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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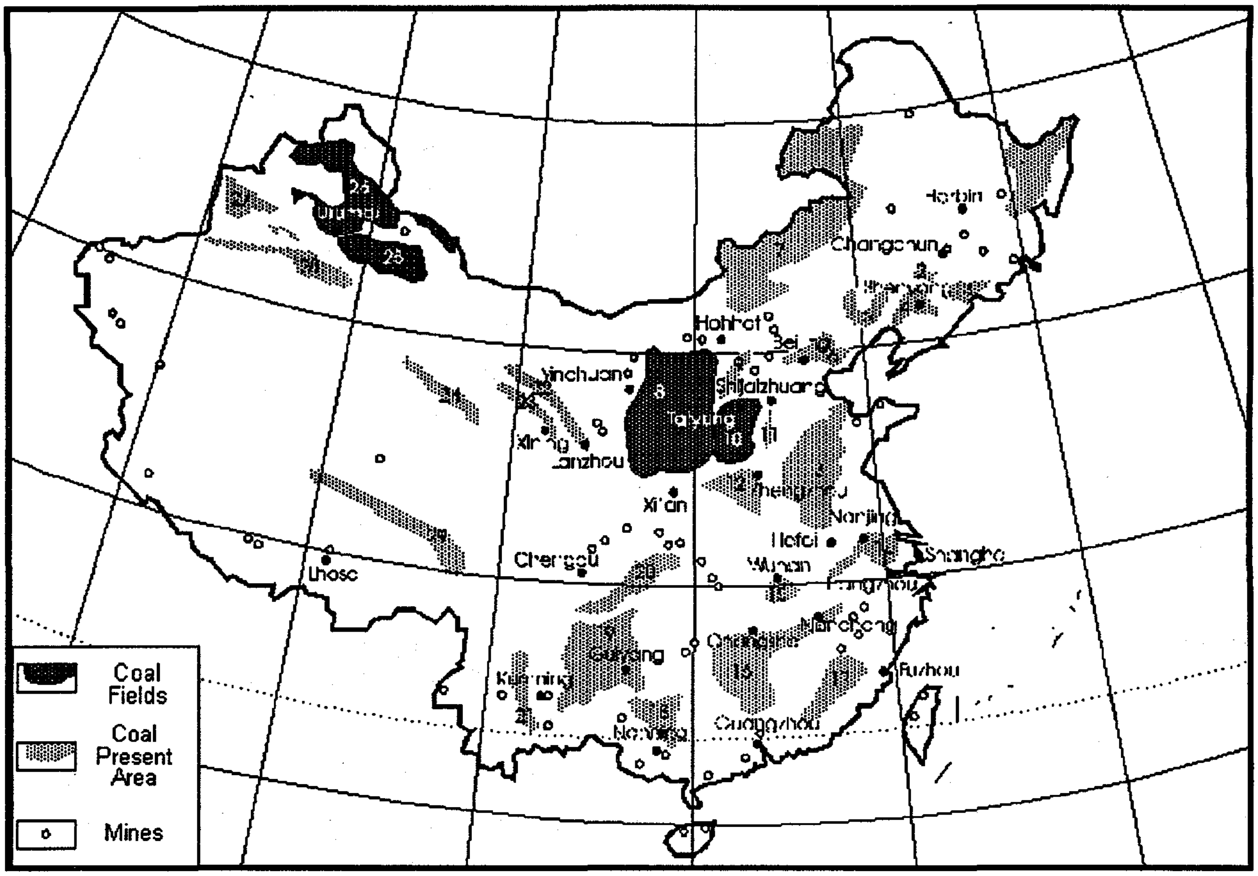

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Figure 1 Distribution of China's Coal Resources

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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