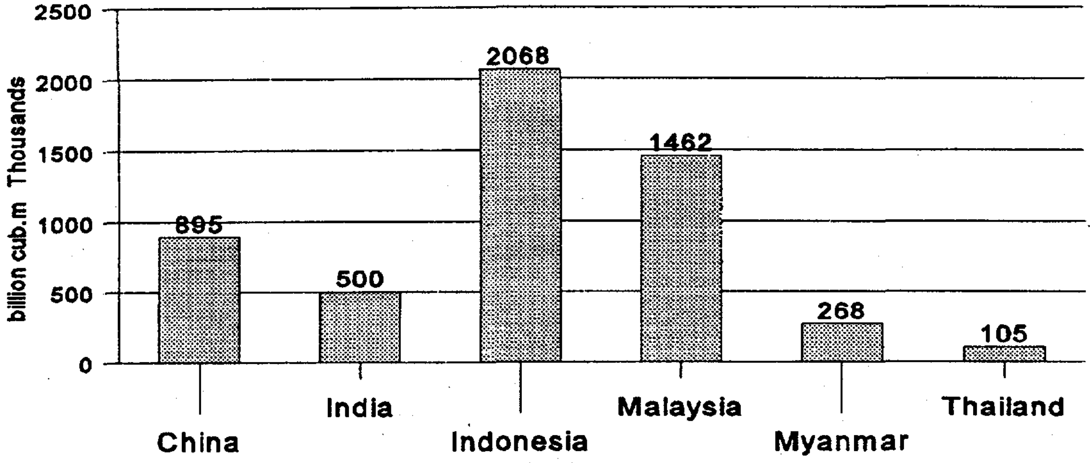
世界上储量丰富的煤炭资源已较为人知 - 尽管定期出现对新的可开采的煤炭资源的重新估计 - 石油和天然气开采工业一直积极地寻找重要的新发现。在八十年代，除了个别情况外，在一些新的地区主要的发现不多，在那些地方的石油储备看似前景广阔但未得到证明。到了九十年代，石油开采工业似乎开始转移方向，集中力量在那些已经发现石油的地方提高产量。在大范围亚洲地区，注意力集中于俄罗斯，哈萨克斯坦，印度支那地区，中国 (陆上) 和其它地方。

交通业，化学及其它工业，某些使用柴油型燃料的发电及制热 / 制冷装置在可预见的将来还会继续依靠石油。亚洲这类用户对石油的需求，尤其是交通业，将继续增长。这种需求加上当地石油加工基础设施所面临的不足将限制使用石油作为发电燃料。

天然气 - 世界能源工业最近的一些情况很可能对天然气的未来以及它在发电方面的更多使用产生重要影响。烧天然气发电在效率方面具有技术长处，烧天然气对环境又有好处，这些对目前主要依靠煤炭的中国和其它亚洲国家具有吸引力。

图 10 显示的是已知的亚洲可开采的天然气资源的详细统计。在这个地

区，天然气作为工业的燃料和原料，其地位越来越重要。



Source: World Resources, WRI, 1990-91

图 10 1987 年某些亚洲国家可开采的天然气储量

发达国家，如日本，一直从亚洲当地和波斯湾进口天然气用于发电及工业领域。这是根据长期协议合同进行的。不太发达的国家正计划加快一些工业，如塑料生产及其它方面的发展，这些工业需用天然气作原料，同时这些国家也要使用天然气来发电以尽快满足电力不足。

将天然气通过管道或液化后运输需要投资，所以就要求天然气产地和工业大用户之间订立长期的协议或者两者之间距离要近。除了某些重要的例外情况，如要靠建设一条横穿东南亚的输气管线(从马来西亚，印度尼西亚和文莱的油田供气)，或者从中亚，西伯利亚甚至北美洲供气的更远期的输气管线计划，亚洲的重要地区不可能立刻用到天然气。

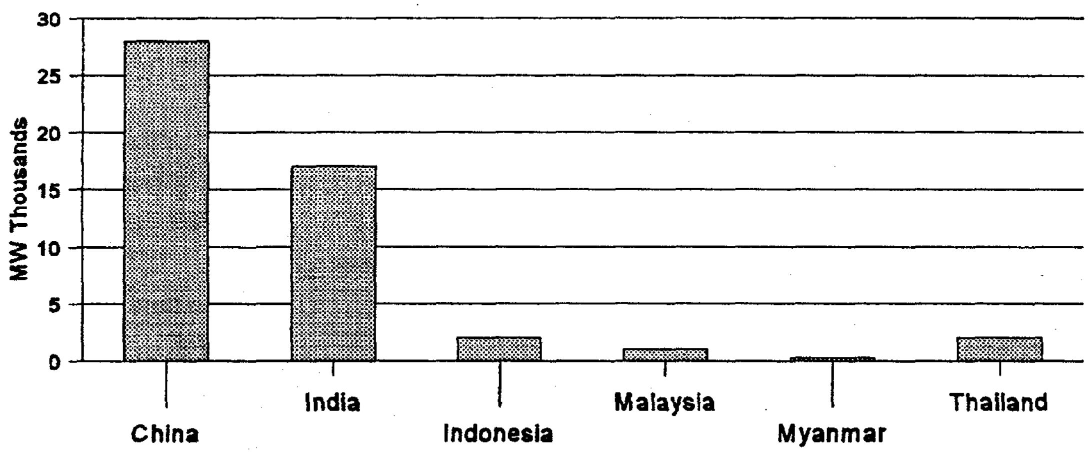
世界上大部分液化天然气 (LNG) 贸易集中在亚太环地区，占全部 LNG 贸易的约四分之三。印度尼西亚，马来西亚和澳大利亚是主要的出口国，而日本，韩国和台湾是主要用户。这六个国家和地区极有可能继续成为 LNG 贸易的主体。虽然缅甸和泰国的生产水平无法与上述国家相比，但它们有潜力在天然气生产方面取得重要发展。中国有相当的天然气储量，由于它的洁净燃烧性质，它对使用煤炭的地方是一个有吸引力的选择。中国也在积极努力在

煤田开采矿井气，这会带来大量的天然气补充资源。

核能－中国，韩国，台湾，印度以及亚洲其它几个国家和地区目前都在运行核电站并有扩大核能的主要规划。除韩国外，与它们自己的能源需求相比，这些规划都是小型的，但今后会有增长。到 2010 年，菲律宾和朝鲜也将有它们的规划。到 2010 年，该地区的核电能力将达到 27.7 至 35.7GW 之间。

可再生资源－亚洲在水能及其它可再生资源的利用方面也将有快速的增长。在非 OECD 的亚洲国家和地区，这些能源的使用量在 1990-2010 年间预计将增加两倍以上，从 3 quadrillion Btu 增加到 8 quadrillion Btu 。这个地区的很多国家都具备相当多的水电资源。到 2010 年，中国使用可再生资源的数量预计将是 1990 年水平的三倍以上。可再生能源用量的增长主要来自水电。

显然亚洲具有重要的水电潜力，但在规划它的发展时，需要认真研究。中国水电发展潜力很大，据统计，超过 350GW 。图 11 为亚洲水电装机容量的统计。



Source: World Resources, WRI, 1990-91

图 11 1987 年某些亚洲国家水电装机容量

除水电外，风力和太阳能也将在能源供给方面发挥重要作用，特别对于那些分散的地区和用户，它们在这一地区能源需求中占重要的份额。在这个

地区很多国家中风力发电尤具潜力。

能源生产及发电燃料

图 12 表明 1990 年作为一次能源供给来源的不同燃料的分配情况。中国和印度以煤炭作为它们主要的能源供给燃料，并处于亚洲国家的前列，用量分别达 5.15 和 1.01 亿 TOE 。韩国，印度尼西亚和台湾用石油作为主要能源供给来源。

1987 年一些亚洲地区发电种类及电力生产情况见图 13 。

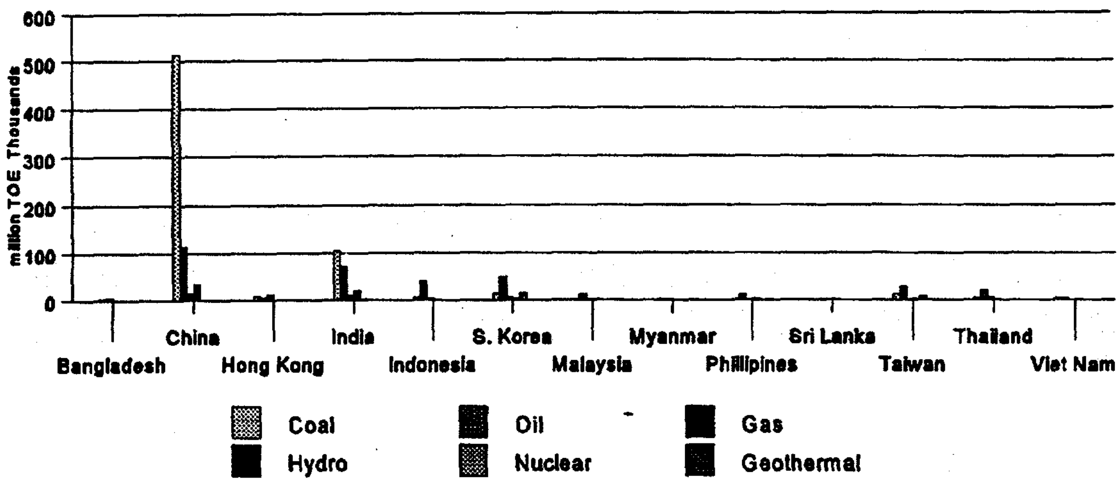
二氧化碳排放量

几乎一半的 CO_2 排放量来自煤炭。在 1990 年，全世界用煤产生的 CO_2 排放量达到 2,343Mt 。到 2010 年，预计非 OECD 的用煤 CO_2 排放总量约为 1,352Mt 。

图 14 和图 15 为亚洲 CO_2 排放总量和用煤产生的 CO_2 排放量。据估计，1990 年中国的 CO_2 排放量为 1,145Mt 。CO_2 排放量到 2010 年预计将达 2,248Mt 。然而，即使中国使用象 IGCC 这样可改善排放量控制并提高燃料效率的发电工艺，全世界排放量的改善也需很长时间。

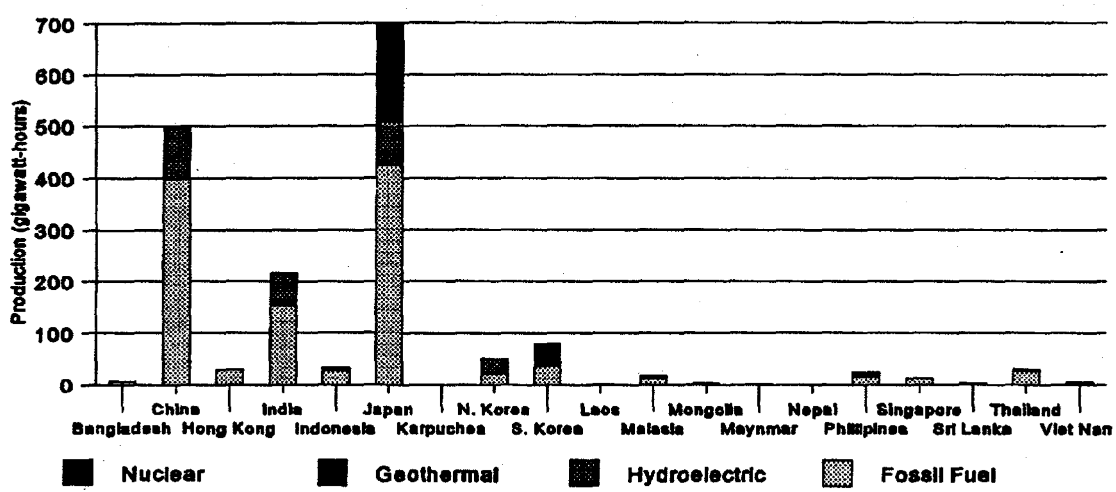
IGCC 在中国的市场潜力的总结

显然， IGCC 在中国的市场潜力在长期范围内 (15-20 年) 是相当可观的，但是，这些潜力的实现将依靠项目资金的到位。中国与美国已经采取一些重要步骤，共同努力来把 IGCC 计划引进中国的电力系统。然而，由于项目资金的要求，有必要让多边金融机构如亚洲发展银行和世界银行加入这种讨论和计划过程。



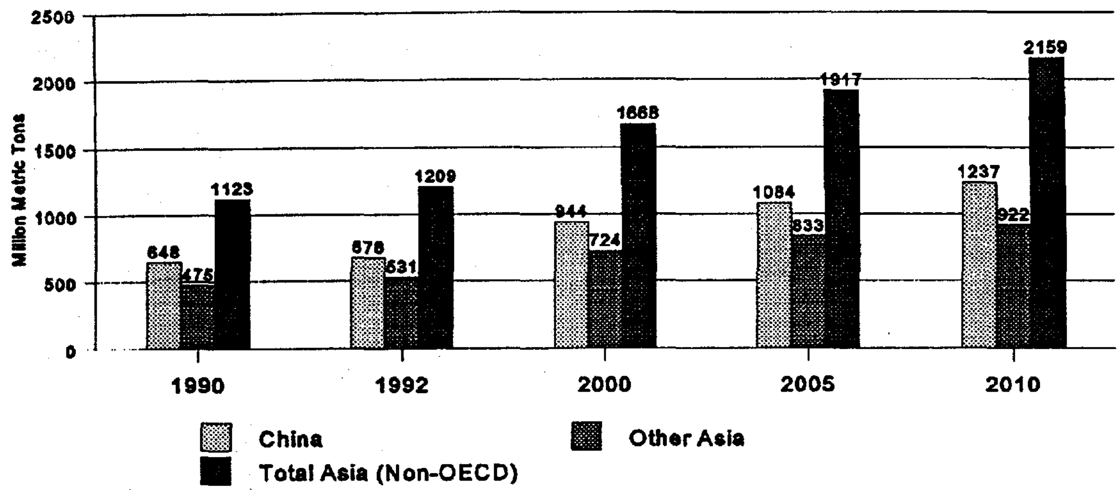
Reference: ADB, 1992

图 12 1990 年亚洲地区一次性能源供应的分配情况



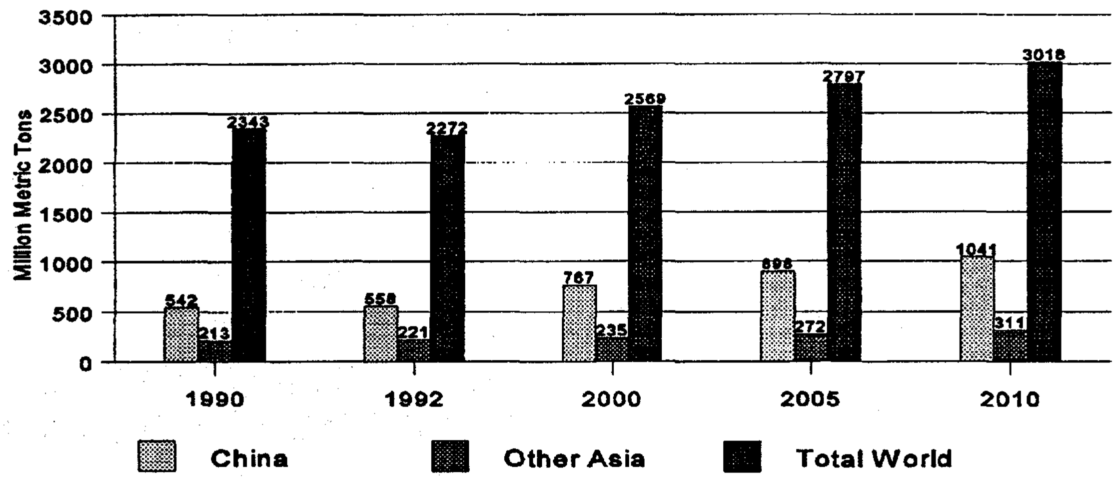
Reference: World Resources, WRI, 1990

图 13 1987 年某些亚洲地区的电力生产情况



Asia (Non-OECD) Includes Countries with 53% of World Population
Reference: International Energy Outlook 1995, U.S. DOE

图 14 1990–2010 年非 OECD 亚洲国家和地区预计的 CO_2 排放总量



Asia (Non-OECD) Includes Countries with 53% of World Population
Reference: International Energy Outlook 1995, U.S. DOE

图 15 1990–2010 年预计的用煤产生的 CO_2 排放量

4. 美国 IGCC 技术在中国使用对全球环境的潜在影响与益处

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从减少污染排放看 IGCC 在中国使用对全球环境的潜在影响

中国燃煤发电的快速发展使人们切实关注它对当地及全球环境的影响。如果关于全球变暖的新信息提高了控制 CO_2 排放量的重要性，这种影响可能会更巨大。中国的电站甚至没有最基本的污染控制装置来限制 SO_2 和 NO_x，而这些设备在大多数发达国家里都非常普遍，因此，中国今后在燃煤电站方面的举措都会产生全球影响。

中国以煤炭为主的能源带来了严重的大气污染，这包括城市尘粒，酸雨地区的扩大以及大量的温室气体排放。在中国北方，尘粒密度比世界卫生组织公布的水平要高 4-6 倍。中国北方，有四分之一的城市，其 SO_2 排放量高于国家标准三倍。由于燃煤作为能源，中国是世界第三大温室气体排放国。随着能源消耗的增加，特别是煤炭使用的增加，能耗造成的污染在今后还会更严重。中国已经制订了一系列政策和规则来减轻这种形势，其中包括使用洁净煤技术。而在这些技术中， IGCC 的污染最小。

根据各种能源报告，中国至少在今后十年内，每年需新增加 17GW 的发电能力。现在的电力需求比供给高出 20% 以上。据说中国准备在十年内把发电能力由目前的 165GW 提高到 265GW 以满足这种需要。这相当于增加二百个 500MW 的 IGCC 电站。考虑到这种情况不太可能出现，我们对 IGCC 电站从现在到 2020 年在中国的市场份额作了一个估计，市场占有情况可能为： 1996–2005, 0%; 2005–2010, (1 到 1.5GW 或 2–3 个， 500MW IGCC 电站) 2–3%; 到 2015 年， 5–10%; 到 2020 年， 15–20% 。

如果 15% 的估算能够实现，市场上的 IGCC 电站将超过 3,000MW 。另外，IGCC 也是使老的燃煤电站更新的有效技术，即在利用现有的设备和结构上加一个燃气轮机和气化炉。通过这种办法还可以用较低的成本来提高老电站的能力并延长其技术和经济使用寿命，同时避免了建新电站所需的大量投资。

表 1 显示的是一些国家的电力生产及预计的发电发展情况，从中可以了解一些中国发电对世界环境的有关影响。

表 1　电力生产

	电力生产量 10^9kWh	预计增长率 %	预计每年增加产量 10^9kWh/yr
世界的总量	11,771.0	3.63	427.8
美　国	3,040.9	2.59	78.8
俄 罗 斯	1,726.0	2.92	50.5
中　国	**621.6**	**7.54**	**46.8**
印　度	286.0	9.14	26.1
南　非	166.7	6.41	10.7
印度尼西亚	44.3	12.05	5.3
捷克 - 斯洛伐克	89.3	2.08	1.9
保加利亚	41.3	1.73	0.7
匈 牙 利	28.4	1.74	0.5

由于中国电力的约 75% 是由煤炭产生的，因此通过技术更新在污物排放方面的任何改善都会对全球环境产生重要影响。 IGCC 是目前最清洁的先进发电技术， (见表 3), 使用它会比其它相竞争的技术更能减少中国排放物的不良影响。

IGCC 在中国发电方面的示范和应用产生的经济与社会效益

中国需要大的电力增长并愿意参加 IGCC 示范，尽管时间和经费情况还

不清楚。与其它燃煤系统相比，使用 IGCC 不仅能带来明显的环境优点，它还会有更多的效益。

中国是缺水国家，IGCC 电站的用水量比其它燃煤技术相对要少得多 (30-50%) 。这些电站可以建在水资源较少的地区，而传统电站则不能。因为缺少电网输送能力，这就意味着那些由于水资源不足不能建大型电站的地方也可以用到电。农村地区的经济发展要靠商业能源的可用性。

IGCC 电站的可用率很高，可达 85%, 而中国现在典型电站的利用率为 50-70% 。IGCC 发电可减少中国各地经常出现的限电，停电。中国的经济发展和公共福利都受到经常性限电的制约。在今天中国市场上的新电站的主要好处就是能终止停电。

IGCC 电站可以使用广泛类型的煤炭和生物质，这可以解决废物处理的问题。

在十年内，先进的 IGCC 电站可以投入使用，它们的效率可达到 50%, 同时保持着无可相比的环保优势。这包括控制 CO_2 方面的巨大的潜在益处。

IGCC 的建设可以分段进行，可先安装一个烧天然气的燃气轮机，然后安装联合循环，最后安装气化炉。这可以降低最初的成本并有其它财政方面的好处。其中之一是使用者可以用较少的最初建厂成本就进入市场。在中国，由于没有丰富的天然气供给，这种益处不明显。

因为 IGCC 能够使用相关的新技术，它可以为新兴的，先进的技术工业开创好的前景。例如，使用先进的燃气轮机和亚临界 / 超临界蒸汽参数的 IGCC 电站，通过使用加湿空气达到高效率低成本的整体煤气化湿空气透平循环以及使用燃料电池技术的先进的整体煤气化燃料电池联合循环。

IGCC 技术在中国使用在技术和经济方面的风险

煤的气化并不是一个新技术。多年来，各种煤炭及生物质就被气化来生

产商品化的城市煤气及化工产品。 Texaco 和 IGT 已经为中国提供气化炉来生产用于化肥及其它用途的化学产品。然而，气化炉还没有在中国的电力生产中使用，也没有计划让一些电站成为 IGCC 示范电站。在中国和在美国一样，类似化工厂的 IGCC 能否被电力工业界接受是值得忧虑的。此外，中国倾向于使用气流床氧气气化炉。即使使用常温煤气洁净法，这种技术也必须在中国使用本国煤炭来示范，此后才可考虑用于大型电站。上海焦化厂计划在 1997 年安装一个 50 MW 的 IGCC 电站。这将是一个很小的 IGCC 电站并可能使用现有的低压 U-Gas 气化炉。

关于 IGCC 电站如同其它技术一样，还有一些其它技术性的问题要考虑。中国虽然有丰富的煤炭资源和开采能力，但交通基础设施会制约那些需要增加电力的地区使用煤炭。沿海地区需要电力，但煤炭资源却远离海岸。坑口电站可以作为一种考虑，但输电网和配电网又没有发达国家那麽多。因此，一个大型 IGCC 电站的位置成为一个重要的问题，即使确定了位置并建立了电站，煤炭能否保证运到也不能完全确定，这会成为一种风险，而这对其它国家来讲通常不是一个问题。

Texaco 最近签订了一项合同，为化肥生产提供九个煤气化工厂。现在在中国共有十四个 Texaco 气化企业，其中八个使用煤炭。第一个是 1978 年得到使用权的。这些经验有助于证明气化炉可以使用中国煤，但是这些并不是 IGCC 电站。 Texaco 有二十多个许可证可以把气化炉引进中国，至少其中一家公司可以从事工程设计工作。

从商业角度讲， Texaco 的气化炉可供给经冷却不含尘粒，碱金属和氨的洁净煤气，同时产生一些可供发电的蒸汽。当用氧气气化时，煤气的高热值达 300Btu/SCF, 它不需预热就可以在燃气轮机里燃烧。这个气化炉与 Selexol 常温脱硫法结合可除去 H_2S, 加上联合循环中一台 GE7F 型燃气轮机就可产生 300MW 的净电力。这个系统说明使用一些中国煤在商业上是可以保证的，这是 IGCC 的一个近期选择。

从准备购买大型 IGCC 发电设备的中国人来看，尽管 IGCC 在中国的推广通常会担心其商业上可用率，技术保证，建厂成本和发电成本，在燃烧低

Btu 煤气时燃气轮机的寿命，低含硫煤的使用以及与其它技术的竞争，但一旦一个示范电厂的运行令人满意，就不会有令人十分担忧的技术或经济上的风险。但是，中国没有能力为新电站项目提供资金，她必须依靠其它国家的销售商来提供技术，专业知识和资金。中国官员曾说他们准备在 2010 年前将 2,000 亿美元用于电厂，其大部分是依靠外国资金。这些资金提供者 / 设备供应者会面临一些具有风险性的问题。它们包括：

- 政府的政策；
- 太快的经济增长；
- 燃料供应与运输的保证；
- 中方人员运作的能力；
- 三极权力机构的及时批准和许可；
- 货币的兑换；
- 合同政策的不同；
- 不理想的回报率；
- 省级或外国的财政来源；
- 大部分新增加的发电能力将以建设 - 运行 - 转交 (BOT) 的方法来投资建厂；
- 中国劳动力的较低生产率；
- 缺乏对知识产权的重视；
- 外国产权不超过 49% 。

最后，IGCC 的销售者还必须参与激烈的国际市场竞争，其结果，为了得到第一个项目，他们可能要进行不太有把握的投标。为了竞争，美国的制造商需要把 IGCC 的价格降低到 800-900 美元 /kW 。

中国已经成立了一个洁净煤委员会并制订出一个叫作 21 世纪议程的规划。这个议程的重点是在二十年内在中国实行 IGCC 。现在的一个主要问题是需决定是否应在今后五至十年内安装 IGCC 还是等到更晚些时候。根据 21 世纪议程的安排，1995 年应完成预可行性报告，1996 年进行招标。由于资金的问题，这个日程发生了变化，目前的状况还不清楚。

IGCC 在中国使用对与污染排放有关的额外的环保费用的潜在影响

我们很难用经济数值来衡量污染物对一个国家经济的潜在影响，但这里有些统计。一个关于东欧国家的研究估计了货币价值相当于污染对人类和环境所造成的损失估价。(见表 2) 。经济分析中使用如表所示的费用数据来比较和估价技术选择。与传统的燃煤电站和流化床煤炭燃烧相比，IGCC 排放的污染物更少，因此这些额外的环保损失费用使 IGCC 比其它选择更为有利。

表 2 环保费用

项目	额外费用
CO_2	$25/ 吨
SO_2	$590/ 吨
NO_x	$300/ 吨
粉尘	$2,590/ 吨

表 3 显示的是一个超临界煤粉锅炉电站和一个 IGCC 电站的排放量情况。两者都使用先进的方法来控制污染。IGCC 的排放量明显少于煤粉电站。中国的煤粉锅炉实际上没有污染控制。中国煤粉电站的排放情况不明。

表 3 排放物的比较

项目	超临界煤粉锅炉电站 (65%CF) 磅 /10^6Btu	氧气气化 IGCC 电站 (Destec) 磅 /10^6Btu
SO_2	0.34	0.04
NO_x	0.30	0.08
粉尘	0.004	0.004
CO_2	204.3	204.3

对 IGCC 和有污染排放控制的常规煤粉电站排放量的进一步比较见表 4。

表 4 IGCC 电站与煤粉锅炉电站的比较

技术情况	建厂成本 \$/kW	可降低排放量 %			电站效率 %
		SO_2	NO_x	CO_2	
有排放控制的煤粉锅炉电站	1,500–1,800	90–95	60	NA	33–35
IGCC 电站 (新建的)	1,100–1,300	95–99	90	20–40	39–47
IGCC 电站 (老厂改造的)	950–1,200	95–99	90	20–28	39–42

在新电站中利用 IGCC 技术的优势，特别是考虑到污染的影响，已在上述表格中得到了明显的显示。在中国制订并执行排放量规定之前，真正的外加成本影响难以估计。如果中国今后涉及燃煤电站排放的规定不象其它工业化国家那样严格，那么 IGCC 与其它污染更多一些的技术之间的成本对比就不会是合理的。

5. 从美国电业看 IGCC 技术

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前言

整体煤气化联合循环 (IGCC) 用于发电在美国已成为现实。现在已有一个电站投入使用，另外两个也接近完工，这样 IGCC 在商业运用上很快可有 60 万 kW 以上的发电能力。这篇文章从美国一个使用 IGCC 的电力公司的角度来看这项技术。里面涉及的内容包括： 1) 效益， 2) 排放量的减少， 3) 燃料的灵活性， 4) 副产品， 5) 老厂改造， 6) 新电厂。这里也包括关于 Tampa 电力公司的 Polk 电站 IGCC 工程项目的介绍。

技术

在 1960–1970 年美国的电力高速发展时期，装机发电量从 190,000MW 成倍增长到大约 400,000MW 。那时候最普遍的发电方式是使用大型煤粉燃烧蒸汽发电设备，发电规模可达 1,000MW 。通过使用这些大型设备，电力工业在 1968 年实现发电的最高效率。从 1970–1984 年，安装了更多的发电机组，几乎再次翻番。在那段时间里，电力工业面临着日益增多的环境法和规定，涉及空气，水及固体废料的排放。由于使用烟气脱硫装置和排除粉尘的静电除尘器，发电效率降低了许多。使用煤炭发电且要同时达到更加严格的环境标准变得越来越昂贵和困难。

燃气轮机技术用于电力工业已有多年，因为它们原来主要用于高峰负荷，因此它的低效率及高燃料费用并不是一个大问题。飞机发动机工业的最新发展对燃气轮机的重要促进是燃料的多样化和效率的提高。许多新安装的

设备使用 150-200MW (60 赫兹) 的燃气轮机，其好处是简单循环运行效率就达 40%, 在联合循环中可超过 50% 。美国许多最新的发电装备是把烧天然气的燃气轮机用于联合循环模式。由于天然气的价格较低，燃气轮机已成为大多数新装设备的技术选择。

气化技术在化学工业中已经使用多年，但对电力工业则非常新。在七十和八十年代，美国遇到了石油供应危机，政府和工业界意识到越来越依赖外国石油对美国是一个战略上的劣势。于是大量的研究迅速转向那些能够利用美国丰富的煤炭资源的技术上。把低成本的煤转化成清洁的煤气并在高效率的燃气轮机 / 联合循环中使用，人们认为它具有重要的潜力来解决能源战略上的难题。

在八十年代后期，冷水煤气化项目成为美国第一个 IGCC 工程。它的目的是示范把煤气化技术与效率日益提高的联合循环技术结合起来。几年的试验证明 IGCC 在技术上是成功的，并且可以用于大型发电项目的商业发展。随着煤价的降低，天然气价格的提高，电力企业界开始认真考虑 IGCC 。能源部的洁净煤技术计划把 IGCC 引入大型商业化规模。

效率的优势

即使使用了超临界压强运行并改进蒸汽轮机，大型煤粉装置也只能达到大约 40% 的效率。通过使用效率很高的燃气轮机技术， IGCC 现在的效率就可高于 40%, 在今后几年内还将达到 45% 。美国蒸汽发电机组的平均热耗是 10,568 Btu/kWh 。洁净煤技术计划下的 IGCC 项目设计的热耗范围为 8,500-9,000Btu/kWh 。因此，IGCC 比其它已商业化的技术在总效率上要高出 10-20% 。在一个竞争日趋激烈的商业环境中，对一个面临着天然气价格上涨以及发电设备老化的电厂来说，更高的效率和更低的燃料成本会带来很多好处。

排放量的降低

1990 年清洁空气法修正案要求电力企业大幅度降低 SO_2 和 NO_x 的排放。减少的总量约为 10Mt SO_2 和 2Mt NO_x 。减少排放量的过程将分为两个阶段。

第一阶段从 1995 年开始，要求 110 个电站降低排放量。从多方面讲，这些电站都是美国最大的，它们使用的是高硫煤。大部分电站改用低硫煤能够达到降低排放的要求。其它电站则安装了烟气脱硫 (FGD) 系统。

第二阶段将从 2000 年开始，它将从根本上影响到美国所有的电力企业。降低硫排放量的要求会比第一阶段更严格，届时会要求燃料种类的改变或加装高效率的 FGD 设备。但是，很多老设备，如果在不长的使用寿命内使用 FGD，在成本上不会有好的效益。IGCC 中使用的酸气排除设备比燃煤电站中通常使用的石灰石基的烟气脱硫装置更能有效地回收硫化合物。进一步研究和发展锌基的高温净化技术会使硫化氢排除率接近 99%。

IGCC 技术的一个额外好处就是让电力企业能继续使用低成本的高硫煤，同时又能实现很高的除硫率。这就使那些已考虑要退役的老设备通过老厂改造，实现出力不减甚至可以提高，同时又能符合清洁空气法修正案的要求。

IGCC 工艺本身 NO_x 的排放就很低。由于在燃气轮机中燃烧器的改进，燃烧天然气可使 NO_x 的排放量低于 10 ppm。使用煤气并保持同样低排放量的燃烧器发展很快。当将从空分装置分离出的氮气重新回注，IGCC 可以很有效地控制 NO_x。氮气注入使火焰降温，减少了 NO_x 的形成，从而不需要下游的排除技术，如选择性催化还原法的除氮技术 (SCR)。这样可以用较低的成本满足关于 NO_x 的规定。

表 1 显示的是几个不同的电站的 SO_2 和 NO_x 的排放量。数据是以每 MWh 发电所产生的以磅为单位的排放量。这个指标比用每百万 Btu 的输入热量为基础的排放量 (磅) 要准确，因为它把 IGCC 机组本身的效率计算在内。这里所列的电站包括老厂改造前后的 Wabash River 电站，Indiantown 流化床燃烧机组，传统的 Orlando 燃煤电站，Polk 电站 (IGCC) 以及荷兰的 Demkolec IGCC 电站。由于燃烧低硫煤，Demkolec 的 SO_2 排放量很低。读者可以看出，IGCC 对新的及更新改造的电站都是一种有效率，也有效果的方式，来达到控制排放量的要求。

表 1　排放量 /MWh

	SO_2 磅	NO_x 磅
Wabash River 1 号机组改造前传统燃煤电站	32.4	7.9
Wabash River 1 号机组改造后 IGCC 电站	2.3	0.8
Indiantown FBC 电站	1.76	1.76
Orlando 2 号机组传统燃煤电站	1.58	1.58
Polk 1 号机组新建 IGCC 电站	1.49	0.87
Demkolec 新建 IGCC 电站	0.48	1.36

燃料的灵活性

如表 2 所示，煤气化工艺给电站带来了重要的燃料方面的灵活性。除了电站使用的传统燃料 (煤和石油), 很多“进料”都可以利用这个化学工艺来发电。因为燃料是发电中最大的一项成本，因此每个电站都必须想办法降低燃料成本。在电力企业竞争日益激烈的情况下，这一点变得尤其重要。

表 2　燃料灵活性

- 高硫煤
- 低硫煤
- 石油焦
- 混合燃料
- 废物燃料
- 重油

为了达到 1990 年清洁空气法修正案的要求，很多电站转向使用东部的低硫煤。在很多情况下，低硫煤的成本都高于高硫煤。但是，随着电力企业越来越多地使用西部廉价的 Powder River Basin 的煤，燃料成本得到了明显降低。电力企业现在已经开放市场，使用多种类型的煤炭，包括其它国家的煤。第二阶段的要求使电力企业更重视 SO_2 排除技术，这是因为煤的低含硫量还不能

达到满足有关要求的程度。

通过用 IGCC 的改造和更新，电厂可以开放它的燃料市场，可以购买低质但含碳高的燃料，这些包括低挥发分煤，石油焦，废物燃料，重油以及这些燃料的混合使用。因为气化工艺只需要一种含碳的进料，电力企业于是可以使用从未考虑过的燃料，这是由于过去设计的燃煤锅炉使用的燃料范围较窄。IGCC 既可满足环保上的要求，又可以降低燃料成本。

副产品

传统的燃煤电站产生以下一种或多种燃烧副产品：飞灰，炉底灰渣，熔渣，烟气脱硫污泥以及副产品石膏。很多电站卖掉这些副产品，使它们在工业中再次使用。当这些副产品没有市场时，电站每年都剩下几十万吨的固体废料，需求投入大量资金来处理。大片的土地需用来堆存废料。对新电站以及为适应法案要求而增加了 FGD 的现有电站来说，堆存大量的固体废料会引起社区的反对。因此对于电站和靠近电站的社区而言，能够产生可出售的副产品变得越来越重要。IGCC 可以产生可销售的熔渣，硫以及硫酸，这些产品都有很好的国际市场。这样可以解决成本和社区关注的问题。

老厂改造

美国目前大部分电站已有三十多年的历史，都达到了六十年代设计的使用期限。通过一些延长使用期限办法，很多电站的使用时间接近五十年。由于增加 SO_2 和 NO_x 控制设备增加了额外的费用，很多企业现在都面临着艰难的选择，即继续进行延长使用期限的工程还是放弃老设备。由于很难找到新的厂址并且为新厂得到环境部门许可，更新改造老厂成为一个重要选择。

例如，印第安纳公众服务电力公司的 Wabash River 第一机组是在 1953 年投入运行的。这个燃煤电站的发电能力大约为 100MW 。通过洁净煤技术计划使用 IGCC 更新改造，新的第一机组的净出力为 262MW 。这个电站提高了它的发电能力，同时避免了建新厂址的费用，在环境许可方面的手续也很少。

使用 IGCC 改造老厂可在较低增加建厂成本条件下带来更好的效率，更高的出力，和延长使用寿命。随着美国电业竞争的加剧，电厂的老化以及更严格的环境法的出台，选择老厂改造会变得更加重要。

新电厂

随着美国人口的不断增加，对额外电力的需求也随之增长。电力企业需要新的发电能力，但由于新的厂址，环保影响，社区关注等问题，新厂的选址和许可过程会使发电扩大计划拖延很多年且费用可观。如果考虑到前面所讲的好处，如效率，低排放量，低成本燃料，可销售的副产品以及优越的环保效果， IGCC 是新发电技术的一种选择。部分由于更高的效率， IGCC 工艺比传统燃煤锅炉使用更少的水来冷却或用于其它用途。

管理部门现在更加了解 IGCC 的优点，能够更好地来评估它和其它有潜力的技术。与其它技术相比， IGCC 的一个主要优势是每 MWh 发电所产生的以磅为单位的的低排放量。今后对空气有害毒素的控制，如水银会使电力企业更需要 IGCC, 因为大部分水银，（即使不是全部）在气化工艺中都与熔渣结合在一起了。

Tampa 电力公司 Polk 电站

地点

Tampa 电力公司 (TEC) 是投资者拥有的电厂，总部在佛罗里达州的 Tampa, 它是 TECO 能源公司的一个主要附属公司。TECO 是一家与能源有关的企业，从事采煤，运煤以及利用煤来发电。 TEC 的发电能力为 3,415MW 。约 97% 的发电由燃煤机组完成。 TEC 的用户大约有 50 万，分布在 Tampa 及附近。

佛罗里达州是美国一个发展迅速的地区。在 TEC 的发电扩大计划中，它估价了多种不同的发电工艺和燃料来源。在这期间，能源部 (DOE) 的洁净煤技术计划也正在寻找一个地方建立氧气气化的 IGCC 电厂。 TEC 和 DOE 达成一项协议，DOE 为 TEC 的新电站出资 20-25%, 并命名为 Polk 电站一号机组。

Polk 电站建在佛罗里达州内陆地区的 Polk 县。这个地方原来用于开采磷酸盐的矿场，现在被重新整理后作为电站发展地区。这个地点由一个与 TEC 无关而独立的社区选址任务组选出，这个小组是由 TEC 授权来为电站寻找厂址的。

这个由十七人组成的小组包括环境保护者，教育家，经济学家，商业人员以及社区选出的领导人。这个调查始于 1989 年，它考虑了六个县的三十五个地点。小组推荐了 Polk 县西南的三块土地，那里原来一直用于开采磷酸盐。这些地点在小组看来有最好的整体环境和经济评估，该地区总面积为 4,300 亩 (17.4 平方公里) 。这地方的约三分之一将用于发电厂。 TEC 负责全区开发。原有的矿场已被改造用来建成一个 850 亩 (3.4 平方公里) 的冷却用的水池作为整个计划的一部分。

气化技术和工艺

电站将使用 Texaco 的氧气气化气流床煤气化技术。全厂流程工艺见图 1 。煤将在磨煤机中被粉碎并制成含 60–70% 固体的水煤浆。机组的设计能力为每天制备大约 2,000 吨煤。水煤浆和氧气 (来自空分厂) 将在气化炉中混合。水煤浆在 2,500°F(1,370°C) 以上的温度下部分被氧化。这将产生有 250Btu/SCF (LHV) 热值的合成煤气。合成煤气从气化炉排出进入辐射废热锅炉，在那里煤气被冷却到约 1,300°F(700°C) 。辐射废热锅炉产生 1,600psia(110bar) 的高压蒸汽，用于蒸汽轮机发电。从辐射废热锅炉出来，煤气被分成两股 (各 50%), 分别进入两个对流废热锅炉，它也将产生高压蒸汽。经过这些冷却器，合成煤气进入气体 / 气体换热器，这个设备将分别用于加热氮气，洁净煤气，随后它们进入燃气轮机。在气化炉中产生的熔渣将集中在辐射废热锅炉的底部，然后把它们出售给当地工厂。冷却后的合成煤气将进入酸气排除系统，在那里 95% 以上的硫化合物将被除掉。传统的常温煤气洁净系统 (CGCU) 将使用 MDEA 作为吸收剂。这种被回收的浓缩的硫化氢气体将被送到硫酸厂。

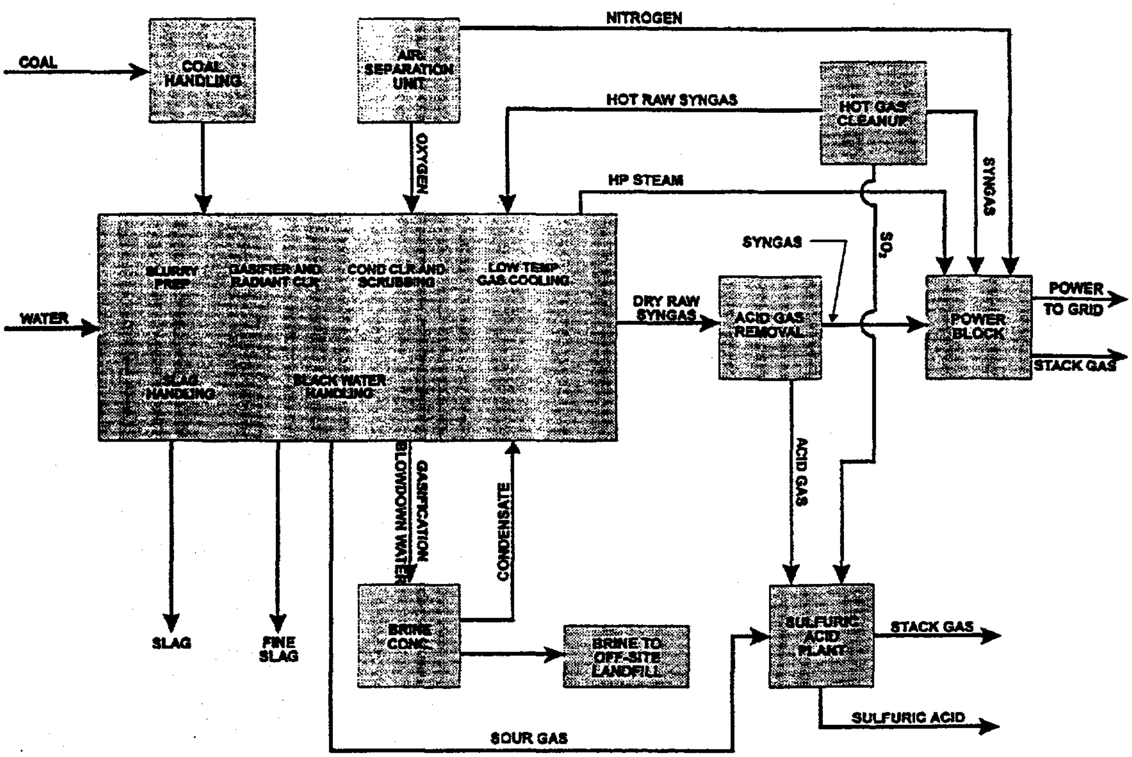

图 1 Polk 电厂 1 号机组 (PPS–1) 流程图

空分厂将使用大气中空气来产生用于气化炉的氧气和用于燃气轮机中和辐射废热锅炉中除灰用的氮气。这个空分厂的生产能力为每天产生 2,100 吨氧气， 6,300 吨氮气。

作为 DOE 示范项目的一部分，这个 IGCC 机组还将试验高温煤气净化 (HGCU) 系统。它将用来处理 10–15% 的合成煤气，通过在 900°F(480°C) 的温度下使用金属氧化物球 (锌或氧化锌) 来除硫。在常温煤气净化系统中，煤气必须被冷却，洁净，然后再加热，进入燃气轮机。高温煤气净化系统的潜在优势就是可以避免常温煤气净化系统中不可逆的热力损耗。高温煤气净化系统中还将试验用碳酸氢钠来除去氯化物，并使用高温陶瓷过滤器在下游的流程中除尘。

联合循环工艺

这部分的关键组成是燃气轮机，余热锅炉和蒸汽轮机。燃气轮机是一个 GE 7F 型。它的全部装机能力为使用合成煤气和氮气注入达到 192MW 。蒸汽轮机是一个双流再热式加上低压抽气式的汽轮机组。这个汽轮机组设计是用于高效率的联合循环，蒸汽的进口压力和温度是 1,450psia(110 bar) 和 1,000°F(540°C)，其再热温度为 1,000°F(540°C) 。正常运行时，燃气轮机先用柴油启动，然后达到某一负荷时切换成煤气和氮气。

副产品

常温煤气净化系统中产生的浓缩硫化氢和高温煤气净化系统中产生的浓缩 SO_2 将被送入硫酸厂作最后处理。硫酸厂每天最高将生产达 210 吨的 98% 的硫酸。这些将卖给当地的磷酸盐工厂，在那里用来生产磷肥。

气化炉和辐射废热锅炉中产生的熔渣将卖给当地工厂。从 TEC 目前的燃煤电厂中产生的熔渣近三十年来一直出售。它被用作喷沙器中的沙砾 (用于上漆前的表面清洗准备)，屋顶瓦及铺路用的沥青填充物。

煤中的氯化物将在盐水浓缩系统中被回收为氯化氨，这种副产品将用于电镀工业。因此，这个 IGCC 电站的所有副产品都可销售并作为有用的商品。这将显示出 IGCC 工艺的另一个益处。

日程

工程建设于一九九六年七月初完成，七月十九日，使用水煤浆的煤气化炉第一次点火。机组在八月和九月间进行调试。十月初，煤气化炉已运转数百小时。性能测试计划在十月进行，然后是机组的商业运行。

V. 结论和建议

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关于 IGCC 在中国的发展潜力，从本报告中能够得出积极的结论，它支持 IGCC 在中国进行示范和长期的商业使用。中国需要经济发展，发电厂，煤炭资源的发展和环保控制。根据过去十年中国的经济发展速度，她在今后二十到五十年内每年需要 15-18GW 的新增发电能力。煤炭是用作发电燃料的首要能源来源，中国每年的原煤产量超过 12 亿吨，它占能源总需求的 70% 以上，而燃煤电站占总发电量也达 70% 以上。中国工业界也依靠煤作为化工生产的能源来源和原材料。要保持清洁的环境，中国需要控制燃煤产生的 SO_2, NO_x, 固体及液体废料的排放量，这就要求更高效的煤炭能源转换技术以及由它带来的用水量的减少。中国的"九五"计划清楚地说明了高效利用洁净煤的 IGCC 技术的市场。它指出"洁净煤技术的发展应适应国家宏观发展战略的转变"。中国的 21 世纪议程也支持 IGCC 在 2000 年后用于发电，这一议程清楚地表明中国的发展道路将从传统的发展模式转变成高效利用煤炭资源的持续模式。

在目前可用的洁净煤发电技术中， IGCC 是最清洁，最有效和最成熟的技术之一。与其它燃煤发电技术相比，它更具环保优势，有利于全球排放量的降低和空气质量的改善。中国需要这样的 IGCC 洁净煤技术来支持经济发展，并可以借鉴美国能源部洁净煤技术计划带给美国的经验。能源部洁净煤示范计划的 IGCC 项目目前处在不同的完成阶段，并在中等范围 (250MW) 内示范。 CCT Wabash River 项目 (250MW) 已达到发电的商业运转阶段， CCT Tampa

电力 IGCC(250MW) 项目也已进入商业运行。中国在发电中大规模示范 IGCC 技术会有助于证明在更大使用范围内该技术的可靠性，可用性和可维护性，这将促进中国使用更有效的洁净煤技术。这种示范也将有助于从商业角度接受 IGCC 技术，把它看作燃煤发电的一种效率高且于环保有利的手段，可用于全球发电业。现在需要在大于 250MW 的范围示范这项高效率无污染的煤发电技术来证明技术的按比例增加和使用中的可靠性。

根据美国洁净煤计划的有利结果，中国相信 IGCC 现在具有成熟，可靠，灵活等特点，可适用于中国的多种煤炭。很多中国煤已在中国生产的气化炉中得到试验和使用。现在需要大范围示范 IGCC 技术以为它在中国做好商业准备。通过运行 IGCC 电站，中国可以获得第一手的技术和经验。中国从化学工业中已积累了很多煤气化的经验，因为其 60% 的化工生产都以煤为基础。从电力部支持的项目中，中国也得到了联合循环电站运行方面的经验。最近建一个用精炼油作燃料的 IGCC 电站的计划将进一步为使用煤作燃料的 IGCC 商业化计划作准备。

借鉴美国 IGCC 示范的经验，中国的 IGCC 示范项目的风险会大大减少。与美国的 IGCC 示范电站相比，使用中国生产的设备也将降低电厂资金和投资成本。这是由于美国使用非专利设备和系统的成本比中国同样的设备和相关电厂成本要高得多。目前，电厂成本水平，燃料成本以及环保规定都因地区和国家而异，这将影响到大型新建电站的总体项目成本。此外，电厂成本也受到当地劳动生产率，劳动力价格，部件及系统生产费用的影响。如果这些由中国当地生产，与外国进口设备相比，其成本会大大降低，中国自己必须进行工程建设，这笔费用也会相对较低。因此，加上技术示范和从自己的示范项目中获得的有关运行经验，IGCC 电站在中国的成本能够得到显著降低。

中国为在更大范围内示范 IGCC 技术提供了一个特别的机会，这将提高这项技术在中国，美国和其它国家投入商业使用的可靠性，可用性和可维护性。采用更高效且利于环保的 IGCC 技术在中国市场会有更好的机会，因为在那里经济增长是推动力。此外燃料是发电中最大的单一成本，发电企业必须通过使用更高效的技术如 IGCC(它将比传统技术的效率高 20%) 来在电站运行中降低燃料成本。

要证明 IGCC 与其它选择相比在经济和技术上的表现，中国可使用的唯一办法是通过建设运行一个 200-400MW 的项目。美国和欧洲都是在洁净煤示范项目完成后才给予 IGCC 技术认真的考虑。通过试验这个项目，中国将遇到实际资金和运行成本问题，这将为提高今后项目的经济状况提供有用的信息。美国与中国合作在中国示范 IGCC 树立了一个榜样，它有利于今后世界范围内进行合作来确定和解决对效率高且有利于环保的技术如 IGCC 的需求。