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## 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.

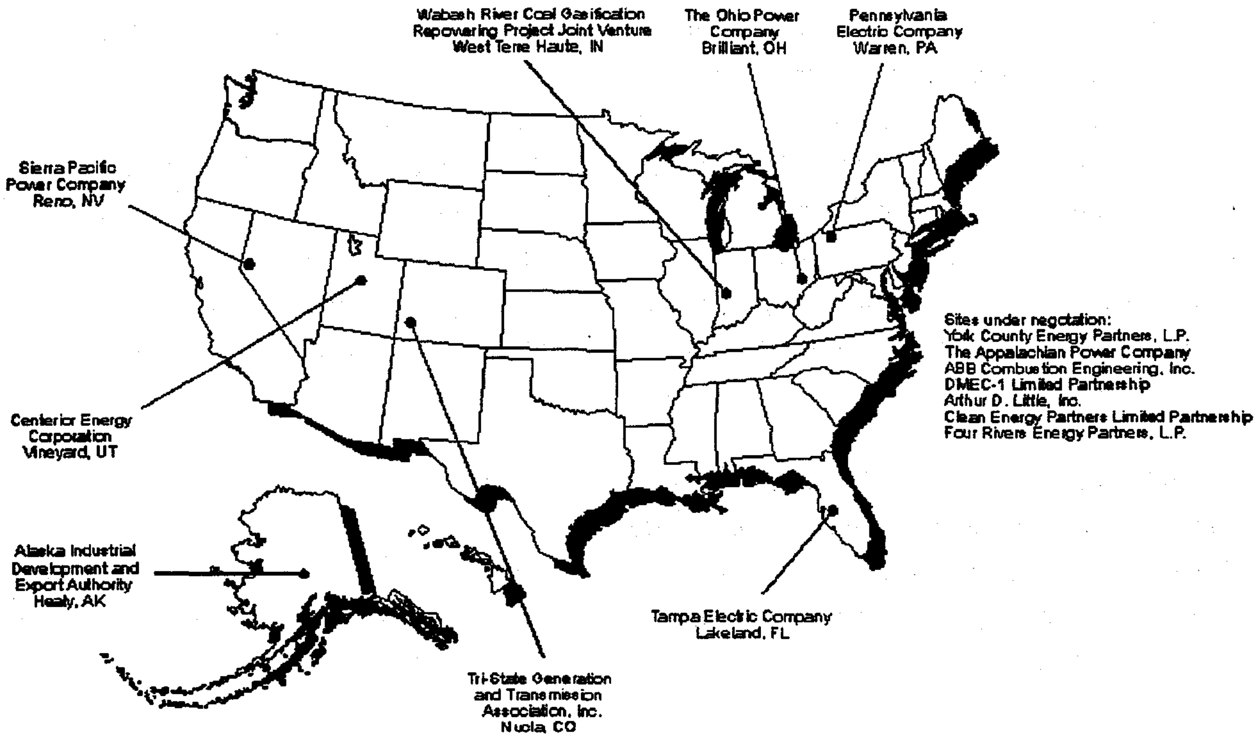


**Figure 1. United States Clean Coal Project Locations**

- ***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.

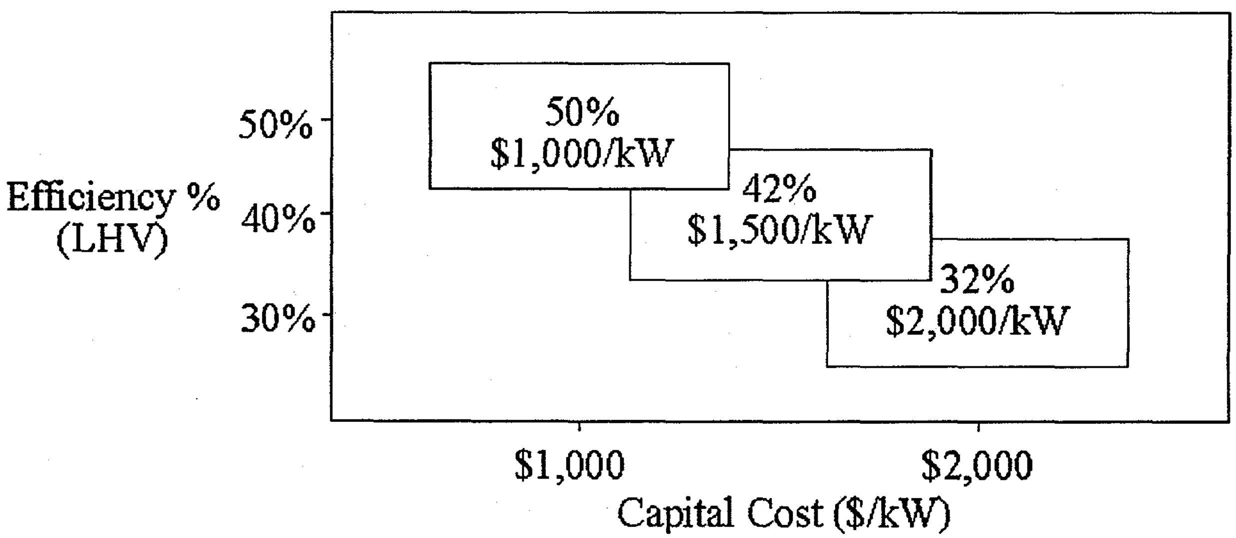


**Figure 2. IGCC LHV Efficiency vs. Capital Cost**

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.

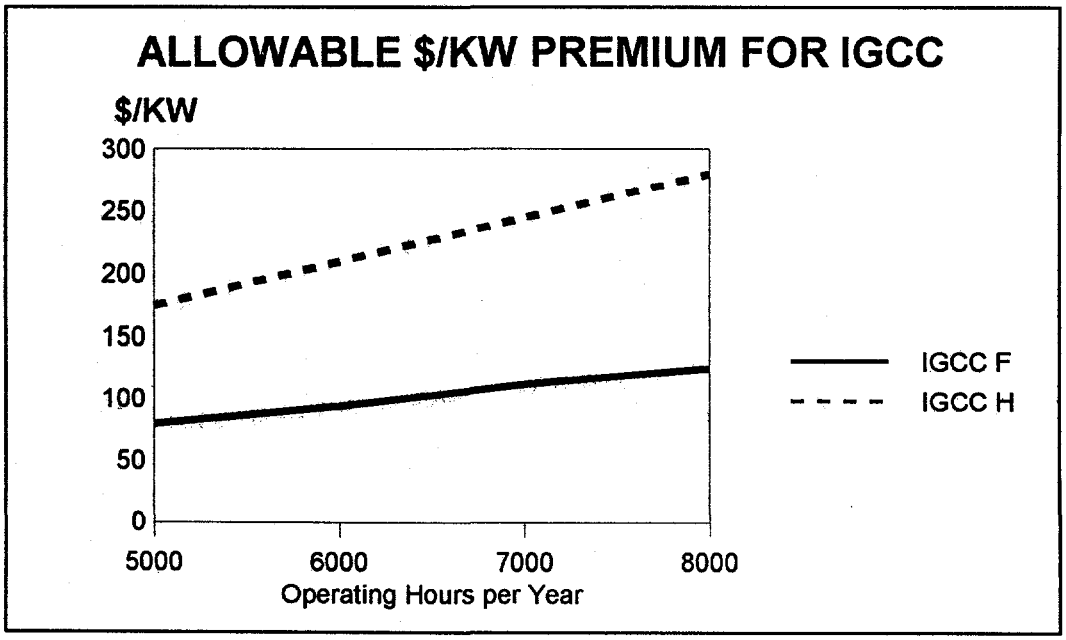
Since the plant cost is the only variable parameter in these calculations, the results show the allowable capital cost premium for the IGCC technologies to break even with a conventional coal-steam plant were based on levelized cost of electricity over a 25 year period. Values were calculated for operating 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.