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.