China National Energy Strategy and Policy Study

Sub-project 11:
Policy study on development and utilization of CCT

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Abbreviations

$	US dollar
A_d	ash content (dry basis)
AFBC	atmospheric fluidized bed combustion
°C	Degree Celsius
CAE	Chinese Academy of Engineering
CAS	Chinese Academy of Science
CCT	clean coal technology
CEM	continuous emission monitor
CFBC	circulating fluidized bed combustion
CFB-FGD	circulating fluidized bed - flue gas desulfurization
CO_2	carbon dioxide
d	day
DMFC	Direct Methanol Fuel Cell
EBA	electron beam exhaust gas treatment apparatus
EPDC	Electric Power Development Corporation, Japan
FGD	flue gas desulfurization
g	gram
gce	gram of coal equivalent
GDP	gross domestic product
GHG	greenhouse gasses
GJ	giga joule
Gm^3	giga cubic meter
GSA	gas suspension absorption
GTCC	gas turbine combined cycle
HHV	high heat value
IEA	Internal Energy Agency
IGCC	Integrated Gasification Combined Cycle
kcal	kilocalorie

kg	kilogram
kW	kilowatt
kWh	kilowatt hour
LHV	Lower Heating Value
LIFAC	limestone Injection into a Furnace and Activation of Unreacted Calcium
LNG	liquefied natural gas
LPG	liquefied petroleum gas
m^2	square meter
m^3	cubic meter
MCFC	molten carbonate fuel cell
mg	milligram
mg/Nm^3	milligram per normal cubic meter
MJ	megajoule
mm	millimeter
MPa	megapascal
Mt	megaton
MW	megawatt
MWe	megawatts of electric power
MWh	megawatt hour
NDRC	National Development and Reform Commission
Nm^3	normal cubic meter
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NSFC	National Natural Science Foundation of China
NSPS	New Source Performance Standard (USA)
OECD	Organization for Economic Cooperation and Development
PC	pulverized coal
PEMFC	proton exchange membrane fuel cell
PFBC	Pressurized Fluidized Bed Combustion
PFBC-CC	Pressurized Fluidized Bed Combustion Combined Cycle
PM_{10}	particulate matter for particles with less than 10 microns

$PM_{2.5}$	particulate matter for particles with less than 2.5 microns
ppm	part per million（10^{-6}）
$Q_{gr,ad}$	gross calorific value (air dried basis)
RTD	research and technology development (European Commission)
S	sulfur
SCR	selective catalytic reduction
SO_2	sulfur dioxide
SOFC	solid oxide fuel cell
SO_x	sulfur oxides
$S_{t,d}$	total sulfur (dry basis)
t	ton
t/a	ton per annum
t/h	ton per hour
tce	tons of coal equivalent
TSP	total suspended particulates
UGI	a kind of intermittent fixed bed gasifier (UGI Corporation)
V_{daf}	volatile matter (dry ash free basis)
Vn	converted sampling volume under normal state(0 ℃ 、101,325Pa), unit: m^3

Executive Summary

This report identified current barriers to clean coal development in China. It was based on (1) the analysis of current laws, regulations and policies used to accelerate the development of clean coal technology in China, (2) the evaluation of the implementation of these regulations, policies and economic incentives, and (3) on the comparison between Chinese and foreign experiences. Through the evaluation of available clean coal technologies based on four main users of coal, i.e. power sector, industrial boiler, chemical production and fuel oil substitution and household use. The clean coal technologies and development plan suitable for Chinese situation are put forward. The Clean Coal Development policies put forth are based on techno-economic evaluation, policies, and countermeasure recommendations.

CHINA MUST DEVELOP CLEAN COAL TECHNOLOGY

China is a large energy consumer with coal as the dominant energy. The consumption of coal in China in 2002 was 1390 Mt, accounting for about 67% of primary energy consumption. All forecasts indicate that the proportion of coal in Chinese primary energy consumption will still be at above 60% and the total coal consumption will rise to above 20 Gt in 2020. The current situation and forecast of coal consumption are listed in Table 0-1.

Table 0-1 Current situation and forecast of domestic coal consumption in China

Year	Total consumption (Mt)	Proportion (%)				
		Power	Industrial boiler	Coking & injection	Chemical & fuel oil Production	Household use
2002	1315	54.8	~27	9.1	3.0	6.0
2020	2120	66	14	11	4	5

Coal plays an important role in the development of national economy. Coal accounts for about 72% in power structure, about 50% of feedstock for chemical production, about 90% of fuel for industrial boilers, and about 40% for household fuels. However, large amount of utilization of coal at low efficiency brings about serious environmental pollution. How to control SO_2 emission and acid rain pollution caused by coal combustion has become the most pressing task in current air pollution control in China.

The energy source situation and economic development level in China determine that coal is the fundamental energy of China. Coal dominated energy consumption mix will not change for a considerable period of time in the future. The future China will face more serious environmental pressure if not accelerate development of clean coal technology.

Clean coal technology is a technical system composed of new technologies including coal mining, combustion, conversion and pollution control, which aims to improve coal utilization efficiency and decrease environmental pollution. The feature of CCT is that it can ensure energy security, save the energy, realize clean and high-efficiency utilization of coal and solve current coal-related environmental problems while well utilization of the abundant and cheap coal.

Development of clean coal technology can begin from the source, using different ways to improve coal quality and reduce SO_2 emission. It can also realize a whole-process pollution control from coal mining to utilization through a combination of different technologies. Further more, it can also improve end energy consumption mix by increasing the conversion ratio from coal to cleaner electricity, gas and oil.

Under the condition that coal-dominated energy mix will not change largely, vigorous development of clean coal technology is a realistic choice for solving the energy balance between supply and demand in China, and a strategic and necessary choice for realizing the coordinative development of energy, environment and economy in China.

THE CURRENT STATUS OF CCT DEVELOPMENT IN CHINA

Great Progress Has Been Made in Chinese CCT Development

Chinese clean coal technology includes 18 technologies in five areas which are coal processing, high-efficiency coal combustion and advanced power generation, coal conversion, clean and efficient comprehensive utilization of coal, and pollution control and recycle. Among of them, coal washing, blending, CWM, CFB have been put into commercial operation; the supercritical units, FGD and large coal gasification technology with independent intellectual property are under development; coal liquefaction, IGCC, CBM development, which are mainly imported from abroad, have entered into commercial demonstration; briquette, retrofit of small-medium industrial boilers, comprehensive use of coal refuse and fly ash, reuse of mine water are being improved and perfected.

In recent years, China has promulgated many laws, regulations and policies related to clean energy sources/technologies and environmental protection. Unlike foreign countries where CCT development is driven by environmental policies, the development of CCTs in China is, instead, significantly driven by the promotion of technical policies. Of the technical policies, industrial policies are implemented more effectively than R&D policies due to more concrete goals in combination with encouragement and elimination. The increasingly strict environmental policies and measures have also played important promotion roles to the CCT development in China. The environmental measures such as total emission control, emission fees, control of key pollution sources and continuous emission monitors and increasingly stringent emission standards force local cities and enterprises to have to take advanced technologies, which is obviously reflected in the development of advanced power generation technology and dissemination of CFB application.

Generally speaking, CCT development in China lags behind market demand and environmental demand, so it needs to be accelerated further.

The Obstacles Existed in CCT Development in China

- **Obstacles in institutional and managerial system**
  - Lacking overall arrangement and coordination of CCT development by a national energy department. Management by multiple governmental departments and lacking the coordination between them result in no overall plan and arrangement for the technologies
  - Little financial support to development and commercial demonstration of new technologies and key technologies. It is required that commercial demonstration mainly relies on enterprises but most enterprises have not the ability to take the demonstration risk as a result of lacking corresponding risk mechanism. Favorable investment and financing policies and credit channels for commercialized clean coal technologies are very few.
  - The coal supply system is uncontrolled. Steam coal is managed only as the primary fuel but not as the energy product that can be standardized and serialized. The market mechanism for promotion of coal processing is not established. Power sector that can use central desulfurization has a first priority on low sulfur and low ash coal and great number of small-medium users use low-quality coal, which aggravates coal-related pollution.
  - There is lack of effective monitoring of small-medium users and a great number of small-medium users have gradually become the second largest pollution source only next to power sector, even exceeding the pollution from power sector in some cites. The building of national environmental quality monitoring network and environmental monitoring technologies cannot keep pace with the increasingly stringent environmental requirement. The phenomenon of regional protection and paying the emission fee through negotiation existed in environmental law enforcement goes against popularization of clean coal technologies.
- **Obstacles in laws and policies**
  - No special policies on CCT development. Current policies related to CCT development (R&D policies, industrial policies, environmental policies, energy saving policies, policies on comprehensive utilization of resources, etc.) are not compatible. Many laws, regulations and policies lack a corresponding detailed implementation requirement, which restricts CCT development to a large degree.
  - The government lacks initiative policies to the technologies that need emphasizing the development.
  - Some of emission standards are not practicable, failing to consider the influences of scale differences and whether existing technologies can meet emission standards. The level of SO_2 emission fee is still lower than the cost of SO2 control in two control regions, which results in that enterprises prefer to pay emission fees rather than use new technologies or invest in installing FGDs.
- **Technical obstacles**

- Low localization rate of commercial application for large-scale key equipment and technologies. Some key equipment and technologies, such as ultra supercritical boilers, turbines, flue gas cleanup system, large-scale CFB boilers, coal gasification, coal liquefaction, urgently need research and development to possess independent intellectual property right as soon as possible.
- The limitation and elimination for backward small-medium equipment and technology are not enough and monitoring and supervision are insufficient. Some equipment and technologies that have been proclaimed to eliminate are still in use, which result in discouraging the deployment of advanced technologies
- No all-around comparisons and argumentations for energy system for long-term strategic technologies, such as fuel oil substitution technologies including coal-derived methanol and di-methyl ether (DME), influence the arrangement and plan of technical development.

Many obstacles are existed in the development of clean coal technology in China, but mainly come from management, institution and policies, which not only influence the overall arrangement, development and popularization, but also influence R&D and industrialization speed and level of new technologies. It will be difficult to settle he obstacles and problems existed in specific technical development if these issues are not solved.

EXPERIENCES OF PROMOTING CCT DEVELOPMENT IN FOREIGN COUNTRIES

CCT development is generally driven by environmental regulations and policy initiatives internationally.

First of all, special laws with strict legal requirements are established. The formulation of emission standards is in close combination with the economic and technical development level. The effect of enforceability is satisfactory because there is no limit on technology selection as long as emissions from this equipment is in compliance with emission standards. For example, the CAA in the U.S. and national policies for air pollution control in EU not only have the requirement of detailed time limit and standards for environmental control but also provisions for criminal sanctions against non-compliance.

Next, the government invests large amount of fund to the development of new technologies and offer multiple credit channels in order to promote the introduction of clean coal technology. For instance, the total investment of the American CCT program is 7.14 billion dollars, of which, the proportion of government funding is about 35%. The Japanese government grants more than 57 billion yens every year to the “New Sunshine Program”.

Effective enforcement of regulations is realized by adopting environmental protection measures, such as collecting fees on total emissions, imposing penalties on emissions exceeding regulations, emission trading scheme, collecting environmental taxes (such as sulfur tax). Meanwhile, incentive policies such as preferential taxation, low-interest loan and so on for introduction of advanced technologies encourage the enterprises to implement the environmental control technologies.

PROPOSALS ON DEVELOPMENT STRATEGY FOR CCT TECHNOLOGY IN CHINA IN 2020

Proposals on CCT Development Arrangement in 2020

The role of government is crucial in the progress of future CCT development in China. The government should encourage the development and deployment of advanced technologies and accelerate elimination of backward technologies through policy direction and environmental restriction. Development of specific technologies should be selected by the enterprise itself in combination with policy direction and market drives.

- **Power generation technologies**
  - New coal-fired units: Internationally commercialized supercritical and ultra supercritical coal-fired units (equipped with FGD) will be the major generating units, supplemented by CFBC units.
  - Retrofit of existing coal fired units: FGD should be installed consecutively in the units if conditions permit. For the old power plants that are not suitable to install FGD due to limitation of space at site or other reasons, low-sulfur coal (or washed coal) with sulfur content less than 0.6%) should be used. At the same time dedusting and denitration should be improved.
  - Demonstration of IGCC and second generation of advanced PFBC should be arranged to accumulate experiences. It is necessary to consider that the demonstrations are carried out in combination with poly-generation technology.

- **Coal-fired industrial boilers**
  - Different regions will develop technologies for industrial boilers that are suitable to local conditions after overall consideration of availability of energy sources, demand of environment and economic conditions, and make all-round arrangement of refurbishment of industrial boilers.
    - <10t/h: switching to briquette and natural gas according to the local energy availability
    - ≥10t/h: supply of high-quality coal step by step, with sulfur content less than 0.5% or central desulfurization and dedusting and developing gradually to the large-scale technologies.
    - >35t/h: introduction of CFB technology and so on, central heating and combined heat and power generation (CHP).
  - New industrial boilers should be developed to large scale, high efficiency and cleanness through adoption of effective measures.
  - It is necessary to improve the operating and automatic level of existing industrial

boilers, and quicken the step of eliminating the out-of-date coal-fired industrial boilers. Control will be exercised from the boiler-manufacturing source. Re-use of eliminated equipment should be stopped resolutely.

- **Chemical production**
  - Priority is given to development of chemical production based on natural gas in regions where natural gas is sufficient, easily accessible, and at lower price. In other regions, chemical production based on advanced coal gasification technology will be developed.
  - Continue to eliminate backward coal gasification technologies and small fertilizer enterprises should be continued.
  - Accelerate R&D and commercial demonstration of large-scale advanced coal gasification technologies so as to achieve independent intellectual property of commercialized technologies as soon as possible.
  - Put more efforts on research of poly-generation technology, so as to reduce further its cost and promote its commercialization.

- **Fuel oil substitution**
  - In the near future, CWM technology will be developed appropriately as the first option for substitution of fuel oil.
  - Coal liquefaction is suitable for China to develop as a strategic reserve technology and as a supplement for making up partial shortage of oil.
  - An overall comparison and authentication of using methanol and di-methyl ether (DME) from coal to replace fuel oil technology, which is based on energy system, should be made for the long term development.

- **Household fuels**
  - Energy used in cities: The proportion of natural gas, LPG, LNG and electricity for household living will rise further. For heat supply in winter seasons, coal-fired combined heat and power generation, and central heating plus follow-up desulfurization units will be popularized, and dispersed small-sized coal-fired boilers will be replaced or eliminated step by step.
  - Energy used in countryside: The proportion of small hydropower, biogas and kindle-saving stoves will further increase and consumption of superior quality coal (washed coal and low sulfur coal) and briquette will go up.
  - The State will reform its mechanism for energy supply for domestic purposes into a new coal supply system. Under the new supply system, priority will be given to supply of superior quality energy for commercial and domestic purposes, supply of bulk coal for domestic use will be canceled gradually, low sulfur and low ash good quality coal will be supplied in priority to medium- and small- sized industrial boilers and other medium- and small-sized end users, and inferior quality coal will be sent to boilers in the power plants for central handling.

- **Steam coal washing**
  - Vigorous development of steam coal washing and processing under energetic policy support in order to supply a multiple of products of steam coal with a diversity of specifications.
  - In the future five to ten years, emphasis will be laid on building and modification of coal preparation plants for steam coal. For newly built steam coal preparation plants, it is encouraged to develop complete technology and installation for modular type of plants with heavy medium cyclone as the core, in order to promote construction of high-efficiency coal washing plant with excellent quality. For existing coal preparation plants for steam coal, efforts will concentrate on improving the technical level so as to meet the demand for a multiple of products and higher quality. The small coal preparation plants, which adopt out-of-date technologies and equipment, resulting in great waste of resources and bringing about serious pollution of environment, will be eliminated step by step.
  - The government will enhance combined development of coal washing & blending, briquetting, CWM through macro adjustment and restructuring of coal market, so as to achieve integration of production, processing, sales, distribution of coal. It is hoped that all steam coal will be washed or processed by other methods, such as, blending screening, etc. step by step before long distance transportation.

Recommendations CCT Development Options in 2020

The general target is to quadruple the GDP of the year 2000 by 2020. The Guiding ideology is to set up a clean coal technology development system with Chinese character based on the energy resources and economic conditions to achieve a concerted development of energy, environment and economy in a long period in China under the energy strategy of “development of a multiple of energy resources with coal as predominant primary energy, increase of energy utilization efficiency and reduction of pollution”. The development target is that total emission of SO_2 from coal combustion will be reduced by around 60% as compared to 2000, the environmental status and energy utilization efficiency will be much improved, under the condition that demand for coal will be 2.2 billion tons in 2020 and coal will constitute over 60% of the consumption mix of the primary energy in 2020.

Based on the above-mentioned targets and ideology, the arrangement of future CCT development for several categories of users, including power generation, industrial boilers, chemical production and fuel oil substitution, domestic use, etc, and measures to be taken are proposed as Table 0-2.

If the clean coal technology development scheme in Table 0-2 is realized, the pollution due to coal combustion in China will be effectively solved by 2020. As compared with emission of SO_2 in 2000, it may reduce by about 9 million tons and PM emission by about 2.million tons in 2020. When compared with the existing technologies of the similar scale, the above-mentioned schemes can reduce emission of CO_2 by more than 500 million tons in 2020. The State will achieve tremendous overall benefits through development of clean coal technologies. It is recommended that the State take reference to this scheme when considering arrangement of the technology development.

Table 0-2 Clean coal technology development options in China in 2020

	Power sector	Industrial boilers	Chemical production	Fuel oil substitute	Household use	Coal washing
Scale	Increase of new coal units by 345 GW	Gross capacity will decline from 1.2 Mt/h to ~1.05Mt/h	8 Mt/a of new and upgraded capacity of synthetic ammonia	/	Proportion of coal may reduce from current 37.9% to 15.5%	800 Mt of washed coal
Coal use	1.4 billion tons	300 Mt	40 Mt	~30Mt	100 Mt	/
Technology options	10% of new units are CFB, and 80% are supercritical, & 10% are ultra supercritical. 50% of existing units install FGDs	Retrofit in Class I, II & III regions with different ratio of natural gas, washed coal, briquette, CFB, FGD & dedusting, in different phases	Of the new capacity, proportion of natural gas and advanced coal gasification will be 50% respectively	CWM may replace 3 Mt/a of oil. Coal liquefaction may produce 5 Mt/a of oil products and 6 Mt/a of chemicals	Clean energy sources mainly in cities and transfer of coal use to countryside. Bulk coal will be forbidden and briquette and washed coal are encouraged	Heavy medium separation, etc. Developing comprehensive processing including coal blending, briquetting, CWM, screening, etc.
Investment	About 1966.3 billion Yuan, 96.3% for new units. 60.9 billion Yuan of fuel cost will be saved as compared to that for subcritical units at the same capacity	~124.3 billion Yuan. Operating cost will increase by 27.2 billion Yuan per annum after the retrofit	944.5 billion Yuan within 20 years, 433.5 billion Yuan less than that coal chemical process is used in all chemical production	119.2 billion Yuan within 20 years	/	/
Benefits	5.64 Mt/a of SO_2 emission Reduction as compared to 2000 and total reduction of 39.3 Mt of SO_2 emission and 6.45 Gt of CO_2 emission within 20 years	Boiler efficiency may increase by nearly 12% averagely. SO_2 PM, and CO_2 emissions may reduce by 2.71Mt, 1.78 Mt, and 80.91 Mt per annum as compared to 2000.	Emission of SO_2 and CO_2 emissions may reduce greatly	>10 Mt of Substitutes for fuel oil	Emissions from coal combustion are slightly less than current level	Steam coal quality will be improved greatly. High quality coal will be supplied in priority to small users. Industrial boilers and domestic use can meet environmental standards.

POLICY RECOMMENDATIONS FOR FUTURE CCT DEVELOPMENT IN CHINA

In order to achieve the goals listed in Table 0-2, the following policies and mechanisms are necessary to push forward the campaign.

Enhance the Unified Management for CCT Development

- To resume the activities of the former National Leading Group for CCT Dissemination and Planning on the basis of the current Energy Department of the National Development & Reform Commission (NDRC).
- To reformulate a national CCT development plan, which will sort out the focusing points and sequence of priority, and make a united arrangement and control of development of clean coal technologies in whole country.
- It is requested that all the places realistically make the local energy development plan and CCT development plan according to the national environmental target and based on availability of indigenous energy resources, economic capability, etc. It is permissible that all the places will develop technologies suitable for local conditions to avoid impose uniformity on all regions.

Form a United Policy System for CCT

- The national unified CCT policy should be formulated to organically combine CCT with environmental protection, energy conservation, and development and utilization of high technology.
- To work out specific implementing regulations for relevant existing national laws and policies, e.g. “ Atmospheric Pollution Law”, “ Coal Law”, and some national macro statutes and policies for effective enforcement of law, regulations, rules and policies.
- To provide necessary incentive policies to large-scale commercialized project of clean coal technology.
    - It is necessary to set up special funds for technology development, or fund-raising channels and provide low interest loan for commercialized projects of clean coal technology.
    - Preferential taxes should be given to clean coal technology, which is of great importance to environmental protection and social benefits, such as zero rate of investment direction regulatory tax, transitional reduction and exemption of VAT and income tax and proper reduction and exemption of land holding tax.
    - The imported equipment and technology necessary for national-level large-sized demonstration projects of CCT may enjoy reduction or exemption of import tariff and VAT for imports.

Formulate Reasonable National Standards

- In view of the fact that most of coal-fired equipment follows a general emission standard, it is necessary to formulate some reasonable special standards for all the coal-fired equipment as supplements of the general standard.

- Current unreasonable emission standards and coal quality standards should be revised and refined and the instructive coal quality standards for small users should be changed into mandatory standards.
- To amend and improve the existing unreasonable emission standards and relevant coal quality standards. The coal quality standard for small-sized coal users will upgrade from guidance standard to mandatory standard.
- To work out a new guiding standard for steam coal pricing, so that premium steam coal has a higher price. There must have a greater difference between the good and inferior quality of steam coal.
- The development of advanced technologies will be guided by environmental standards, but not by restrictions on fuels or coal combustion technologies.

Strengthen Development and Early-Stage Research for Key Technologies

- To enhance R&D of large-sized key technology and equipment, such as, ultra supercritical boiler, steam turbine, flue gas cleanup system, large CFB boiler, coal gasification, coal liquefaction technologies, etc., so that China will get hold of autonomous intellectual property of technologies as soon as possible.
- To arrange necessary first phase research for development of technologies of long-term strategic importance, e.g. relevant fundamental research on poly- generation technology, overall comparison and authentication as well as first phase research on coal-based methanol and DME to substitute fuel oil based on energy system, etc.

Make more investment for R&D and commercial demonstration

- To put more investment in R&D. The government will set up funds for R&D of fundamental and universal technologies and build R&D bases. The State will arrange subsidies for digestion and absorption of the key technologies introduced.
- To increase investment in demonstration projects. Financing support should be given to projects with good environmental protection benefits, heavy investment and certain risks, such as coal gasification and coal liquefaction. Low interest loan will be given to enterprises that undertake demonstration projects. Preferential policy will be given to draw investment from non-governmental organizations and enterprises in order to promote demonstration and commercialization of new technologies.

Enhance environmental monitoring of coal-fired users

- To request all the big coal users (including non-power sector) to install FGD units and continuous emissions monitors (CEMs), have specific requirements on operating rate and serviceable rate of equipment, and inspect their operation periodically and non-periodically. At the same time the government will make efforts to strengthen the establishment of the environmental quality monitoring network.

- To strengthen supervision and management of medium- and small-sized coal-fired users, such as, to popularize the installations of continuous emission monitors in large- and medium-sized industrial boilers, strengthen the management of coal supply to medium- and small-sized users and set up energy contract management mechanism and socialized service system suitable for Chinese conditions.
- To continue to restrict and eliminate the out-of-date medium- and small-sized coal utilization equipment and technologies, and to strengthen law enforcement.
- To allow raising the level of SO_2 emission fee in areas with stringent requirements on environment and to introduce as soon as possible the SO_2 emission trading system. The environmental capacity should be regarded as a scarce resource for free trade in the market to persuade the polluters to apply actively the CCTs.
- To strengthen the propaganda on CCTs to enhance public consciousness of environment and awareness of CCT development, and environmental supervisory capacity. It is necessary to raise the vocational level of enforcement staffs and their capability of guiding the enterprises through various modes like training, etc.

Set up and perfect coal supply market mechanism

- The government shall make efforts to realize standardization and serialization of steam coal products under the guidance of policies, measures and standards to achieve provision of a variety of high quality steam coal products with multiple specifications. The unprocessed coal is not allowed to enter the market as a product.
- The existing coal consumption and distribution modes should be reformed. The links of coal sales should be reduced through improvement of policy-making and management. The coal supply system should be rectified and sorted out. A new coal supply system, which integrates production, supply, sales, transport and distribution of coal, will be developed.

Set up a mechanism for CCT development with enterprises as the main body

- The State, as a main body of policy-related investment, shall devote its efforts to support earlier-phase R&D and commercial demonstration of key technologies. At the same time the State shall encourage through policies the enterprises to be the main body of operative investment in commercial development of CCTs and encourage them to set up technology development centers.
- The government shall through policies encourage investment from a multiple of main bodies, all types of combination and cooperation among different industries and trades (e. g., combination of coal, electricity and chemical production), development of modern complexes for coal processing, conversion and utilization, and development of large CCTs projects in combination with making plans for building large-sized energy and coal complexes.

- The government will adopt a strategy of “grasping the large”. It encourages that the large sized enterprises or groups, to expanding investment horizontally or vertically. That is to say, it encourages them to enter into the domain of coal production, utilization and conversion trans-regionally, conglomerately and cross ownership systems. The phenomena of separation of coal upstream and downstream industries and self- closed circulation within an industry should be overcome. The superiorities in resources, production, technology and funds between the upstream and downstream as well as among different regions could supplement each other, which may enhance competitiveness of enterprises and promote technical progress, and result in a superior conglomerate, consisting of a number of medium- and small-sized enterprises headed by a large enterprise.

Policy study on development and utilization of CCT

1. Introduction

Fossil energy is the key primary energy in the world. Primary energy consumption mix is changing to be multiple and high quality due to many driven factors such as resource, economy, environment, science and technology. Although renewable energy technology will develop rapidly in next 20-30 years, fossil energy will still dominate the world fuel mix. The world continues to face the competition among coal, oil and gas, which is the coordination and integration issue of energy availability, economy and cleanness.

The proven recoverable reserve of coal in China ranks 3rd in the world while oil ranks 11th and natural gas 19th. Coal is relatively abundant in China's fossil energy sources and the proven recoverable reserve reaches more than 200 billion tons, more than 10 times equivalent to total petroleum and natural gas reserves if calculated based on equivalent calorific value.

Coal is the main energy source in China and it continues to take heavy percentage in China's primary energy consumption structure. Percentage of coal consumption reduced from 76.2% in 1996 to 66.3% in 2002 along with the adjustment of energy mix and industrial structure in these years. Total coal consumption reached 1.39 billion tons in 2002 in China.

About 50% of coal consumption is used for power generation, 30% for industrial boilers and direct combustion for household use (mainly raw coal). Environmental pollution problems caused by inferior coal quality and backward combustion technology have affected sustainable development of national economy and health of the people. Inferior energy efficiency and deteriorating energy environment require the development of advanced clean coal technology (CCT) urgently so Chinese government has been attaching more and more importance to clean combustion and utilization of coal.

Based on Chinese energy resource conditions and economy levels, forecast data indicate that coal consumption will account for more than 60% of total primary energy consumption in 2020, reduce a little compared with current situation. But the amount of consumption will increase to at least 2.2 billion tons. This means that coal will dominate China's energy structure in quite a long period and coal continues to play an important role in economic development in China.

Forecasts from many sources indicate that, based on Chinese energy source condition and economic level, the proportion of coal consumption will still be over 60% of the total consumption of primary energy, slightly lower than current proportion, and its total consumption will rise, over 2.2 billion tons in 2020 in China. That is to say, the status of coal predominance in the energy mix in China will not change in a considerably long period of time and coal will continue to play an important role in economic development in China[1].

Therefore, in the next 20-30 years, China should accelerate development of clean coal technology and achieve clean and effective utilization of coal according to characteristics of its own resources; meanwhile it should strengthen adjustment of energy mix and increase consumption of clean energy sources.

From the point of view of economy, coal is the cheapest fuel. The prices of natural gas, diesel oil and heavy oil are 4 times, 4 times and 3 times respectively as high as steam coal of equivalent calorific value in Beijing. In shanghai, the above numbers become to 4 times, 3 times and 2 times respectively. After considering the environmental factors, the ratio of operating costs of industrial boilers from coal, heavy oil and natural gas is 1:2.3:3.1. So the price of coal is the cheapest in fossil energy sources in China.

From the view of environment and energy saving, coal could be used cleanly. Successful experiences abroad show that clean coal technology can reduce emissions, increase efficiency and save energy. For instance, coal preparation can reduce 50-80% of ash content and 30-40% of sulfur content, combustion of washed coal can increase efficiency by 3-8%; sulfur capture briquette can reduce 30-40% of SO_2 emission; circulating fluidized bed (CFB) with in-bed desulfurization can reduce 85% of SO_2 emission; coal gasification and liquefaction technologies can convert coal into clean secondary energy; flue gas clean-up technology can decrease 90% of SO_2 emission from coal combustion.

From the point view of energy security, there are rich coal reserves in China. The ratio of coal reserves to mining is higher than that of petroleum and natural gas. This is the foundation of coal to be supplied steadily. In response to petroleum and gas shortages, coal liquefaction technology can convert coal into clean liquid fuel and CWM can also replace some of fuel oil.

Clean coal technology is a technical system composed of new technologies including coal mining, combustion, conversion and pollution control, which aims to improve coal utilization efficiency and decrease environmental pollution. It can ensure energy security, while well utilization of the abundant and cheap coal. Clean coal technology can begin from the source, using different ways to improve coal quality and reduce SO_2 emission. It can also save energy, realize whole-process clean and high-efficiency utilization of coal and pollution control from coal mining to utilization through a combination of different technologies, to solve current coal-related environmental problems. Although coal-dominated energy mix will not change in a considerable long period of time, development of clean coal technology can increase the conversion ratio from coal to cleaner electricity, gas and oil products, improve end energy consumption mix and realize high-efficiency and clean end energy sources. Much can be accomplished in this respect.

Implementing CCT strategy and promoting its industrialization is the fundamental way to increase energy efficiency and optimize end-energy mix in China, a practical option to solve energy balance between supply and demand in China, and a strategic and necessary choice to realize coordinative development of energy, environment and economy and to secure energy safety and sustainable development in China. Thus, China should develop CCT vigorously in next 20-30 years.

The speed of CCT development in China is not satisfactory because of various reasons. Development and utilization of many techniques lag behind the demand of market or environment. Such and such problems appears in the process of commercialized application and popularization of CCT, for example, there is no necessary policy system related to energy, environment, economy, finance and taxation to form a mandatory and incentive role for laws and regulations, resulting in no enthusiasm for enterprises to develop CCT by themselves, lack of independent intellectual property rights for advanced technologies and so on. How to push the development of clean coal technology in China? What is the crux that affects the development of CCT?

The purpose of the study is trying to find out the main obstacles to CCT development in China through review of CCT development and relevant polices and comparison of experiences at home and abroad. Based on technical and economic appraisal of CCTs for end users such as power generation, industrial boilers, chemical production and fuel oil substitution, suggestions on how to develop clean coal technology in China are proposed. Furthermore, recommendations on policies and measures are put forward based on above studies, which can provide assistance to Chinese government in its establishment of clean coal technology development policies.

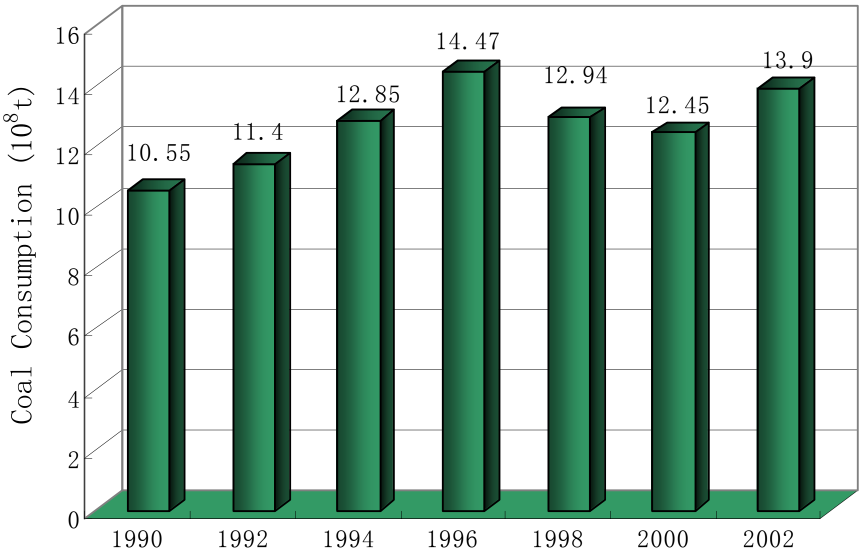
2. Status and Trend of Coal Consumption and Demand by sectors

2.1 Introduction of coal consumption in various sectors in China

Chinese economy has been developing rapidly for over 20 years since reform and opening. Meanwhile, energy production and consumption nationwide have also grown dramatically. Primary energy consumption in 2002 reached 1.48 billion tce, two times of 603 million tce in 1980.

In 2002, primary energy consumption mix was: 66.1% of coal, 23.4% of petroleum, 2.7% of natural gas and 7.8% of hydropower. Compared with that in 1980, proportion of coal consumption in total primary energy consumption dropped by 6.1% and petroleum rose by 2.7%. The percentage of natural gas dropped slightly, but total consumption amount rose greatly. Coal is still the major energy source in China.

In late 1990s, production of coal was surplus in China so a series of measures were taken by Chinese government such as to stop operation of small coalmines so as to control coal production. Swift growth of coal production and consumption turns up again under vigorous energy demand growth boosted by rapid growth of national economy in past 2-3 years (see Fig. 2.1).



Source: China Statistical Yearbook 2003 (data of 2002 are estimated.)

Fig. 2-1 Coal consumption in China in recent years

According to elementary statistics, total amount of domestic coal consumption reached 1.315 billion tons in 2002 in China and has risen in 2003.

Chinese coal consumption is mainly in industries. Energy consumption in industrial sectors takes more than 80% of total primary energy consumption in China. Coal consumption is concentrated on four main coal-consuming sectors including power, building materials, metallurgical and chemical industries.

In 2002, 720 million tons of coal was used for power generation and heating, accounting for 54.8% of total domestic coal consumption, of which, 646 million tons was used for power generation, accounting for 49.12% of total domestic consumption. Subtotal of coal consumption in metallurgical, building materials, chemical and coal industries reached 427 million tons, or 32.47% of total domestic coal consumption, of which, 9.1% for coke production, 3.0% for feedstock gas production in chemical industry, 27% for heat supply and heating in industrial boilers and kilns. Coal consumption in non-power industries such as metallurgical, building materials, chemical, coal, papermaking and food industries took 40% of total coal consumption. See Table 2.1 for details.

Table 2-1 Coal consumption in major industries and for household use in 2002

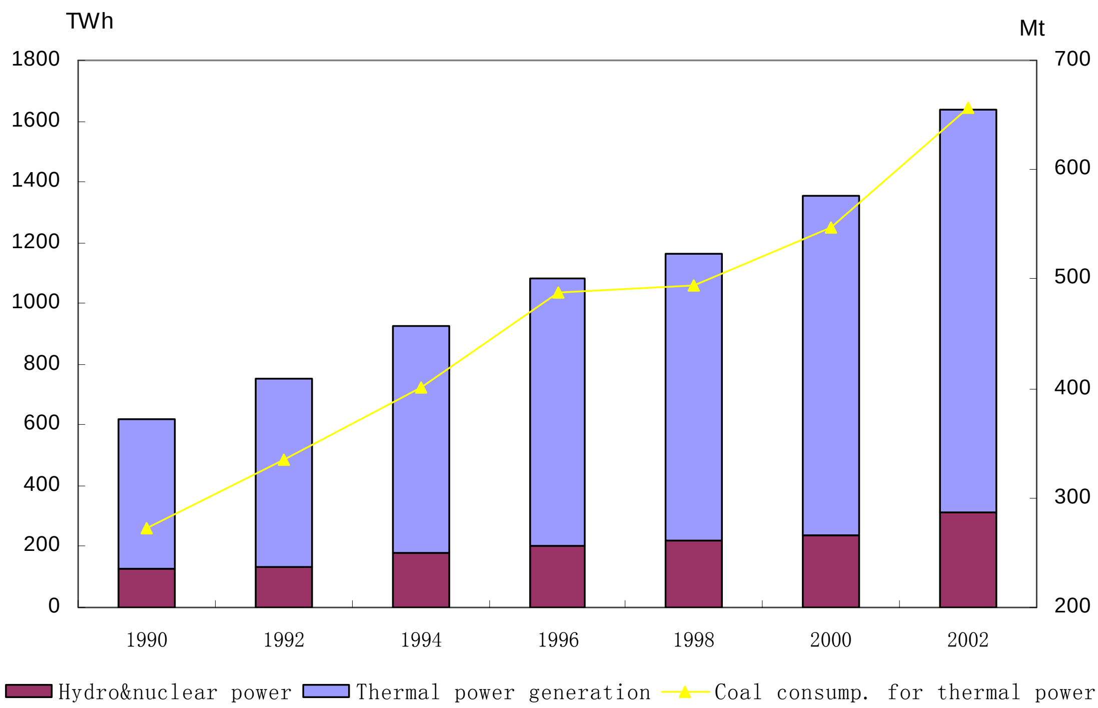
Unit: Mt/a

Year	Total	Power	Heating	Metallurgical	Building materials	Chemical	Coal	Others	Household use
2000	1245.37	546.11	66.92	123.23	159.4	76.4	67.27	285.11	79.07
2002	1315	656	74	120	160	80	67	90	78

Source: data of 2000 from "China Statistical Yearbook 2002"; data of 2002 are estimated

Coal consumption tendencies in recent years were that: industrial consumption grew rapidly with fastest speed of power industry; percentage of household use decreased continuously but the consumption amount kept steadily with annual decrease in large and middle cities but increase in small towns and rural areas. Household consumption of coal in 2002 was 78 million tons, about 6.0% of total coal consumption in whole country.

Fast growth of coal consumption in power industry was the major contributor to total increase of domestic coal consumption in recent two to three years (see Fig. 2.2).



Source: China Statistical Yearbook of past years, China Energy Statistical Yearbook(2000-2002)

Fig. 2.2 Relationship of coal and power growth

2.2 Main problems in coal consumption

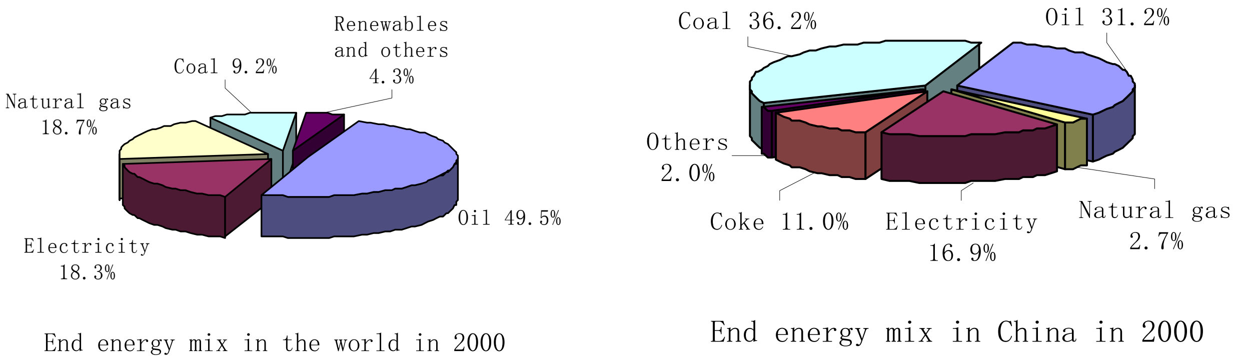
(1) Too much percentage of coal in end energy consumption mix

Chinese end-energy consumption mix has been improved greatly in these years due to adjustment of energy mix. Coal took 59.3%, oil 19.3%, electricity 7.3%, natural gas 3.2% and others 10.9% in end energy consumption mix in 1980. The proportion of oil and electricity consumption rose to 31.2% and 16.9% respectively and coal dropped to 36.2% in 2000. However, compared with world average level, percentage of coal in end energy consumption is still high and percentage of electricity consumption is still small. The gap is wider if compared with advanced countries (see Fig. 2.3).

(2) Low conversion level of coal

Chinese government has been paying more and more attention to conversion of coal to clean secondary energy sources (electricity, gas, oil, etc.) through various conversion technologies. Nowadays, about 50% of coal has been converted to electricity in China, and the conversion ratio is increasing greatly in recent years, but still less than that in advanced countries where coal consumption for power generation accounts for 90%.

At present, only 3-4% of coal is converted to gas in China (including coal gas for chemical production).



Sources: China Statistical Yearbook and Energy Policy Research

Fig. 2-3 End energy mix in China and in the world

(3) High proportion of coal for direct and high-efficiency combustion

Nearly 40% of coal is used for direct combustion in thermal power, industrial boilers and household use, resulting in serious low-efficiency problem of coal combustion in small users. Average operating efficiency of industrial boilers in China is about 60%, 20% less than international level. Combustion efficiency of direct combustion of coal for household use is very low, sometimes less than 20%.

(4) Inferior coal quality

Average sulfur content in commercial steam coal in China is about 1.01% and average ash content is 23.85% (see Table 2.2).

In 2002, washing rate of raw coal in China was 33% with 456 million tons of raw coal washed. Most of coal washed was coking coal, and steam coal washed only accounted for 31.7%. Washed steam coal was used mostly as feedstock for chemical production or was exported and little was used in power generation or other type of combustion. Washing rate in China is far less than that in major coal producing countries in the world. For example, in USA, washing rate is 55%, average sulfur content in commercial steam coal is about 0.95% and ash content is

9.2%.

Table 2-2 Ash and sulfur content distribution in commercial steam coal in China

(Data of 1999) (%)

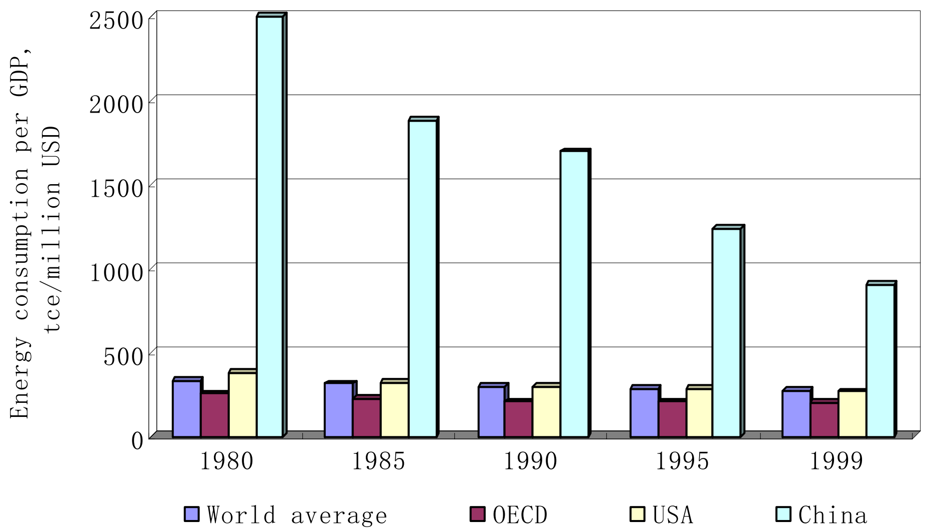
Ash content	Average	≤5.00	5.01~10.0	10.01~20.0	20.01~30.0	30.01~40.0	40.01~50.0
	23.85	0.48	2.74	34.95	40.70	16.60	4.53
Sulfur content	Average	0.5	0.51~1.00	1.01~1.5	1.51~2.0	2.01~3.0	3.0
	1.01	39.56	29.69	15.34	2.98	5.12	7.31

Source: 10th Five-year Plan and Development Program to the Year 2015 for CCT of Coal Industry

(5) Backward coal utilization technology and low efficiency

In recent years, coal fired power generation technologies developed rapidly and the gap between China and international level was lessen gradually. In 2001, average unit coal consumption for power supply was 385gce/kWh in China, 44gce/kWh higher than world advanced level. Coal utilization technologies in other industrial sectors are out of date, especially coal utilization equipment for medium-small users.

Comprehensive efficiency of processing, conversion, transportation and end utilization of coal is only 31-32% in China, averagely 7-8% lower than that in advanced countries. Unit energy consumption of major energy-consuming products in China is much higher than that in industrial countries. In 2000, energy consumption per GDP in China was 3.4 times of average world level, 3.5 times of that in USA and 9.7 times of that in Japan (see Fig. 2.4).



Source: Energy Policy Research, 2002, (1)

Fig. 2-4 Energy consumption per GDP in China and in the world

(6) Serious environmental pollution due to coal combustion

Based on Report on the State of the Environment in China 2002, total SO_2 emission was 19.27 million tons, smoke emission was 10.13 million tons and industrial dust emission was 9.41 million tons in 2002. Acid rain areas were about 30% area of the territory. Relevant studies indicated that SO_2 emission has a close relationship with coal consumption, and 75% of SO_2 emission in China was caused by coal combustion.

Large amount of direct combustion of coal in end energy consumption, backward coal utilization technology and equipment, low energy efficiency and high energy-consumption level per GDP are main reasons of serious environmental pollution in China.

2.3 Future tendency of coal consumption in China

The formulation of national medium- to long-term energy development strategy and energy development plan of 2020 is in progress. Relevant organizations and departments are carrying out relevant studies and researches in combination with the energy development plan. Forecasts of energy demand for 2020 from different sources are listed in Table 2.3.

Table 2-3 Forecasts of energy demand in China in 2020 by different sources

Sources	Year	Base year	Forecast method	2010 (M tce)		2020 (10^8 tce)	
				Total	Coal	Total	Coal
IEA	2002	2000	Segment analysis	1860	1220	2439	1512
Energy Research Institute, NDRC	2003	2000	Scenario analysis	2068	1365	2896	1788
CAE	1996	1990	Segment analysis	2270-2400		2900-3150	
China National Association of Coal Industry	2003	2002	Segment analysis	2020	1228	2360	1464 -1578

Source: China Energy Outlook 2002 (IEA), Scenario Analysis on China Energy Demand in 2020 (by Energy Research Institute of NDRC), Development and Utilization of Chinese Coal Resource during 10^{th} Five-Year Period (by China National Association of Coal Industry)

According to the forecast of Scenario Analysis on China Energy Demand in 2020 (by Energy Research Institute, NDRC), if China can quadruple the GDP of the year by 2020, total energy demand will reach 2.896 billion tce based on scenario B (intermediate scenario), of which, coal demand will be 2.5 billion tons, 61.7% of domestic primary energy consumption. Total energy demand will be 3.28 billion tce and 2.466 billion tce respectively based on scenario A (business-as-usual scenario) and scenario C (strengthening the influence of policies of economy, energy and environment), of which, demand for coal will be 2.9 billion tons and 2.05 billion tons respectively, 63.2% and 59.4% of total energy demand.

According to the forecast of Development and Utilization of Chinese Coal Resource during

10th Five-Year Period by China National Association of Coal Industry, if GDP grows at the speed of 7.3% during 11th Five-Year period and 7.0% from 2010 to 2020, domestic primary energy demand will increase to 2.02 billion tce in 2010 and 2.36 billion tce in 2020. If the utilization of oil, natural gas, hydropower and nuclear power is taken into consideration, total coal demands will be 1.8 billion tons in 2010 and 2.21 billion tons in 2020, of which, net coal export will be 80 million tons in 2010 and 90 million tons in 2020. Proportion of coal in domestic primary energy consumption will be 63% in 2010 and 62% in 2020 (see Table 2.4).

Table 2-4 Coal demands in main sectors and forecast on import and export

Unit: Mt

	2000	2001	2002	2010	2020
Total	**1283**	**1350**	**1385**	**1800**	**2050-2210**
Domestic demand	**1230**	**1260**	**1310**	**1720**	**1960-2120**
Power industry	591.92	645.61	720	1095	1350-1510
Metallurgical industry	109.5	115	120	215	220
Building materials industry	160	160	160	150	130
Chemical industry	80	80	80	90	100
Others	28858	25939	22500	12000	10000
Net export	5293	8769	7500	8000	9000
Import	5505	9013	8500	9000	10000
Export	212	244	1000	1000	1000

Source: Development and Utilization of Chinese Coal Resource during 10th Five-Year Period

All completed and ongoing forecasts indicated that in next 20 years, whether from the point view of security and stability of energy supply or from the point view of economy of energy, China has to take coal as the dominant primary energy source. By 2020, total coal demand will increase greatly and reach twice as much as that in 2000, accounting for more than 60% in primary energy mix. Along with the adjustment of energy mix and improvement of energy utilization level, coal consumption will be further concentrated on power, building materials, metallurgical and chemical industries, especially on power generation sector. Coal consumption in small and middle boilers will reduce dramatically. Coal consumption for household use in urban areas will drop continuously but that in rural areas will increase. Total coal demand for household use will not change greatly.

Researches based on different sectors are made in this report according to the forecast in Table 2.5. In order to further increase the utilization of clean energy, we assume that total coal demand in 2020 will be 2.12 billion tons, which is approximately consistent with the forecast of high option (scenario) C in Scenario Analysis on China Energy Demand in 2020.

Table 2-5 Forecast on coal demand in different sectors in 2020

	Total	Domestic subtotal	Power generation & heating	Coking & injection	Production of chemical feedstock & fuel oil	Household use	Industrial boilers	Export
Demand (Mt)	2210	2120	1400	240	80	100	300	90
% of domestic subtotal	/	100	66	11	4	5	14	/

Under the condition that coal dominated energy consumption mix, which is determined by energy resources, economic level and so on, will not change fundamentally in China in next 20-30 years, facing rapid coal consumption in the future, China must develop CCT vigorously and carry out whole-process pollution control in order to ensure obvious improvement of air environment and effective increase of energy efficiency while keeping fast development of social economy. Otherwise, China would face more serious environmental pressures.

The development of CCT can effectively reduce particulate and SO_2 pollution and increase coal utilization efficiency, and be benefit for environmental protection; can convert coal into cleaner oil and gas while good use of rich coal resource, which can offset the shortage of oil and gas supply to a certain extent and secure energy supply. It can widely increase the technical and equipment level of coal combustion and conversion, develop more advanced coal utilization technologies and adjust industrial structure. It can also increase enterprises' market competitiveness and economic benefits through development of new technologies in favor of response to the challenges and opportunities after China's entrance to WTO. It will efficiently improve the end energy mix and play an active role in the coordinative development of energy, economy and environment. Development of CCT is the practical and necessary option to realize sustainable development of Chinese society and economy.

3. General Situation of CCT Development in China

3.1 Review of CCT Development in China

Chinese government has been paying much attention to the development and dissemination of CCT. According to the instruction of State Council, National Leading Group for CCT Dissemination and Planning was set up in 1995, with former State Development and Planning Committee (SDPC) as group leader, former State Science and Technology Committee (SSTC) and former State Economic and Trade Committee (SETC) as vice group leader, 13 relevant ministries, committees and administrations as group members. In 1997, approved by State Council, SDPC issued China's 9th Five-year Plan and Development Program to the Year 2010 for Clean Coal Technology. The Program becomes a guideline to push forward the development of CCT in China and it pointed out that CCT was composed of 14 technologies in areas of coal preparation, processing, conversion, advanced combustion and flue gas clean up.

Hereafter, related governmental departments including former SSTC, former SETC, Ministry of Science and Technology, State Environmental Protection Administration have made a lot of efforts in promulgation and implementation of relevant policies, arrangement of technical research programs and introduction of advanced technologies. At present, many technologies including advanced coal preparation, CWM, CFB, wet desulfurization technologies have realized localization and put into commercial applications. IGCC and coal liquefaction technologies have entered into commercial demonstration stage. CCT has made considerable progress in China.

Along with the development of CCT at home and abroad, some Chinese experts suggested that the coverage of CCT be broadened, including clean and high-efficiency utilization of coal (including poly-generation and fuel cell) as a new CCT area, adding conventional supercritical and ultra super-critical power generation technologies into the area of “high-efficiency coal combustion and generation technology”. Then CCT in China is comprised of 18 technologies in 5 areas (see Table 3-1 for details).

Table 3-1 CCT areas in China

Areas	Process	Technologies and their development & dissemination stage
Coal processing	Before utilization	Coal washing (application and dissemination) Briquette (dissemination for household use; demonstration and application for industrial briquette) Coal blending (application and dissemination) Coal water mixture (application and dissemination)
High-efficiency combustion and power generation	During combustion	CFBC（scale-up and dissemination） PFBC（demonstration） Conventional supercritical and ultra supercritical units Transformation of small and middle industrial boilers
Coal conversion	During utilization	Coal gasification (large-scale gasification, mild gasification, underground gasification, etc.) Coal liquefaction (engineering demonstration)
Clean and high-efficiency utilization	During utilization	Fuel cell (development) Poly-generation (cogeneration of multi-products incl. electricity, gas, liquid fuel, heat coal gasification and IGCC as head and) (R&D)
Pollutant control and comprehensive utilization of resources	After combustion	Flue gas clean up (de-SO_2 & de-NO_x)（development and localization） Flue gas clean up (dust and particulate control) Comprehensive utilization of fly ash（application and dissemination）
	During mining	Coal bed methane (development, application and demonstration) Eco-environmental technology in coalmines: comprehensive utilization of mine water, coal refuse

3.2 Review of CCT related policies in China

China has made a lot of efforts in policies and laws relating to clean energy sources/

technology and environmental protection. Some laws[a] such as the Law on Prevention and Control of Atmospheric Pollution and the Law on Coal were issued as well as many regulations[b] and policies[c] to promote the development of CCT in China. All these are called "policies" in this report, including three kinds: technical, environmental and incentive policies[d].

3.2.1 Technical policies

Unlike OECD countries where CCT development is driven by environmental regulations and policy incentives, the development of CCT in China is significantly driven by the promotion of technical policies, supported by central and local governments' environmental policies and economic incentives. Technical policies issued by include the followings: scientific & technical policies and industrial policies to encourage the development of CCT, clean energy technology and energy saving technology. These policies could be divided into national comprehensive policies and local policies.

Chinese government issued CCT-related technical policies, including R&D policies and industrial policies to encourage the development of CCTs, clean energy technologies, and energy conservation. These technical policies have been formulated at both the national and local levels[e].

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[a] Since 1995, China has formulated laws and regulations on environmental protection, such as the Law of People's Republic of China on Coal, the Law of the People's Republic of China on Electric Power, the Law of People's Republic of China on Energy Conservation and Regulations on Environmental Protection and Management of Construction Projects, amended the Law of the People's Republic of China on Prevention and Control of Atmospheric Pollution twice. The "Crime of Damaging Environmental Resources" was added to the Criminal Law of the People's Republic of China after amendment. By the end of 2001, the State has formulated and perfected 13 laws on management of natural resources, 6 laws on environmental protection, more than 100 administrative regulations in aspects of population, resources, environment and disasters. The environmental departments have issued more than 90 regulations on environmental protection, and over 1,020 regional laws and regulations on environmental protection.

[b] The regulations refer to all the stipulations and rules approved by the State Council for execution.

[c] Relevant national policies are issued by governmental departments individually or jointly. The governmental departments which are responsible for management of Clean Energy Resources and Clean Coal Technology are: State Development Planning Commission (responsible for large-scale capital construction project), State Economic and Trade Commission (technology updating projects), State Ministry of Science and Technology (research projects of basic theory or application technology research), and State Environmental Protection Administration (environmental assessment and supervision of all the projects) and Ministry of Foreign Trade and Economic Cooperation (important import and export projects for technology and equipment). These governmental departments can issue relevant policies individually or jointly. In addition, relevant industrial sectors make policies for their own sectors. Local governments or department issued local policies

[d] Technical policies are mostly issued solely or jointly by SDPC, SETC, MOST and/or organizations in China's industrial sector. Technical policies are generally instrumental in encouraging or discouraging technical development in China. Environmental policies -- which typically originate from, or are directed by, SEPA -- generally define and establish environmental requirements and constraints. Economic incentive policies -- which often originate at the Ministry of Finance and/or several other governmental departments – propose and establish possible economic incentives in terms of finance, taxation, and charging.

[e] The GoC had previously formulated sector-specific policies. Sectoral policies have not recently been formulated for non-power sector consumers mainly because administrative departments for various sectors had been discontinued.

a) R&D policies

R&D development orientations are pointed out clearly in a series of technical policies and development plan.

b) Industrial policies

China also issued various industrial policies to guide the orientation of technical development and support comprehensive utilization of resources. These policies request to adopt advanced and low-emission technologies in new enterprises, upgrade and retrofit existing technologies in existing enterprises and eliminate backward small enterprises and equipment. Incentive or compelling clauses are often contained in these policies.

3.2.2 Environmental policies and measures

The overall strategy for formulating environmental regulations and policies in China might be described as a "coordination of environment and economy" with emphasis on gradual strengthening environmental controls while accounting for the practical aspects of current economic realities in China. Chinese environmental protection has evolved from one that has concentrated on single control of emissions concentrations from polluting sources to one that has focused on both control of emissions concentration and control of total emissions. Increasing stricter environmental requirement and total emission control in two control zones (acid rain control zone and SO_2 emission control zone) force some cities to have to adopt stricter and stricter environmental policies and environmental enforcement, resulting in disseminations and applications of new technologies, such as advanced power generation technologies, desulfurization and de-dusting technologies, etc. Environmental policies issued by Chinese government are classified as follows:

a) Change air pollution control measures from single control of emission concentration to total emission;

b) Set up national environmental quality monitoring network to carry out emission monitoring;

c) Set stricter environmental requirement and standards and strengthen environmental enforcement;

d) Encourage switching to clean energy sources from coal or control the quality of coal.

Joint promulgation and execution of environmental policies and technical policies has achieved significant achievement[f] in improvement of Chinese environmental conditions. Under the

[f] SO_2 emission from the "two control regions" was reduced by over 1.8 Mt in 2000 as against 1997. Within 175 cities in the "two control regions", the number of cities with SO_2 emission concentration meeting the National Second Class Standard, increased from 82 in 1997 to 110 in 2000. The deterioration trend of acid rain in China was controlled.

condition that the average annual growth rate of GDP being at 8.3%, the total emission of 12 main pollutants including SO_2, smoke, industrial dust, COD in wastewater, oil-related pollutants and heavy metals, was reduced by 10-15% in 2000 as against that in 1995[2].

3.2.3 Incentive polices

Main economic incentives for air pollution control in China are SO_2 emission fee and emission trading scheme and other familiar economic incentives such as subsidy policy, taxation policy, and low interest (discount interest) loan policy.

3.2.4 Case studies on promotion rule of Chinese policies in CCT development

Taking power industry as an example, Chinese government has issued a series of policies to support development of clean coal power generation technology. Please see Table 3.2 for details.

According to the guideline of national policies, relevant governmental departments have initiated National Basic Research Priorities (973) program, high-tech R&D (863) program, key technologies R&D program, national special R&D projects, etc. to support R&D and commercialization of advanced combustion and power generation technologies. These technologies included CFBC, ultra supercritical power generation, pressurized fluidized bed combustion (PFBC), IGCC, flue gas desulfurization (see Appendix Table A1). Meanwhile, China has introduced several CFBC boilers in a planned way, large-capacity supercritical generating units, a batch of advanced flue gas desulfurization technologies and equipments (see Appendix Table A2).

CFBC is the technology with independent intellectual property right that develops at fastest speed. The role of policy could be seen from development of CFBC in China. On one side, together with technology import, the government arranged a series of R&D projects of key CFBC technologies so that research institutes could cooperate closely with main manufactures to develop technologies with independent intellectual property rights; On the other side, the government requires that new condensing PC boilers with capacity less than 220t/h (50MW) and without flue gas treatment system not be approved except CFBC since 1996, new condensing PC boilers with capacity less than 410t/h (100MW) and without flue gas treatment system not be approved except CFBC since 1998, and condensing PC boilers with capacity less than 130t/h (25MW) and without flue gas treatment system retire except that with flue gas cleanup system or retrofitted into CFBC since 1999.

In 1996, the State Economic & Trade Commission, the State Development Planning Commission, Ministry of Finance and State Administration of Tax amended List of Resources for Utilization. It encouraged development of coal refuse fired power plants and CHP generation, requested that refuse fired power plants choose CFBC boilers with capacity more than 75t/h; regulated that refuse (stone-like coal and oil shale) and slime fired power plants approved after March 1, 1998 must use CFBC boilers and specific preferential taxation policies were provided.

Table 3-2 Main policies on clean coal power generation in China

R&D policies	Industrial policies	Incentive policies	Environmental policies
Encourage development of PFBC, CFBC with large capacity and advanced FGD[3]	In power sector, clean coal generation is listed in "Catalogue of Industries, Products & Technologies Currently Encouraged by the State". CFBC ≥ 100MW and FGD and de-NOx equipments are included in machinery industry.[4, 5]	SDPC delivered a notice for preferential policy on earlier stage work and production operation of demonstration of CCT generation in July 2001[6].	Trial program for SO_2 emission fee due to industrial coal combustion.[7]
Encourage development and dissemination of FBC suitable for domestic coal[8]	FGD and complete set of equipment, high-efficiency & low-pollution coal fired generation system and large supercritical units are listed in Hi-Tech Commercialization Priorities Currently to be Developed by the State.[9]。	Preferential policy to encourage and support enterprises in comprehensive utilization of resources[10]	Confirm the scope and criteria of SO_2 emission fee[11]
Strengthen R&D of new generating technologies such as FBC, IGCC, etc[12]	Technical development orientation and emphases in power sector: 1) large supercritical units; 2) clean coal power generation (CFBC, PFBC & IGCC); 3) Environmental technology (FGD and low NOx technology in thermal power plants). Development emphases in environmental machinery: CFB boilers and in-bed de-SOx & de-NOx, CFBC, PFBC, IGCC, etc.[13]	Regulate clearly that no network charge for power plants with comprehensive utilization of resources. Other preferential policies include halving the VAT for power plants that use coal refuse, slime, oil shale and wind energy from 1st Jan., 2001[14]	In two control zones, new thermal power plants and other large and middle plants should install necessary desulfurization and de-dusting equipment or take other measures to control SO_2 and dust emissions if they could not use low-sulfur coal. Existing plants that could not use low sulfur coal should take measures to control SO_2 and dust emissions. Government encourages enterprises to adopt advanced desulfurization and de-dusting technologies.[15]
10th Five-Year Plan for Energy Conservation & Comprehensive Utilization of Resources stressed the development of large coal refuse generation technology, CFBC ≥ 410t/h, IGCC, high-efficiency and low pollution coal fired generation technology, etc.; demonstration of CFBC ≥ 410t/h and FGD technology.[16]	Air pollution prevention equipment includes high-efficiency & multi-function deduster (de-dusting, de-SO_2, de-NOx, explosion prevention), high efficiency FGD and SO_2 recovery equipment[17]	Encouraging and supporting policies for environmental friendly equipment and products.[21, 22]	New & expanded thermal power plants and other large and middle plants should install necessary desulfurization and dedusting equipment or take other measures to control SO_2 and dust emissions if their emissions exceed regulations or total emissions target[18]
Tenth Five-Year plan of Power Sector specified to speed up the localization of large supercritical units and CCT generation equipment[19]	Air pollution control equipment includes: limestone (lime)-gypsum wet FGD, in-bed desulfurization plus humidification & activation at the tail end, semi-dry FGD, and FGD-CFB. Energy saving and renewable energy utilization equipment includes CFBC boiler.[20, 21]	Other policy initiatives[22]	Coal-related air pollution control technology was listed in key R&D fields during 9th Five-Year period with the emphasis on setup of 3-4 large FGD demonstration projects for power plants[23]
The 10th Five-Year Plan of Machinery Industry specified: study on key material preparation and contour machining technology for supercritical units, IGCC, and high temperature desulfurization; acceleration of development of large supercritical units, large CFBC boilers, FGD technology in thermal plants to master the design & manufacturing technology and improve product grades and levels.[24]			Decision on total emission control for 12 pollutants including SO_2 during 9th Five-Year period.[25]
Recommend and disseminate energy-saving achievements including 35t/h of FBC boilers burning coal slime[26]			The localization targets of FGD are to master initially wet FGD design technology for thermal power plants at the end of 2001, startup demonstration project of domestic FGD for thermal power plants.[27]
Coal refuse fired power plants must mainly use refuse and CFBC[28]			
Issue technical routes for FGD in power plants.[29]			

Pushed by these policies and measures, the capacity of CFBC boilers increased from 35t/h to 420 t/h only in several years. First set of 130 t/h CFBC boiler and 240 t/h boiler with independent intellectual property right were put into operation in Yaojie Bureau of Mines, Gansu and Zhenxing Group, Shanxi respectively. Nowadays, there are nearly 20 sets of 130t/h boilers and 2 sets of 240t/h medium-pressure boilers under operation[30], and more than 20 sets of 220t/h (50MW) CFBC boilers under construction. High-pressure and reheated CFBC boilers with capacity of 100MW-150MW will realize commercialization in 2005.

Chinese government will issue new Emission Standard of Air Pollutants for Thermal Power Plants and stricter demands will be imposed on pollutant emissions. Currently, principles for power plants to select de-SO_2 technology includes: new coal power plants with sulfur content more than 1% must install FGD. Generating units with capacity more than 300MW use wet FGD (limestone-gypsum) chiefly; units less than 300MW use cheaper methods such as rotary spraying desulfurization, in-bed calcium injection desulfurization, CFB-FGD at the tail, etc. Large-scale utilization of seawater desulfurization in power plants located in coastal areas still needs argumentation. Large-sized generating units with sulfur content of coal more than 1% which were built several years ago are required to install FGD gradually; medium and small old units should be retrofitted through simple desulfurization. China is developing the technologies with independent intellectual property rights, of which, limestone-gypsum method has been put into commercial demonstration.

3.3 The Obstacles Existed in CCT Development in China

Although CCT has made quite great progress in China, there are still many obstacles in management system (i.e. mechanism, associated policies and regulations and technical development in China, which result in insufficient and ineffective application and dissemination of CCT.

3.3.1 Obstacles in institutional and managerial system

a) Regarding overall arrangement and management

There is no overall arrangement and coordination of CCT development by a national energy department. After stipulating China's 9th Five-year Plan and Development Program to the Year 2010 for Clean Coal Technology, National Leading Group for CCT Dissemination and Planning set up in 1995 basically stopped its operation because of institutional restructuring of Chinese government. In these years, multiple governmental departments have been in charge of energy sector, energy, environment and industrial sectors worked separately and each department did what it was interested in. There lacks coordination among coal production, distribution, utilization and environmental protection. Development and dissemination of CCT do not combine intimately with energy saving, environmental protection, and dissemination and application of new technologies. There is no overall planning for development of various technologies, which discourages all-round and effective development and dissemination of CCT and influences R&D and demonstration of key technologies.

b) Regarding development and application of new technologies

Little investment has been given to development and commercial demonstration of new technologies and key technologies, especially lack of financial support to large-scale demonstration projects. It is required that commercial demonstration mainly relies on enterprises and central financing merely provides some of grants or low (discount) interest loans. Due to the features of long R&D period, high investment and high risk of large CCT projects, most enterprises have not the ability to take the risk of demonstration projects because most of them are at development stage and are short of capital funds. This caused the slower development speed of key technologies. Favorable investment and financing policies and credit channels for commercialized clean coal technology projects are very few, which influences commercial popularization of new technologies to a considerable degree.

c) Regarding management of coal supply

The coal supply system is uncontrolled. There are two many sale intermediaries so high quality coal could not be sold at high price. The market mechanism for promotion of coal processing is not established in China. Steam coal is managed but not as the energy product that can be standardized and serialized. Consumption market of high quality steam coal has not formed, resulting in low preparation ratio and low quality of steam coal. The existing situation goes against formation of reasonable coal supply mode (medium and small users have a first priority on low sulfur and low ash coal and power sector uses higher sulfur coal with central desulfurization and CEMs), which has caused difficulties to solve coal-related pollution though this kind of reasonable supply mode has extensively applied in developed countries and has been proved very effective for pollution control.

d) Environmental supervision on coal users

First, there is lack of effective monitoring of small-medium users. China has made lots of achievements in monitoring of power plants and key polluting sources, but CEMs haven't yet been installed in many small power plants and most of large non-power key polluting sources. A great number of small-medium users have gradually become the second largest pollution source only next to power sector, even exceeding the pollution from power sector in some cites. Second, the monitoring stations of national environmental quality monitoring network are not enough and the level of environmental monitoring technologies and equipment cannot keep pace with the increasingly stringent environmental requirement, which affected the implementation of environmental enforcement and emission trading. Third, proceeding from the consideration of economic benefits, the phenomenon of regional protection of large taxation payers, that cause serious environmental pollution in environmental enforcement, and the phenomenon of paying the emission fee through negotiation existed in environmental law enforcement goes against popularization of clean coal technologies.

e) Public propaganda

The public always put all the blames of environmental problems caused by backward coal utilization technology on coal pollution, and some local governments forbid utilization of coal but not adopt CCT or increase technical level to solve pollution problems. Chinese government should pay more attention to disseminate environmental policies and regulations, knowledge of environmental protection and CCT to the public and provide citizens with information consultancy and services to increase public awareness through propaganda, mass media and network.

3.3.2 Obstacles in laws and policies

a) Relative policy system

There have not been special policies on CCT development. Current policies related to CCT development (R&D policies, industrial policies, environmental policies, energy saving policies, policies on comprehensive utilization of resources, etc.) are not compatible due to coming from multiple departments. Some policies require to be implemented nationwide but lack of consideration of the differences in energy reserves and supply, and economic and technical levels among various regions. Many laws, regulations and policies lack a corresponding detailed implementation requirement, which restricts CCT development to a large degree.

b) Incentive policies

Generally speaking, the government lacks initiative policies to the technologies that need emphasizing the development. Existing policies for some of environmental friendly projects or clean energy sources/technology involve preferential taxation but only limit to reserve tax, adjustment tax of fixed asset investment, part income tax, not dealing with principle taxes, such as value added tax.

c) National standards

Some of existing emission standards are not practicable, failing to consider the influences of scale differences and whether existing technologies can meet emission standards. The level of SO_2 emission fee is still lower than the cost of SO_2 control in two control regions though the level has been heightened by the government, which results in that enterprises prefer to pay emission fees rather than use new technologies or invest in installing FGDs.

3.3.3 Technical obstacles

There is wide gap between China and foreign countries in some key technologies:

a) Large-scale key equipment and technologies

The localization rate of commercial application for large-scale key equipment and technologies is low. There exists wide gap as compared with international level in some key equipment and technologies, such as ultra supercritical boilers, turbines, flue gas cleanup system, large-scale CFB boilers, coal gasification, coal liquefaction, urgently need research and development to possess independent intellectual property right as soon as possible.

b) The limitation and elimination for backward small-medium equipment and technology

The limitation and elimination for backward small-medium equipment and technology are not enough and monitoring and supervision are insufficient. Some equipment and technologies that have been proclaimed to eliminate are still in use or even newly built and put into operation, which result in low operating efficiency and discouraging the deployment of advanced technologies

c) Long-term strategic technologies

Table 3-3 Main obstacles to the development of CCT in China

Issues	Technical areas	Analysis of causes	
		Comprehensive issues*	Technical issues
Leave production capacity unused	Coal preparation	Unreasonable product price, intermediate charging, emission standards and emission charging	Increase users' benefits, coal preparation technology and cost, users' technology
	Briquette		Briquette price, technology and cost of briquette plant, technology and equipment of briquetting before furnace
	Coal water mixture	Layout and economy, layout of CWM preparation plants, construction of redundant projects	
Insufficient domestic technical support	Liquefaction, gasification	System, policy, organization and mechanism of scientific and technical development	Technical problems
	Localization of flue gas clean up	Investment, cost, environmental policy	
	Advanced small and medium boilers	Scientific and technical development policy	Technology and cost
Unbalance of development between sectors		Information, technology and organization	
Management and capacity	National and local management	Organization, mechanism	
Policy, regulation		Coordination of policies	

Note: * "Comprehensive issues" mean government's function, i.e. policy, regulation, organization, standard and mechanism.

No all-around comparisons and argumentations for energy system for long-term strategic technologies, such as fuel oil substitution technologies including coal-derived methanol and di-methyl ether (DME), influence the arrangement and plan of technical development.

In general, many obstacles are existed in the development of clean coal technology in China, but mainly come from management, mechanism and policies, which not only influence the overall arrangement, development and popularization, but also influence R&D and industrialization speed and level of new technologies. It will be difficult to settle he obstacles and problems existed in specific technical development if these issues are not solved.

Development of each CCT faces different obstacle because of different development basis, level, technical difficulties and policy support. For example, development of coal preparation technology faces policy and mechanism obstacles, and FGD technology faces policy and technical obstacles. See Table 3.3 for details.

4. Experiences of Promoting CCT Development in Foreign Countries

As such, as a result of the ever tighter environmental regulations being introduced, its market share within Europe has reduced considerably in recent years although it is still significant (~15%).
Coal is the fossil energy with the richest reserve in the world. Coal is viewed by OECD countries as a cheapest and non-renewable primary energy source with potentially major environmental issues countries. But before renewable energy becomes economically competitive and commercialized, coal will still account for quite a percentage in primary energy consumption mix (at present 24% in USA, 15% in OEDC countries, 17% in Japan), so these countries pay a lot of attention to the development and application of CCT.

OECD countries made a lot of efforts to solve SO_2 emission and acid rain problems caused by coal consumption in 1970s-1990s. Development of CCT and adoption of a series of environmental protection measures have controlled regional environmental pollution fruitfully. In recent years, they emphasized the research on how to develop advanced coal utilization technologies so as to increase energy efficiency, reduce energy consumption, reduce CO_2 emission and realize “zero emission”. At the same time, a series of measures on reduction of greenhouse gases emissions are used.

CCT development is generally driven by environmental regulations and policy initiatives internationally. Main measures are as follows:

Firstly, special laws with strict legal requirements are established.

Secondly, comparatively strict emission standards are formulated and the limitation of maximum emission standards is in close combination with the economic and technical development level.

Thirdly, there is no limit on technology or fuel selection as long as emissions from this equipment is in compliance with emission standards.

Fourthly, environmental measures, such as real-time monitoring, collecting fees on total amount of emissions, imposing penalties on emissions exceeding regulations, emission trading scheme, collecting environmental taxes (such as sulfur tax), are adopted so as to stimulate the enthusiasm of enterprises, meanwhile strengthening law enforcement so as not to give enterprises the space to violate laws and regulations.

Fifthly, incentive policies such as preferential taxation, low-interest loan and so on for introduction of advanced technologies encourage the enterprises to implement the environmental friendly technologies. The government invests large amount of fund to the development of new technologies and offer multiple credit channels in order to promote the introduction of clean coal technology.

On the basis of above commonness, different country has taken different measures based on its resources and technical conditions.

4.1 **Experience in USA** – promotion of CCT development through combination of energy policy and environmental policy

(1) Energy policy

In order to meet more and more stringent environmental laws and regulations and strengthen competitiveness of coal, USA put forward strengthening CCT development in its energy policies. It took the lead in the world in implementation of Clean Coal Technology Demonstration Plan (CCTDP) on a large scale. 45 commercial demonstration projects were selected and the planned total investment reached 7.14 billion US dollars. The investment was shared by government and enterprises (about 35% from government). Four general types of projects are included in CCTDP, i.e. emission control equipment, advanced generating technology, coal processing and industrial processes.[31]

Of the generating projects, 5 SO_2 control technologies, 6 NOx control and SO_2/NOx joint-control technologies have been into operation successively; fluidized bed combustion projects (1 AFBC, 1 atmospheric boiling fluidized bed, and 3 PFBCs) and advanced coal heat engines have been run successively, and 3 IGCC projects have been put into operation.

Support and input from the government promote the research and development of CCT in USA. Commercial demonstration proved that new technologies could decrease emissions greatly and satisfy the stricter environmental standards at the same time reduce investment and cost, which speeds up the commercialization of new technologies. At present, more than 400 new FGDs are in commercial operation and investment and operating cost reduced to half of that in 1980. From 1980 to 1998, coal consumption in power stations increased by 60% while total SO_2 emission reduced by 23%. 75% of existing power plants have been retrofitted with low NOx burners and NOx emission could satisfy the requirement of “Clean Air Act” issued in January 2000 while operating cost was only 1/2 to 1/10 of that originally.

43 states of USA are disseminating CCT technologies. Short-term goal of CCT generation plan is to meet the requirement of current and new environmental laws and regulations and decrease emission control cost greatly. Middle-term goal is to develop low cost PC power plants with efficiency 50% higher than current level; long-term goal is to develop low cost zero-emission coal power plants with efficiency of twice as much as current level (Vision 21).

Because of rise of international oil price and failure of power supply in June 2000, Bush administration has readjusted its energy policies. 10 billion US dollars will be used to construction of energy infrastructure in next 10 years, of which 2 billion US dollars will be used to the research and development of CCT. Taxation exemption policy on existing research and development of CCT will be prolonged over a long period of time. On 15th, Jan. 2003, Department of Energy announced the first 8 CCT projects, including Clear Skies[g] and Climate Change initiatives and some projects that extract the energy potential of waste coal through advanced gasification and combustion systems. Research emphasis of CCT has been broadened from clean generating technology to other fields.

(2) **Environmental policies**

USA uses environmental policy to encourage the utilization of CCT, restrict and eliminate backward technology. Clean Air Act is the main force of air pollution control with power station boilers and industrial boilers as the main objects.

CAA Amendments in 1990 constituted the Federal Acid Rain Program, requiring that total SO2 emission will decrease 50% based on 1980 level. EPA used an emission-trading system to allow a plant, which has made emission reductions in excess of its existing emission limits, to earn credits. Plants that earn credits can sell them to others that need additional reductions or save credits for their use in future years,

Currently, more than 95% power plants in USA have introduced various pollution control systems. It is expected that coal consumption for power stations will increase by 17% in 2005 as compared with that in 1997 but SO_2 and NOx emissions will reduce by 43% and 33% respectively as compared with that in 1997 and investment will decrease further. The first generation system of CCT demonstration technologies has decreased 25% emissions of greenhouse gases.

Environmental policies allows U.S. companies to select their own industrial technologies and emissions control equipment as long as emissions from this equipment is in compliance with emission standards. For example, they could adopt energy saving measures, increase utilization of renewable energy, decrease consumption of energy and fuels, introduce pollution control technology, use low sulfur fuels or develop other substitute products.

EPA of USA established new strict New Source Performance Standards (NSPS) for new power

[g] Clear Skies Program requires reduction of SO_2, NOx, and mercury emissions in future 15 years to a large extent.

plants and boilers built after 9 July 1997. It regulates companies can select any technologies and equipment as long as emissions is in compliance with standards. Most environmental laws in the U.S. contain provisions for criminal sanctions that allow for indictments to be sought against individual partners, corporate officers, or the corporate entity itself for continued non-compliance. Subsequent violations can result in a doubling of the original penalties. Criminal penalties can be up to $1 million per violation for a corporation or $250,000 per violation for an individual, or up to 15 years imprisonment. All these measures have forced enterprises to implement environmental friendly projects like CCT voluntarily.

4.2 Experience in EU—promotion of CCT development by strict environmental requirements

Within energy policy framework in EU, coal is viewed as an energy source with potentially major environmental issues. Strict environmental standards are driving force for the development of CCT.

Main purposes of CCT development program are to reduce the dependence on petroleum, reduce environmental pollution caused by coal utilization, decrease emission of CO_2 and other harmful gases by increasing energy efficiency. Improvement of energy conversion and utilization is one of four fields in energy research and technical development (RTD). The related projects include IGCC, co-gasification (or co-combustion) of coal, biomass and wastes, integrated solid fuel gasification fuel cell combined cycle, CFBC, etc.

Currently, “Advanced PC Power Plant” program (Thermie 700℃) supports supercritical generation projects. Main objectives are to increase net energy efficiency of PC power plant from 47% to 55% (seawater cooling) or 52% (cooling tower in inland areas), and to reduce cost of PC power stations. About 40 companies in European countries took part in this project, including equipment manufacturers, research institutes, universities and power companies. The implementation of the project is divided into 8 stages, beginning from 1998, and will complete in 2014. Then demonstration power station will be put into operation.[32, 33].

If companies fail to meet emission standards in the EU, a compliance notice is issued, and in most cases, a fine is levied by environmental agencies. A failure to subsequently reach the mandated standards within a defined period of time will lead to further fines and ultimately the closure of the company. These measures have impelled enterprises to upgrade technology and eliminate out-of-date process.

4.3 Experience in Japan- promotion of development and application of coal technologies through coal policy and environmental policy

Pacific Coal Company – the last coal mine in Japan was closed down in Jan. 2002 and then Japan entered an “oversea coal” era completely. Japan is the largest coal importer in the world, whose coal consumption increased from 36.9 million tons in 1997 to 67.9 million tons in 2002 and will reach 83.2 million tons in 2007. Coal policies in Japan are to guarantee stable coal supply abroad, to strengthen CCT development and to carry out extensive international cooperations.

Japan's environmental policies place significant legal liabilities on polluting companies, and cause them to be responsible for addressing the impact of both past and current environmental problems.

Both Japanese government and enterprises invest large amount of funds to support the development of CCT in order to control coal related pollution. Japan regards the development of CCT as the focal point of coal policies. Japan's government began CCT development program (New Sunshine Program) from 1992 and allocated more than 57 billion yen annually to the Program. CCT development projects involves technologies for near-term application and new technologies for 21st century, including:

a) Increase of combustion efficiency and reduction of CO_2 emission, mainly FBC generation technology;

b) Cleanup before and after coal combustion, such as CWM, briquette, de-SO_2, de-NOx and de-dusting technologies;

c) Coal conversion, including coal liquefaction and gasification. Pilot demonstration of 150t/h coal liquefaction technology using NEDOL process accumulated experiences of pilot scale and engineering scale-up of direct coal liquefaction.

d) IGCC technology

e) CCT for 21st century, including more efficient and low pollution combustion technology, in-depth coal processing technology, integrated coal gasification fuel cell combined cycle, etc.

Japanese government provides funds to "clean coal technology and clean energy technology development" plans. Supporting projects low impact on the environment related to use of coal such as desulfurization, denitration and de-dusting technologies, reduction of CO2 by high efficiency combustion and promotion for effective use of coal ash (fly ash).

A prominent feature of Japanese environment policy is that it depends largely on regulatory measures such as emissions standards and economic penalties that are set for enterprises that are neither commonly used nor severe. Officials of enterprises that violate soot emission regulations may be subjected to a maximum of one year in prison or a penalty of five hundred thousand yen. However, the company violating the regulation will incur a loss of social reputation with the public if they are viewed as not adhering to standards. According to the feature that Japanese companies tend to regard the loss of public credibility as a much more severe outcome than having to pay penalties, Japanese government collect ambient monitoring and emission data through telemetering systems and made these data available to the public by means of the news media, posted notices, and signs in front of local city halls. This provides a level of deterrence to polluters and encourages enterprises to use CCT or other new technologies to reduce pollution.

Through a series of policy supports and strict environmental measures, Japan have succeeded in reducing the annual average concentration of SO2 and CO emissions by 85 percent and 70% respectively during the 1970-1996 period

5. CCT and Development Objectives for Future Demands

5.1 Power sector and heat supply

Coal used for power generation in developed countries usually takes more than 80% of total coal consumption. In 2000, coal consumption for power generation accounted for 90.8% of total coal consumption in USA, 41.6% more than that in China in the same period. This indicates that Chinese coal consumption for power industry still has vast space for development.

By the end of 2000, installed capacity of coal fried generation units was 232 GW, 72.7% of total installed capacity in China, whose average coal consumption for power supply was 392g/kWh, most of which were PC boilers. Statistics in 2000 showed that the capacity of totally 262 units with capacity more than 300MW was 90GW, accounting for 40% of total thermal installed capacity, and 60g/kWh lower than national average level in coal consumption for power supply; units with capacity less than 100MW took 32% of total capacity, whose technical level was generally low and coal consumption for power supply was 85g/kWh higher than national average level; others were units with capacity between 100-300MW. At the end of 2000, only 6.95 GW of coal fired installed capacity nationwide was equipped with FGD.

Up to now, 10.2 GW of imported 11.40 GW supercritical units have been put into operation. Through technical innovation and optimization for many years, China has fully mastered design and manufacturing technology of 300MW and 600MW subcritical units. operational reliability of 300MW and 330MW domestic units has been better than imported units. Through optimization and improvement for many times, coal consumption of domestic 300MW subcritical units for power supply could reach 340gce/kWh, close to the level of imported units. Coal consumption of 600MW units for power supply in the eighth phase of construction in Wujing thermal power plant is 309gce/kWh, basically equivalent to imported 600MW units.

Based on State development plan of power industry, Chinese power will develop at the speed of 8.7%-6.3% annually in next several years. It is estimated that installed capacity will increase from 356MW in 2002 to 928MW in 2020 and power generation will increase from 1,618 TWh in 2002 to 4326.6 TWh. Proportion of coal fired installed capacity in total installed capacity will reduce to 62.1%, but total generation from coal fired units will increase. Ratio of coal consumption for power generation to total national coal consumption will increase from current 52% to about 70%, coal demand for power generation and heating will increase from 720 million tons in 2002 to 1.4 billion tons with annual increment of 3.76%, see Table 5-1.

Table 5-1 Forecast of installed capacity of coal fired power generation

Year	2000	2005	2010	2020
Total installed capacity in China (GW)	319	437	629	928
Coal fired installed capacity (GW)	232	307	419	577
Coal consumption for power generation (Mt)	580	830	980	1400

Under this background, SO_2 emission in 2020 from coal combustion will double that in 2000 if CCTs are not adopted in China.

Chinese government requires that all new generating units install FGD equipment since 2003. Coal fired power plants that were built before 2000 and their SO_2 emission exceed regulation should equip with FGD facilities in batches. Coal fired power plants that were built, reconstructed or expanded after 2000 should install FGD facilities before 2010. At same time, Chinese government demands a continuation of eliminating small units continuously and development to the large scale. Advanced generating technologies such as supercritical generating units are being disseminated and utilized rapidly in China. Most of units built in 2003 adopted supercritical technology with wet FGD.

Chinese government has included NOx emission into the collection scope of emission fees from July 2004. This means that Chinese government will promote the development and application of de-NOx technologies meanwhile disseminating and deploying FGD in coal fired power plants.

5.1.1 CCTs to be developed in the future and economic evaluation

The followings are clean coal power generation technologies that are encouraged and can increase combustion efficiency greatly: super (ultra-super) critical units, CFBC, IGCC, PFBC. These technologies are being developed and applied internationally and can decrease SO_2 emission effectively if equipped with FGD or in-bed desulfurization. Detailed description can be seen in section 3.1.

a) Unit investment and emissions of several technologies

- Supercritical and ultra supercritical units

Supercritical and ultra supercritical units develop rapidly in the world due to the feature of high generation efficiency and mature commercialized technologies. According to statistics, there are about 600 supercritical units under operation worldwide, of which, more than 170 units are located in USA, about 60 units in Japan, about 60 units in Europe, more than 280 units in Russia and former east European countries. Technologies in Japan, Germany and Denmark take leading positions. There are about more than 60 ultra supercritical units in the world[34,35].

Based on practical operation experiences, net generating efficiency of conventional subcritical unit (17MPa/538/538°C) is about 37%-38%, ordinary supercritical unit (24MPa/538/538°C) is about 40%-41%, ultra-super critical unit (30MPa/566/566/566°C) is 44%-45%[36,37]. The efficiency and coal consumption of power supply for different steam parameters of super (ultra-super) units are listed in Table 5-2

Table 5-2 Coal consumption of power supply for different steam parameters

Unit	Super	Ultra-super	Ultra-super	Ultra-super
Parameter	24.1MPa/538/566°C	31.0MPa/566/566/566°C	31.0MPa/593/593/593°C	34.5MPa/649/593/593°C
Power supply efficiency (%)	40.94	42.8	43.1-43.3	43.7-44.0
Power supply consumption of coal (gce/kWh)	300	287	284-285	279-291

Source: Chen Duanyu, et al, Discussion of ultra supercritical boiler design, power engineering, 2002,22(4)

Table 5-3 Costs of 600MW units at different parameters

Parameter	16.7MPa/538/538°C	24.2MPa/538/538°C	24.2MPa/538/566°C
Relative investment %	0	+2.0	+2.6

Source: Huang Qili, New power generation technologies for 21st century", gas turbine power generation technologies 2000, 2(1)

Suizhong power plant has imported 2 sets of 800MW supercritical units from Russia with total budgetary investment of 10.3 billion Yuan and unit investment of is 6437.5 Yuan/kW[64]. The first domestic 600MW supercritical units (2 sets in the first phase of construction) are installed in Qinbei power plant, Huaneng group, with of total investment of about 5 billion Yuan, and unit investment of 4167 Yuan/kW, which will be put into operation in 2005.

Super (ultra-super) critical units equipped with FGD can achieve favorable environmental results and de-SO_2 efficiency could reach more than 90%.

- CFB boilers

Combustion efficiency of CFB boiler could reach 97-99%, and thermal efficiency is about 38-40%, equivalent to that of PC boilers with FDG. CFB boiler has wide fuel suitability and wide load adjustment scope. In-bed de-SO_2 efficiency could reach more than 90% and NOx emission will 90% less than conventional PC boilers[38]. Taking 410t/h of CFB boiler in Gaoba power plant, Neijiang, China and 250MW of CFB boiler in Gardana, prowance, Southern France, as examples, emissions could be seen in Table 5.4.

Table 5-4 Emissions from CFB boilers

(Dry flue gas under standard condition, O_2=6%) unit: mg/Nm[3]

CFBC		Capacity	Provider	Combustion efficiency %	SO_2		NOx		CO		dust
					design	acceptance	design	acceptance	design	acceptance	
100 MW	Gaoba power plant, China	Largest in China	FW, Finland	97.2%	700	684	200	78	250	211	198
250 MW	Gardana power plant, France	Largest in the world	Lurgi, Germany		400	103	250	230		8.44	

Source: Encyclopedia of Chinese Power (2nd edition), Beijing, Power Publishing House of China, 2001
Liu Dechang, et al, Main issues and improvement measures for operation of imported CFB boilers
Wang Peizhang, Coal smoke related pollution, desulfurization and large-sized CFB technology

Table 5-5 Estimate of investment cost

Unit: million Yuan

Item	CFB plant	Domestic PC plant	Imported PC plant*	Domestic PC+FGD plant
Dynamic investment	2214.46	1851.23	1914.46	2248.24
Contingency fund for price gap	290.27	356.87	271.48	324.95
Interest on construction loan	67.82	61.29	54.72	63.61
Static investment	1856.37	1433.07	1588.26	1859.68
Equipment cost	1022.64	621.50	776.69	950.26
Installing cost	263.53	248.60	248.6	298.27
Civil engineering cost	351.84	344.60	344.6	362.63
Other costs	218.37	218.37	218.37	248.52

Note: * cost of imported equipments includes: 6% of tariff and 17% of value added tax for CFB boiler and FGD; 12% of tariff and 17% of value added tax for PC boiler

Comparing 300MW CFB power plants with same scale PC power plants, PC+FGD power plants in the world, we can see that total investment of a CFB power plant will be more than a domestic or imported conventional PC power plant, equivalent to PC power plant with FGD facility[39] (see Table 5.5). Along with the technical development of large CFB boilers and increase of localization rate, investment of a CFB power plant will be slightly lower than a PC+FGD power plant.

- Integrated coal gasification combined cycle (IGCC)

IGCC is composed of gasification, cleanup and gas turbine combined cycle. The highest efficiency of IGCC demonstration power stations in the world can reach 45%, with very good environmental results, such as desulfurization rate of 99%, denitration rate of 90%, and CO_2 emission reduction rate of 30%[40]. Please see Table 5-6 for technical and economical indices of IGCC power stations with coal as the feedstock abroad and Table 5-7 for Relations of technical performance and cost.

Table 5-6 Main IGCC power stations abroad

Country	USA	USA	USA	Holland	Spain
Power plant	Wabash River	Tampa	Pinon Pine	Buggenum	Puertollano
MW	262	250	100	253	300
Net thermal efficiency (LHV)	37.8% (HHV)	41.6%	42%	43.2%	45%
SO_2 emission (mg/MJ)	86 (246 mg/Nm^3)	90.4 (258 mg/Nm^3)	/	25.8 (73.7 mg/Nm^3)	25 mg/Nm^3
NOx emission (mg/MJ)	/	116.2 (332 mg/Nm^3)	/	73.2 (209 mg/Nm^3)	150 mg/Nm^3
Investment ($/kW)	1591	2024	2320	1865	2900

Source: Encyclopedia of Chinese Power (2nd edition), Beijing, Power Publishing House of China, 2001
Jiang Lixia, Feature of IGCC system and comprehensive optimization of steam system, thesis for doctor's degree of CAS, 2000
Benjamin C.B.Hsieh, Overview of CCT in the US

Table 5-7 Relation of technical performance and cost of IGCC

Type of IGCC system	Initial temperature of gas turbine（℃）	heat value of IGCC, % (LHV)	Unit investment of equipment ($/kW)
Conventional low temperature cleanup, independent air separator	1260 (F type)	38~42	1400~1600
low temperature cleanup, integrated air separator	1260 (F type)	43~46	1350~1550
High temperature cleanup, integrated air separator	1260 (F type)	45~48	1180~1380
High temperature cleanup, integrated air separator	1370 (G &H type)	46~50	1130~1330

Source: Cai Ruixian, et al, IGCC, a high technology for coal fired power station with higher efficiency, lower pollution and less water usage, A Report of USA-China experts: IGCC. Institute of Engineering Thermophysics of Chinese Academy of Science and Tulane University, 1996

China plans to construct IGCC demonstration power station in Yantai, Jinan and requires main indices as follows: power supply efficiency not less than 43%, desulfurization rate not less than 98%, NOx emission not more than 25ppm, dust emission not more than 2ppm, load rate between 50-100%. Investment of 2 sets of 300MW or 400MW IGCC units would be about $900/kW.

- PFBC

PFBC generating technology has the feature of good suitability of coal type, 99.8% of combustion efficiency and favorable environmental performance, such as low NOx emission due to low combustion temperature, in-bed desulfurization efficiency of more than 90%. Net generating efficiency of PFBC is 2-4% higher than conventional coal fired condensing power station with same parameters. The power supply efficiency of the first generation of PFBC-CC stations in the world can reach 40-42%[41,42], whole main technical and economic indexes could be seen in Table 5.8.

The second generation of PFBC-CC technology is at pilot phase, whose efficiency of combined cycle is expected to be 45-48%.

Total capacity of 2 sets of P200 units imported for the PFBC-CC demonstration project in Jiawang power plant, Jiangsu province, China, is 207.5MW, with total investment of 1.367 billion Yuan based on price level in 1999, and unit investment of 6588 Yuan/kW[43].

Table 5-8 Main technical indexes of PFBC-CC power stations

Country	Sweden	America	Spain	Japan	Japan	Germany	Japan	Japan
Power plant	Vartan	Tidd	Escatron	Wakamatsu	Hokkaido	Cottbus	Osaki	Karita
Operation date	April 1994 Commercial operation	1995, end of verification	1990.11	1997.9 Commercial operation	1998.3 Commercial operation		2000.12 Commercial operation	2001.7 Commercial operation
Output (MW)	135/224	70.0	79.5	71.0	85	62/90 (heating)	250	360
Efficiency (%)	89 (LHV)	36.4 (HHV)	35 (HHV)	37.5 (HHV)	41.2 (HHV)		41.5 (HHV)	42(power supply (HHV)
SO_2 emission (Design/actual) (mg/Nm^3)	70/52	510/255	214/219	119/76	340/29	115	217/20	217
NOx emission (Design/actual) (mg/Nm^3)	119/114	510/178-214	119/178-214	257/171	138/56	115	27/21	84
Fly ash emission (Design/actual) (mg/Nm^3)	12	12	95	17	<5	20	9	30
Investment ($/kW)								1200-1500

Source: Zhang Mingyao, Cai Ningsheng, et al, Development and prospect of PFBC-CC technology

b) Comprehensive comparison of generation technologies

Every advanced coal fired power generation technology mentioned above has its own advantages. After synthesizing above fundamental data, following results have been achieved through comparison of different technology.

- Sequence of new units adopting above technologies based on following indexes

- Technical maturity and availability from high to low: subcritical + FGD, supercritical + FGD, ultra supercritical + FGD, CFBC, IGCC, PFBC-CC. Supercritical units are commercially mature technology and capacity of per unit could reach 1000MW. Ultra supercritical units shows good developing tendency. CFBC boiler is developing to large scale and the biggest capacity per unit could reach 300MW. PFBC and IGCC are still at test or demonstration phase.
- Generating efficiency: Ultra supercritical unit comes the highest one; then IGCC with net heat efficiency up to 45%; supercritical unit with generating efficiency of 41-43%; thermal efficiency of PFBC 42%; thermal efficiency of CFBC equivalent to that of conventional PC power plant.
- Unit coal consumption from high to low: IGCC, ultra supercritical + FGD, supercritical +FGD + SNCR, PFBC-CC, CFBC.
- Effect of SO_2 emission reduction from best to good: IGCC, supercritical + FGD (ultra supercritical +FGD), PFBC, CFBC.
- Capital cost from low to high: CFBC, supercritical + FGD, PFBC-CC, IGCC.

It is difficult to select the technology through comparison of a single index. If we compare generating units at the same scale (1200MW) and same operating period with different technologies, we could find that the super (ultra-super) critical units and CFB technology are mature and coal consumption for power generation are low although lump-sum investment of are higher,. If equipped with FGD, SO_2 emission of these two technologies could reduce by 90%. Comprehensive input of super these two technologies with operating period for 20 years are less than that of IGCC and PFBC greatly, only about half of that of gas fired units (more efficient GTCC) (see Table 5.9).

Table 5-9 Options of generating units (1200MW, operating for 20 years)

Item	Investment (10^8 Yuan)	Fuel consumption (Mt)	Total fuel cost in 20 years (10^8 Yuan)	SO_2 emission (kt)	NOx emission (kt)	Investment and fuel cost (10^8 Yuan)
Subcritical 600MW	44.08	43.164	129.49	531.8	172.7	173.57
Subcritical 600MW+FGD	49.18	43.824	131.47	54	175.3	180.65
Supercritical 600MW+FGD	65.92	42.768	128.30	52.7	171.1	194.22
Ultra supercritical 600MW+FGD	66.58	41.184	123.55	50.7	164.7	190.13
CFB 300MW	64.96	45.012	135.04	55.5	90.0	200
IGCC 485MW	87.9	39.336	118.01	3.1	15.7	205.91
PFBC 206MW	81.25	43.56	130.68	53.7	74.2	211.93
GTCC 350MW	46.55	31.02(convert) 25.08Gm^3	326.04	2.4	12.4	372.59

Therefore, super (ultra-super) critical units and CFB are technologies suitable to long-term development. By comprehensive consideration of conditions of resource, environment, technical maturity, and power plant scale, China should regard super (ultra-super) critical units (equipped with FGD) as key developing units with CFBC as supplementary one.

Meanwhile, China should arrange commercial demonstration of IGCC and PFBC to solve key technical problems and accumulate experiences so as to lay a foundation to the development and realization of multi-products system.

- Comparison of current units to install FGD, switch to washed coal or natural gas

By the end of 2000, there were 232 GW of coal fired generating units in China, of which, only 6.95 GW (3%) have installed FGD. If coal fired units without FGD equipment use coal with sulfur content more than 0.5%, their SO_2 emission would not meet the requirement of national standards. Thus, various technical transformation measures should be taken to about 97% of current units. Transformation measures ordinarily include installation of FGD, switching of fuel type from coal to washed coal or natural gas.

Table 5-10 Input and emissions of existing coal fired units with different technologies

Item	MW	Increased investment (Yuan/kW)	Increased operating cost (Yuan/MWh)	SO_2 emission (mg/Nm^3)	NOx emission (mg/Nm^3)	increased Investment and operating cost for 15 years (10^4 Yuan)
Sub-critical 300MW	2×300			1540	500	
Sub-critical 300MW+FGD	2×300	519	20.00	154	500	130140
Sub-critical 300MW with washed coal	2×300	--	26.72	700	500	132264
Sub-critical 300MW with natural gas	2×300	--	250.8	10	50	1241460

Note: assuming that limestone consumption in 300MW unit is 29.17kg/MWh, price of limestone is 260 Yuan/t, price of 300Yuan/tce, price of cleaned coal 380Yuan/t, and price of natural gas 1.3Yuan/Nm^3. the units after transformation would operate for 15 years and 5500 hours every year.

Taking a 300MW subcritical unit with different transformation methods including installing FGD, switching to washed coal or natural coal respectively as an example, the comparison result based on 15 years operation period shows that environmental effect of switching to natural gas is the best, but its comprehensive input for 15 years' operation will increase by 9 times, while only considering the increment of fuel cost but not considering the transformation investment, so it has no economic competitiveness as compared with advanced coal combustion generating technology. Retrofit of the existing coal-fired generating units with

FGD installation not only can reduce SO_2 emission by 90%, but also can obtain lowest comprehensive input and operating cost, 98.3% of that of switching to washed coal, 10.48% of switching to natural gas (see Table 5.10). Retrofit of the existing coal-fired generating units, that they are equipped with FGD units is the most economic approach for emission reduction, under the condition of meeting the environmental requirements.

5.1.2 Development options of clean coal power generation technology in future 20 years

Table 5.11 and Table 5.12 present suggestions on development options for various CCTs in future 20 years in China. In view of continuous improvement of environmental requirements and generating efficiency, various advanced generation technologies with FGDs will be adopted for new units and installation of FGDs for refurbishment of existing generating units in future 20 years.

Table 5-11 Options for clean generation technologies in different phases in future 20 years

Year	Installed capacity (MW)	Low option	Medium option	High option
2005	New 750	Subcritical + FGD 646.5	Supercritical +FGD 750	Supercritical +FGD 577.5
		Supercritical+FGD 103.5		Ultra Supercritical +FGD 172.5
	Existing+FGD	50	50	50
2010	New 1120	Subcritical + FGD 947.5	Subcritical CFB 103.5	Supercritical +FGD 602.5
		Supercritical +FGD 172.5	Supercritical +FGD 913	Ultra Supercritical +FGD 517.5
			Ultra Supercritical +FGD 103.5	
	Existing+FGD	345	457.3	586
2020	New 1580	Subcritical + FGD 1166	Subcritical CFB 241.5	Supercritical +FGD 545
		Supercritical +FGD 414	Supercritical +FGD 1097	Supercritical +FGD 690
			Ultra Supercritical +FGD 241.5	IGCC 172.5
				PFBC 172.5
	Existing+FGD	951.7	1295	1616.9

The development speed of new units is consistent in three options (the same data as Table 5-1, average 8.7-6.3% annually). Differences exist in the different percentages of advanced technologies and different scales of retrofit for existing units.

In consideration of above three options, we recommend medium option because its investment is appropriate and it can reduce emissions effectively to satisfy the environmental requirements in 2020.

If China develops clean generation technologies on the basis of medium option, by 2020, coal fired generating capacity in China will increase by 345 GW, 10% of which will adopt large CFBC boilers, 80% supercritical units with FGD, 10% ultra supercritical units with FGD. Meanwhile, 180 GW (about 50%) of existing units will be equipped with FGD. Total net investment will reach 1966.3 billion Yuan, 3.7% of which will be used to install FGD in existing units and 96.3% will be used for new units. The investment of medium option will be 480.4 billion Yuan more than the investment of adopting subcritical boilers completely, and 60.9 billion Yuan of fuel cost will be saved within 20 years.

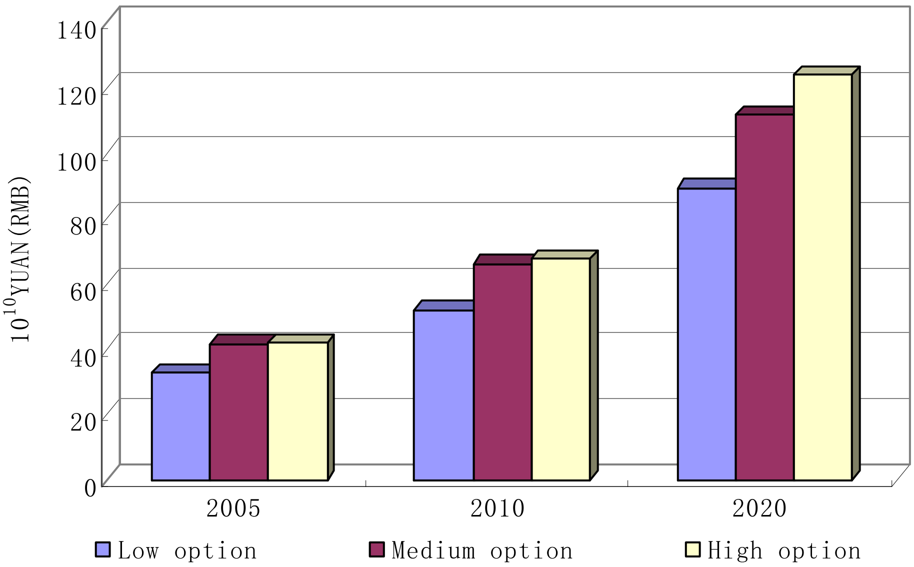


Fig. 5-1 Investment of development options of clean coal generation technology

If target of medium option are realized, by 2020, average coal consumption of per kWh will be reduced from 360gce/kWh in 2000 to 315gce/kWh though the amount of coal used for power generation will double that of 2000. The total emission of SO_2 from coal-fired power stations will not only not increase but also may reduce by 5.648 million tons per annum. The total reduced emission of SO_2 within 20 years may be 39.30 million tons. Compared with existing technologies, coal consumption may reduce by 1.77 billion tons and emission of CO_2 reduce by 4.26 billion tons within 20 years due to adoption of advanced technology and improvement of efficiency.

Table 5-12 Forecast on options of clean generation technologies in next 20 years

Options		Low option	Medium option	High option
2000-2005 年 (subtotal)	Investment (New + retrofit) (billion Yuan)	321.789+2.00	411.975+2.00	412.924+2.00
	Fuel consumption (Mt)	682	668	663
	SO_2 emission from new units (kt)	840.2	823	816.8
	NOx emission from new units (Mt)	2.728	2.672	2.652
	SO_2 emission reduction after retrofit (kt)	-598.8	-598.8	-5.988
2005-2010 年 (subtotal)	Investment (New + retrofit) (billion Yuan)	483.04+14.00	614.958+18.292	618.062+23.44
	Fuel consumption (Mt)	1701	1667	1644
	SO_2 emission from new units (Mt)	2.0956	2.0538	2.0254
	NOx emission from new units (Mt)	6.804	6.474	6.576
	SO_2 emission reduction after retrofit (kt)	-4779	-6065.2	-7606.4
2010-2020 年 (subtotal)	Investment (New + retrofit) (billion Yuan)	705.237+38.068	867.29+51.80	925.337+64.676
	Fuel consumption (Mt)	6269	6156	6039
	SO_2 emission from new units (Mt)	7.7233	7.5843	7.114
	NOx emission from new units (Mt)	25.076	23.33	22.4186
	SO_2 emission reduction after retrofit (Mt)	-33.5082	-43.0881	-53.8656
Total For 20 years	Investment (billion Yuan)	1564.133	1966.315	2046.439
	Fuel consumption (Mt)	8652	8491	8346
	SO_2 emission from new units (Mt)	10.6591	10.4611	9.9562
	NOx emission from new units (Mt)	32.108	32.476	31.6466
	SO_2 emission reduction after retrofit (Mt)	-33.5082	-49.7521	-62.0708
	SO_2 emission reduction (Mt)	-22.8491	-39.291	-52.1146
	Coal consumption reduction by new technologies (Mt)	-1611	-1772	-1917
	CO_2 emission (Mt)	21700	21300	21000
	CO_2 emission reduction(Mt)	-6051	-6451	-6751

5.2 Medium and small industrial boilers

Large amount and different kind of medium and small coal fired industrial boilers are the major equipment in China to supply heat to citizens and industrial processes, which is peculiar in China. The coal consumption is 350-380 million tons annually, about 30% of total coal consumption nationwide and these boilers are the 2nd largest coal users second to power station boilers in China.

By the end of 2001, there were 530,000 industrial boilers (including heating boilers) that were in operation in China, with total installed capacity of 1.2 Mt/h and average unit capacity only about 2.5t/h, of which, coal fired boilers accounted for more than 85%. Of the coal fired boilers, 65% were chain grate boilers, 20% were reciprocating grate boilers, 10% were fixed grate boilers, 3-5% were CFBC boilers and others took 1%. 55% of total capacity was used in industrial production while other 45% in civil use or heating.

The followings are main differences as compared with foreign countries:

Firstly, the number of boilers is large and the unit capacity is small. Of existing industrial boilers, 5% of boilers were with capacity less than 1t/h, more than 80% with capacity less than 10t/h, less than 20% with over10t/h. The average capacity is only at about 2.5t/h while those in Japan, in USA and in former Soviet Union are 5t/h, 14t/h and 40t/h respectively. Central heating is commonly used abroad.

Secondly, automation level is low in China. The properties of combustion equipment and auxiliary facilities are inferior to that of foreign products. Most of boilers have achieved automatic control abroad while in China, they are chiefly by manual control. Qualities and technical levels of operators affect the operating efficiency greatly.

Thirdly, coal quality and boiler design do not match. Most coal fired boilers in China are designed based on anthracite II with the fuel requirement of ash content less than 40%, calorific value between 14.63～20.90 MJ/kg, largest size less than 50mm and not more than 30% of fines with size less than 3 mm. Actually, because there are great differences of coal in various areas and many coal fired boiler users consume raw coal or bulk coal, most coal fired industrial boilers could not operate as designed.

Fourthly, most industrial boilers have not installed desulfurization equipments or taken desulfurization measures because of technical and economic reasons. Many of small boilers are not even equipped with dedusters, resulting in high concentration of smoke and SO_2 emissions.

Fifthly, there is not enough administration from the government for overall improvement of technical levels. At present, State Administration of Quality and Technology Supervision is in charge of only training and management of boiler safety, and there is no other governmental departments who put forward demands on boiler efficiency and technical progress.

Reasons mentioned above caused many problems in Chinese coal fired boilers such as insufficient output, incomplete combustion, low thermal efficiency and serious emissions. At present, average operating efficiency of coal fired industrial boilers is about 60% in China, 20% less than world advanced level. According to experts' estimation, smoke emission from industrial boilers in China reaches 6-8 million tons per year, accounting for 30% of total smoke emission nationwide. SO_2 emission from industrial boilers is about 6-7 million tons per year, or more than 30% of total emission in China. Total emissions of pollutants are only second to that from power station boilers, or even exceeding that from power station boilers in many cities, whose pollution cannot be neglected.

Based on the specific situation of economy and industrial boilers in China, it is impossible in economy and practical operation to replace coal by clean energy such as natural gas. It is estimated that boilers with small capacity, high energy consumption and heavy pollution will be eliminated in future 10 years. New boilers will develop to the large scale. Annual capacity of eliminated boilers will be keep balance with that of newly built boilers (annual capacity of new boilers accounts for 5-8% of the total and annual production of boilers is 1.1 - 1.3 Mt/h). Thus, by 2010, total capacity of coal fired industrial boilers will be 1.2 Mt/h, equivalent to current level, of which, coal fired boilers accounts for about 80% and medium and small boilers with capacity less than 20t/h will still the major type but average unit capacity will increase more or less. There are still a number of coal fired industrial boilers in operation in 2020 but the number will reduce to 400,000 sets, with total capacity of 1.05 Mt/h and coal demand still at about 300 Mt/a.

So the first choice, the most economic and efficient measures to solving pollution and efficiency problems of coal fired industrial boilers are to eliminate small boilers (capacity less than 1t/h, less than 4t/h in some big cities), to switching from coal to clean energy, to disseminate utilization of low ash and low sulfur coal, meanwhile popularizing CFB or central heating and CHP generation.

5.2.1 Comprehensive comparison of industrial boiler transformation technologies

Nowadays, the following technologies and measures are disseminated and used through out China:

- Development to the large scale: popularization of CHP generation and urban central heating, retrofit of existing layer combustion boilers more than 35t/h with CFB boilers
- Energy saving technology: modification technologies such as layered combustion, furnace arch transformation, and air distribution to increase boiler efficiency. Moreover, switching to low ash and low sulfur coal or installation of desulfurization equipment at the tail end to meet environmental standards.
- Utilization of coal processing products: Industrial briquette, low sulfur coal (or washed coal with sulfur content less than 0.5%) and Coal water mixture to reduce SO_2 and dust emission and increase boiler efficiency.

- Dust removal and desulfurization technology: dissemination and application of desulfurization technologies in medium and large boilers (capacity more than 20t/h) and different dust removal technologies for all boilers.
- Switching to oil, gas or electricity boilers: In order to improve environmental quality, some cities eliminated small coal boilers in urban areas and switch to natural gas, electricity or oil boilers. Gas and electricity boilers have been developed rapidly in these years.

In light of the industrial boiler technologies and retrofit measures being adopted by various cities, the result of technical, environmental and economic comparison for CFBC (with in-bed desulfurization), existing boilers with desulfurization and dedusting, and burning different fuels (washed coal, sulfur capture briquette, natural gas, heavy oil and electricity) can be seen in Table 5.13[44].

Table 5-13 Technical, environmental & economic results of retrofit measures for IBs

Evaluation item	Current level (raw coal)	Briquette	De-SO_2 & de-dust	CFBC	Heavy oil	Natural gas	Briquette	Electricity	
								Electricity only	Cogen. of cold&heat
Efficiency (%)	60	65	64	60	78	85	86	94	
Energy saving rate (%)	0	7.69	6.25	0	23.1	29.41	30.23	36.17	
SO_2 emission reduction(%)	—	33.2	35.1	50	69.2	58.5	100	100	
Retrofit investment (Yuan/t)	0	1.25×10^4	1.25×10^4	18×10^4	15×10^4	17.6×10^4	18.7×10^4	20×10^4	
Investment of SO_2 reduction (Yuan/tSO_2)	—	614	466	2941	1180	1639	1018	1089	
Energy saving investment (Yuan/tce)	—	63.2	62	-	84.3	77.6	80.2	71.7	
Increase of operating cost (Yuan/GJ)	0	0.76	4.39	8.23	9.3	22.88	43.8	132.4 (normal) 37.86 (valley)	61.84 (normal) 12.4(valley)
Comprehensive evaluation	/	Clear increase of boiler efficiency, low retrofit investment, 3.8% higher of operating cost than bulk coal and enterprise can accept it; obvious effect of de-SO_2 and de-dust; suitable for popularization & application in cities & towns.	Clear increase of boiler efficiency, low retrofit investment, 22.1% higher of operating cost; certain difficulty for enterprise to accept; obvious effect of de-SO_2 and de-dust; suitable for popularization & application in cities& towns.	large lump-sum investment , more operating cost ; current technology has some problems and is not so mature	High boiler efficiency; obvious effect of de-SO_2 but efficient deduster and in-bed desulfurization needed; 46.9% higher of operating cost; suitable for inferior coal combustion and CHP	High boiler efficiency, retrofit investment &operating cost; SO_2 emission in excess of standards and not consistent with national policies of fuel oil saving and replacement	High boiler efficiency, retrofit investment &operating cost; hard for ordinary users to accept. Suitable for big cities	High boiler efficiency, retrofit investment &operating cost. Suitable for areas with abundant power and downtown areas of big cities	

The following results are achieved through comprehensive analysis and sequencing these technologies and measures:

- Technical maturity: All are mature technologies except that desulfurization and dedusting technology needs to be developed further.
- Thermal-efficiency of the boiler from high to low: electric boiler, natural gas boiler, heavy oil boiler, CFBC boiler, washed coal boiler, briquette boiler, raw coal boiler with desulfurization and dedusting. However, from the view of overall energy efficiency including conversion from coal to electricity and then electricity to heat, efficiency of electric boilers is the least. The development of electric boilers should not be encouraged unless in areas with abundant electricity.
- Energy saving effect from high to low: natural gas boiler, heavy oil boiler, CFBC boiler, washed coal boiler, and briquette boiler.
- SO_2 emission reduction rate from high to low: electric boiler, natural gas boiler, CFBC boiler, desulfurization and dedusting, briquette boiler, washed coal boiler. Because of high sulfur content, SO_2 emission from heavy oil boiler will exceed requirements of standards.
- Retrofit investment from low to high: washed coal boiler, briquette boiler, CFBC boiler, heavy oil boiler, desulfurization and dedusting, natural gas boiler, and electric boiler.
- Increase of operating cost from low to high: washed coal boiler, briquette boiler, desulfurization and dedusting, CFBC boiler, heavy oil boiler, natural gas boiler, and electric boiler (normal/valley) (see Table 5.14 and Fig. 5.2). Main factor affecting retrofit of coal -fired boiler is that enterprises would not like to bear too much increase of operating cost.

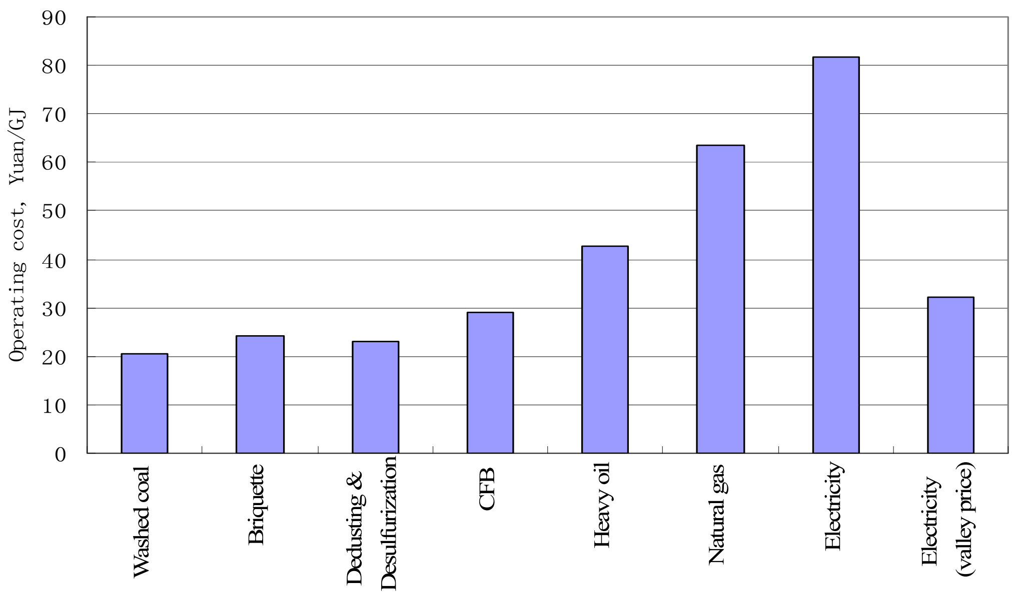


Fig. 5-2 Operating costs of retrofits for coal fired boilers

All of above technologies and measures can be used at current stage. Different regions will develop technologies for industrial boilers that are suitable to local conditions after overall consideration of availability of energy sources, demand of environment and economic conditions, and make all-round arrangement of refurbishment of industrial boilers.

Table 5-14 Operating costs of industrial boilers with different fuels

Fuels	Bulk coal	Washed coal	briquette	CWM	Natural gas	Heavy oil
Ratio of operating cost	1	1.1	1.2	1.45	3.1	2.3

Note: emission fee and environmental influence have been considered.

Source: Consultation project of CAE, High-efficiency combustion and pollution control of medium and small industrial boilers

From long-term point of view, new and existing coal-fired industrial boilers shall develop to the large-size, central heating, combined heat and power generation, central desulfurization and dust removal. Supply of high quality coal or switching to briquette and natural gas should be applied to medium and small boilers that are not suitable for de-SO_2 and dust removal. It is not suitable for industrial boilers to use heavy oil either from the viewpoint of reducing the consumption of fuel oil or from environmental protection (most of heavy oil with high sulfur content).

5.2.2 Technical transformation options of coal fired industrial boilers

It is expected that by 2010 and 2020, the gross capacity will be 1.20 million tons-steam and 1.05 million tons-steam and total quantity of coal to be utilized will be around 300 million tons. If coal fired industrial boilers maintain current technical level and operating conditions, coal related pollution in many cities (especially northern cities in winter) would not be changed thoroughly (coal-related pollution in 2020 would be equivalent to nowadays' level), saying nothing of sustainable development of social economy.

Future environmental status will be improved greatly if all of technologies and measures in Table 5.13 are used for new boilers, meanwhile, existing boilers are retrofitted (adopting technologies and measures in Table 5.13 too) by phases and regions based on different environmental requirements in different regions and life span of boilers (generally 20 years). Overall options could be seen in Table 5.15(1), and Table 5.15 (2). Elimination (or retrofit) of the existing small coal fired boilers will be undertaken at the same time of construction of new boilers. The eliminated capacity will basically equal to new capacity. Most of transformation of boilers will take place by using new boilers to replace old ones.

Based on options in Table 5.15, all retrofit will be completed before 2020. Three options that adopt different retrofit speeds and different percentages of different technologies are proposed according to different environmental capacity and demands in different areas.

We could see from three options in Table 5-15 that input of low option is low but is not able to meet increasing needs of environmental protection. High option is an ideal option in the aspect of technology selection and environmental protection, but the investment is too high to support based on current economic development level of China and economic capacity of many cities. Medium option is a practical and recommended program because it combines technology and economy together with environment and ensures environmental effects but don't cause too much economic pressure to enterprises and local governments.

If the retrofit of industrial boilers is to be accomplished based on medium option, the level of industrial boiler technologies will be improved comprehensively, with the average efficiency of industrial boilers increase by nearly 12%, energy saving by 46.5 Mtce/a. By 2020, emissions from industrial boilers with total capacity of 1.05 million tons-steam will be controlled at 3.2-4.2 Mt/a of SO_2, 4.3-6.3 Mt of particulate. This means that the emission of SO_2 may reduce by 2.71 million tons per annum, emission of particulates by 1.78 million tons per annum, emission of CO_2 by 80.91 million tons per annum, the environmental problems due to pollution of SO_2, smoke and particulates will be eased to a great extent.

Completion of medium option will need 17 years, the investment for retrofit of existing industrial boilers will be 124.3 billion Yuan, and the operating cost compared to that before retrofitting will increase by 27.2 billion Yuan per annum. Increase of operating cost occurs mainly in the first class areas where environmental requirement are strict and economic conditions are good, partly in the second-class areas but with limited scope, number and economic burden (see Fig. 5.3)

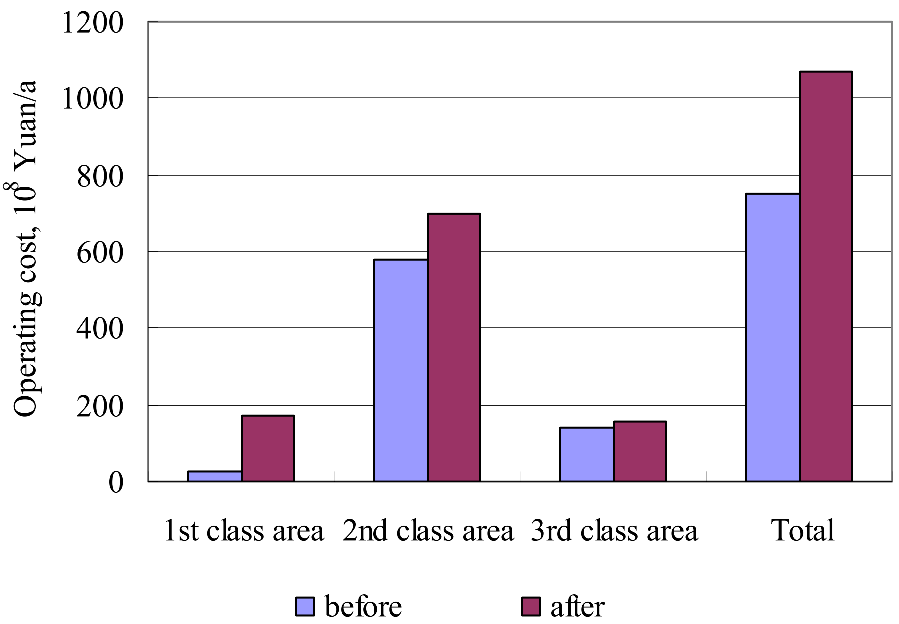


Fig. 5-3 Operating Cost Before And After Retrofit

Four years after retrofitting of industrial boilers in this country, the overall economic benefits to be obtained may make up the retrofit investment, if assuming that economic loss caused by SO_2 emission is 3 Yuan per kg of SO_2 each year, loss by particulates is 1 Yuan/kg, and energy saving benefit is 0.6 Yuan every 1 kg of coal equivalent saved. By 2020, the cumulative overall economic benefits may reach approximately 50 billion Yuan, much more than the input (see Fig. 5.4).

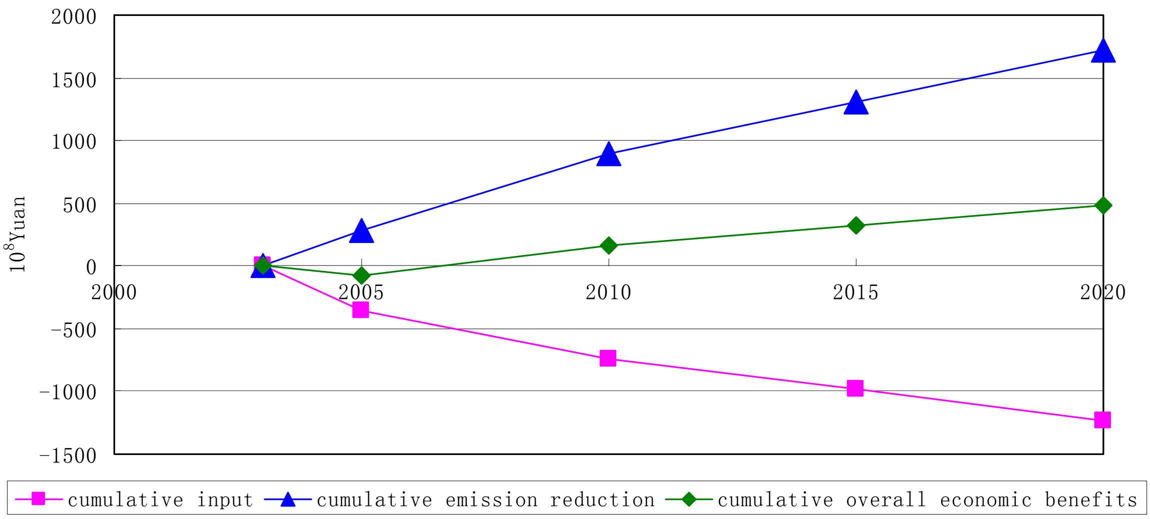


Fig. 5-4 Input and benefit of retrofit of industrial boilers through out whole country

Table 5-15-(1) Retrofit options of medium-small industrial boilers in China - by phases

	Retrofit capacity (kt)	Low option	Medium option	High option
1st class regions	92.8	speed: 30 kt/a 2005: 65% completed 2007: 100% completed	100% completed by the end of the 10th Five-Year period	100% completed by the end of the 10th Five-Year period
2nd class regions	773.1	speed: 45 kt /a 2005: 10% completed 2010: 40% completed 2020: 100% completed	speed: 50 kt/a 2005: 12% completed 2010: 42% completed 2020: 100% completed	speed: 55kt/a 2005: 14% completed 2010: 49.6% completed 2017: 100% completed
3rd class regions	189.8	speed: 20kt/a 2005: 21% completed 2010: 73% completed 2013: 100% completed	speed: 40kt/a 2005: 42% completed 2008: 100% completed	speed: 5kt/a 2005: 52.7% completed 2007: 100% completed

Table 5-15-(2) Retrofit options of medium-small industrial boilers in China - by regions

	Low option (%)			Medium option (%)			High option (%)		
	1st class regions [h]	2nd class regions	3rd class regions	1st class regions	2nd class regions	3rd class regions	1st class regions	2nd class regions	3rd class regions
Natural gas boiler	50	2	/	50	4	/	60	8	5
Oil boiler	15	1	/	15	1	/	15	2	1
Electric boiler	20		/	20	1	/	25	3	1
efficient coal boiler +de-SO_2 & de-dusting	15	/	/	15	/	/	/	10	8
CFBC+in-bed desulfurization	/	8	10	/	10	10	/	15	15
Sulfur capture briquette	/	5	10	/	10	10	/	12	12
Washed coal + boiler retrofit	/	79	65	/	64	65	/	40	48
Coal water mixture	/	5	15	/	10	15	/	10	10

[h] 1st class regions include downtown areas of some big cities, large-medium cities and coastal cities; 2nd class regions include suburbs, towns and countryside; 3rd class regions: some industrial areas

Table 5-16 Effects of boiler retrofit

	Low option				Middle option				High option			
	2005	2010	2020	Total	2005	2010	2020	Total	2005	2010	2020	Total
Retrofit capacity（kt/h）	17.76	36.32	51.50	105.58	26.54	34.20	44.83	105.57	30.10	36.51	38.98	105.59
Coal consumption（Mt/a）	348.88	332.57	312.00	/	339.48	323.37	301.22	/	331.78	310.93	287.93	/
Reduced coal use（Mt/a）	11.12	16.32	20.57	48.00	20.52	16.11	22.16	58.78	28.22	20.85	23.00	72.07
Cost increased (10^8 Yuan/a)	103.82	75.85	37.72	217.38	164.49	40.88	66.49	271.86	224.24	100.31	118.39	442.94
Investment (10^8 Yuan)	232.91	415.42	554.38	1202.70	355.85	383.58	503.15	1242.58	418.17	431.08	465.33	1314.59
SO_2 emission reduction（10^4 t/a）	56.05	94.57	123.86	274.49	83.02	80.35	107.18	270.55	99.75	94.20	102.20	296.14
CO_2 emission reduction（10^4 t/a）	1402	2788	3921	8111	2093	2593	3405	8091	2384	2787	2981	8152
Dust emission reduction（10^4 t/a）	31.37	60.91	85.03	177.31	47.02	56.46	74.41	177.89	54.00	61.28	65.66	180.94

5.3 Chemical Production and fuel oil substitutes

- Chemical production

Energy consumption of chemical sector in China accounts for approximately 10% of the total energy consumption of the country, among which coal consumption does 45%, 80 million t/a approximately. More than 50% of the coal has been consumed as feedstock for chemical production and more than 40% has been burned as power coal.

The coal gasification technology has been applied in China mainly to provide feedstock gas for chemical production and part of the gas has been used for domestic consumption. In the chemical sector of China, 50% approximately is coal chemical processing with coal gasification as the gas head. Taking production of synthetic ammonia as an example, coal as feedstocks accounts for 64%, oil as feedstocks accounts for 16% and natural gas as feedstocks accounts for 20%[45].

In China, large scale fertilizer plants take gas and oil as main feedstocks for production, only 12% of them taking coal as feedstocks with coal gas as gas head. Most of these coal gasification technologies are advanced imported ones, which are respectively the gasification technology of Lurgi pressurized fixed bed that takes coal as feedstocks, gasification technology of Texaco pressurized entrained bed that takes Coal water mixture as feedstocks, gasification technology of Shell pressurized entrained bed that takes dry pulverized coal as feedstocks and gasification technology of GSP pressurized entrained bed, etc. (Please see Table A2 for details of imported technologies.) Among the medium and small-sized fertilizer plants[i] contributing 80% of the country's fertilizer output, 80% approximately of them take coal as the feedstock and produce gas with conventionally atmospheric fixed bed gasifier. The usual types are UGI, two-stage water-gas gasifier and two-stage producer, etc., which are frequently used in the sector of metallurgy, building materials and machinery and partly used in domestic application. As compared with that of the world advanced levels, big gap exists there as the technology applied to these gasifiers is backward, the strength of gasification is low and unit energy consumption of product is high.

In 2000, emissions of waste gases, SO_2, fly ash and dust in the chemical sector of China was respectively 878.7 Gm^3, 819,400t, 420,700t and 103,300t, accounting for 6%, 5%, 4% and 1%[46] of the total emission nationwide.

Limited by the volume, regional distribution as well as operating cost of natural gas resources, the situation that coal has been taken as the major feedstock for chemical production will be very difficult to change in China in quite a long period of time . According to the forecast made

[i] Currently, there are 852 small nitrogenous fertilizer plants (output of synthetic ammonia 15,000-60,000 t/a), 55 medium nitrogenous fertilizer plants (output of synthetic ammonia 100,000-150,000 t/a) and 28 large nitrogenous fertilizer plants (output of synthetic ammonia 300,000 t/a). Total production capacity of synthetic ammonia is 35 million t/a and total output is 31 million t/a approximately.

by the departments concerned, total coal consumption in the chemical sector will be 90 million t by 2010, among which coal as feedstock accounting for 36.5% and coal as steam fuel accounting for 63.5%. The total coal demand in 2015 and 2020 will be basically balanced with the figure of 2010.

Since the Chinese government has set orders clearly to shut down those small-sized and heavily-polluted fertilizer plants with backward technology, chemical enterprises have been gradually developing to large scales. In order to reduce the consumption of fuel oil, the State has required the fertilizer plants originally taking oil as feedstock to gradually turn to take natural gas and coal as feedstocks over the last two years. China’s chemical industry should be directed to develop an advanced chemical industry of natural gas and coal chemical industry focusing on the advanced coal gasification technology.

Great repercussions have been evoked in China after the poly-generation system centering on advanced coal gasification technology was put forward internationally. Currently, the exploration of poly-generation system in China is going on from its concept to its basic research and the pre-feasibility study of building a poly-generation plant is now under way.

- Fuel oil substitutes

China is a country rich in coal and short of oil. The remaining proven reserves of oil per capita in China are 1/10 approximately of the world average. In 2001, the net import volume of crude oil and petroleum products in China was 79.62 million t approximately.

With the rapid development of China’s economy, the demand for oil has been increasing quickly. It is predicted that by 2020 total demand for crude oil will be 420 million t. With the domestic capacity of 44% of the total demand, the shortage of crude oil supply will be still up to 235 million t.

In order to relieve the pressure brought about by oil import, the former State Economic and Trade Commission issued the “*Tenth Five-Year Plan of Saving and Replacing Fuel Oil*” in 2001. It was put forward in the plan that by 2005 the country must be able to save and replace 16 million t of fuel oil. The following technologies were required to employ: replace oil with coal (coal liquefaction and gasification), replace oil with gas (replace oil with natural gas) and switch from oil to coal (burning Coal water mixture and coal instead of burning oil), etc. Some projects have been implemented so far. For instance, the Zhenhai Branch of SINOPEC had employed the CFB technology with petroleum coke replacing the oil-fired boilers. Two sets of 410t/h oil-fired boilers in Maoming Thermal Power Plant in south China’s Guangdong province had been changed to burn Coal water mixture. In the next few years, some more projects intending to use other materials instead of oil will be put into operation.

In the meanwhile, policies issued by the State will encourage that more coal will be converted into electricity, gas and liquid fuels such as liquefied oil in order to provide the society with cleaner energy. To take coal liquefaction as the technology of strategic reserve, preparatory work has been initiated to construct a demonstration plant of direct coal liquefaction with capacity of 1.5 million t/a and its first production line of Phase I Project will be expecting to put into operation in 2008. Besides, the technology of indirect coal liquefaction has been listed in the national hi-tech "*863 Program*" and the development and research of such technology on pilot-scale is now under special concern. Currently, the construction of a commercial demonstration plant of indirect coal liquefaction with capacity of 3 Mt/a has been approved by the State. Research work on fuel substitutes to produce methanol and dimethyl ether, etc. via coal gasification is now in the process of promotion

5.3.1 Chemical production

a) Technical and economic evaluation with different gas sources

Natural gas and coal gas are the two gas sources suitable for chemical production in China.

China is developing the advanced coal gasification technology of pressurized fixed bed, pressurized fluidized bed and pressurized entrained bed respectively of the company of Lurgi, Texaco and Shell. The above-listed technologies are respectively applied to the newly-established projects and upgrade of existing technology. Conventional fixed bed coal gasifiers are unsuitable for further development and will be gradually eliminated.

Table 5-17 Technical features of typical coal gasification technologies in China

	Producer Gas One-Stage	*Water Gas One-Stage*	*Producer Gas Two-Stage*	*Water Gas Two-Stage*	*Lurgi*	*Texaco*	*Shell*	*GSP*
Bed Type	Fixed	Fixed	Fixed	Fixed	Fixed	Entrained-flow	Entrained-flow	Entrained-flow
Suitable Feed Coals	Coke, Anthracite	Coke, Anthracite	Long-flame coal, Non-caking coal	Long-flame coal, Non-caking coal	Lignite, Long-flame coal	Various	Various	Various
Ash Form	Solid	Solid	Solid	Solid	Solid	Liquid	Liquid	Liquid
Pressure	Atmospheric	Atmospheric	Atmospheric	Atmospheric	Pressurized	Pressurized	Pressurized	Pressurized
Gasification Temp., °C	1100	900–1100	1100	900–1100	1050	1400	1600	1500
Capacity	Small	Small	Small	Small	Small	Large	Large	Large
Gas Yield, Nm^3/kg	3	1.2	2.6	1.1	1.0	1.6	1.6	1.6
Gas Heating Value, MJ/Nm^3	4.6	10	5.4	10.8	14.6	9.5	10	10
Gasification Efficiency, %	70	60	70	60	75	75	80	78
Unit Investment, Yuan/MJ-day	20	25	25	30	60	90	—	—
Cost of Gas, Yuan/GJ	40	60	50	70	80	100	—	—
Particulate Emissions	Low	Low	Low	Low	Low	Very low	Very low	Very low
SO_2 Emissions	Low	More	Low	More	Low	Very low	Very low	Very low
NO_x Emissions	Low	More	Low	More	Low	Very low	Very low	Very low

Source: Technology Assessment of Clean Coal Technologies for China, Volume II, World Bank project

Please see Table 5-17 for technical, economic and environmental indexes of typical coal gasification technologies currently used in China.

Taking the construction of a 300,000 t/a plant as an example, let's make a comparison of investment and production cost of a synthetic ammonia plant that will respectively employ natural gas and coal gas as feedstocks (using Texaco gasification technology with Coal water mixture as feedstocks or using Shell gasification technology with pulverized coal as feedstocks).

The difference is very big selecting natural gas or coal as feedstock in terms of the needed investment and workshop cost of the newly-established synthetic ammonia plant. It is a trend of development internationally to produce synthetic ammonia by taking natural gas as feedstock because ammonia products are of good quality, the environmental profits are good and the capital investment is much lower than taking coal as feedstock. It is up to the price of natural gas and the price difference between natural gas and coal when calculating production cost. Please see Table 5-18 and Table 5-19 for details.

It has been proved from the economic evaluation and the investigating results that when the price of natural gas in China is lower than 1.0 Yuan/m^3, the workshop cost with NG is less than the cost of that using feedstock from coal gasification. At this situation, it is an ideal route to choose NG as feedstock for producing synthetic ammonia.

Table 5-18 Investments of new synthetic ammonia plants with different feedstocks

(capacity of 300,000 t/a)

Feedstocks	Coal	CWM	NG
Total investment (RMB 100 million Yuan) (synthetic ammonia 0.3 Mt/a together with urea 0.52 Mt/a)	40	37	20
of which: synthetic ammonia (RMB 100 million Yuan)	32	29	12

Source: *Synthetic Ammonia and C1 Chemistry--Technological Innovation of Nitrogenous Fertilizer Production* by Li Qiongjiu

Table 5-19 Cost of workshop cost of synthetic ammonia with coal and NG

Price of feedstocks	Coal (Yuan/t)	200	250	300
	NG (Yuan/km^3)V_n	500	1000	1600
Workshop cost of synthetic ammonia	Coal (Yuan/t)	1585	1670	1770
	NG(Yuan/t)	825	1255	1770

Source: *Synthetic Ammonia and C1 Chemistry--Technological Innovation of Nitrogenous Fertilizer Production* by Li Qiongjiu

Limited by the volume of resources, regional distribution and prices (usually more than 1.0 yuan/m^3 at present) of natural gas as well as the maturity of poly-generation, China will still need to develop the production of synthetic ammonia and other chemicals in a large scale focusing on coal gasification in next several years.

At present, chemical production should be concentrated on the development of advanced coal gasification technology such as pressurized fixed bed, pressurized fluidized bed and pressurized entrained bed. For a long term, the poly-generation system should be the orientation of future development of chemical production as it has a lot of advantages[47], such as flexible combination of products, multiple varieties of products, good availability of energy ladder, low investment and operational costs. Compared with projects producing only one product, a total volume of investment of 7.7% approximately can be saved. However, it still needs quite some time that such poly-generation system is applied in China commercially.

b) Development option for future chemical production

The development option for future coal chemical processing in China is put forward herewith by taking synthetic ammonia as an example. It is anticipated that by 2005, 2010 and 2020, output of synthetic ammonia will be respectively 35 million t/a, 37-40 million t/a and 40-45 million t/a. Under the condition that small-scaled facilities will be eliminated and the industrial structure of synthetic ammonia will be reconstructed and respective new and upgraded capacity of synthetic ammonia will be calculated[50,48] at 3 million t/a, 7 million t/a and 8 million t/a, NG and advanced coal gasification technology can be used for new projects and poly-generation system can be employed in the long-term projects. The demonstration plant of poly-generation system will be completed in around 2020.

The options are worked out on the basis of capacity of 300,000 t/a of synthetic ammonia. Please see Table 5-20 for recommended low, medium and high options in detail. The proportion of NG used decides the major differences of the three options and the possibility of employing poly-generation system. Since the proportion of NG used is high in the high option (2/3 of NG will be used in the increased capacity), the total investment is low yet the operating cost is rather high (If price of NG is high, the production cost of synthetic ammonia will be rising accordingly) and the supply of NG is limited by regional availability.

When taking all factors (see Fig. 5-5) such as availability, technical maturity, economic capacity and environmental benefits of NG into comprehensive consideration, the investment in the medium option (increased capacity will need to consume 50% respectively of NG and coal) is supposed to be suitable as the state is capable of providing the needed volume of NG, the emission of SO_2 can be reduced tremendously to protect the environment and it suits the conditions of China. Therefore the Medium option is recommended here.

If the Medium Program is adopted, 50% of the newly increased capacity of synthetic ammonia will employ NG in 2005, 2010 and 2020 and the needed NG will be respectively 1.09 billion m3/a, 2.54 billion m3/a and 2.91 billion m3/a. 50% of the newly-increased capacity will employ coal gasification technology and the needed amount of coal will be respectively 1.98 million t/a, 4.62 million t/a and 5.28 million t/a. A total of 944.5 billion Yuan of investment will be needed in the period of 20 years. Compared with the investment for the technology of fully coal chemical processing, a sum of 433.5 billion Yuan can be reduced.

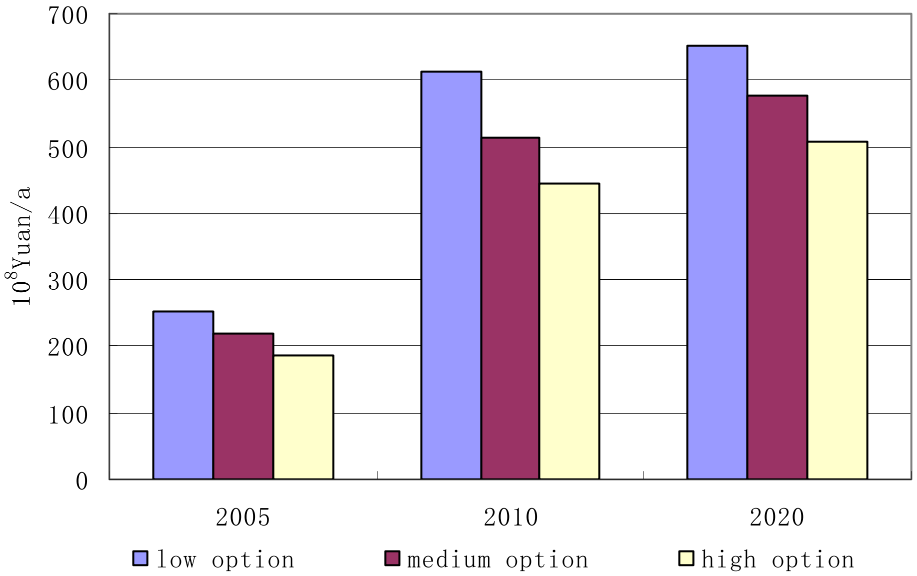


Fig. 5-5 Investment demand for new synthetic ammonia capacity in next 20 years

Table 5-20 Recommended options of developing synthetic ammonia by phases

phases	2005						2010							2020							
options	Low option		Medium option		High option		Low option		Medium option		High option			Low option		Medium option			High option		
Technology adopted	CG[1]	NG[2]	CG	NG	CG	NG	CG	NG	CG	NG	CG	NG	PG[3]	CG	NG	CG	NG	PG	CG	NG	PG
Scale (synthetic ammonia 10,000 t/a)	200	100	150	150	100	200	500	200	350	350	220	450	示范30	500	300	310	400	90	180	500	120
investment[5] (100 million Yuan/a)	213	40	160	60	107	80	533	80	373	140	235	180	29	533	120	331	160	87	192	200	116
SO_2 emission	*[4]	Few	*	Few	*	Few	*	Few	*	Few	*	Few	*	*	Few	*	Few	*	*	Few	*
PM emission	*	Few	*	Few	*	Few	*	Few	*	Few	*	Few	*	*	Few	*	Few	*	*	Few	*

1. CG: coal gasification
2. NG: natural gas
3. PG: poly-generation
4. *: meeting the standard
5. Only the part of producing synthetic ammonia is considered in the investment of poly-generation

5.3.2 Fuel oil substitutes

a) Economic evaluation on the technology

- Coal water mixture (CWM)

When CWM is used as boiler fuels, 1 ton of fuel oil can be replaced with 2 tons of CWM. Taking a CWM project with capacity of 250,000 t/a as an example, please see Table 5-21 for its economic indexes

Table 5-21 Economic indexes of a CWM project(capacity 250,000t/a)

Name	Unit	Estimated value	Remarks
Total project investment (including circulating fund)	10,000 Yuan	4489.09	
Total annual profits	10,000 Yuan	1788.7	After tax
Internal rate of return	10,000 Yuan	51.02	After income tax
payback period	Year	3.05	After income tax
Unit cost of CWM	Yuan/t	340.93	

Source: "*Feasibility Study Report on CWM Technical Transformation of Xizhang Paper Mill, Zhangjiagang City, Jiangsu, China*", June, 2000

Since feedstocks for CWM production are all of washed clean coal (sulfur content generally 0.3-0.4%), burning of CWM can be up to the required standards of emissions specified by the State.

In China, sulfur content in heavy oil is rather high in many cases. If heavy oil will be replaced with CWM, not only fuel oil will be saved, but also the cost of technical transformation can be saved, emission of SO_2 can be reduced and the cost of fuels can be decreased to a big extent. For instance in Baiyanghe Power Plant, the 2×230t/h boilers are burning CWM in satisfactory conditions environmentally. Compared with the oil consumption, 200,000 t of fuel oil can be saved each year, a reduction of 20 million Yuan/a of fuel expenses approximately. Investment for switching from oil fired boilers to CWM boilers is 100,000 Yuan/t approximately[49].

As the first choice of oil replacement technology at the current stage, CWM technology has been well-proven for oil fired boilers and should be applied and promoted in the country in the near future. From a long-term point of view, CWM boilers should be developed properly as it has no competitiveness as compared with pulverized coal boilers economically.

- Coal liquefaction

Coal liquefaction technology is classified into two types, that is, direct liquefaction and indirect liquefaction. When producing oil products through coal liquefaction, many other chemicals and substitutes of petroleum chemicals are produced simultaneously. To some extent, coal liquefaction can play both roles of saving oil and substituting production of oil and gas from chemical production.

Indirect coal liquefaction has been in operation commercially in South Africa and the plants there are in good economic conditions. Domestic research has proved that for an indirect coal liquefaction plant with capacity of 1.6 million t/a (main products including 623 kt//a of naphtha, 391 kt/a of propylene, 325 kt/a of hydrocarbons, 83 kt/a of slack wax, 57 kt/a of LPG, and 106 kt/a of oxygen compounds), total investment for the project is 14.52 billion Yuan, the proportion of oil products is 37.5% and the production cost of oil products is 1,800 Yuan/t. Please see Table 5-22 for major financial indexes in detail.

Table 5-22 Financial evaluation indexes of a 1.6 Mt/a of indirect coal liquefaction project

Name	Unit	Estimated value	Remarks
Total project investment	10,000 Yuan	1452024	
Total average annual profits	10,000 Yuan	131458	normal annual average value
Average annual profits after tax	10,000 Yuan	118209	normal annual average value
Total payback period (after income tax)	year	10.36	Incl. construction period

Source: 《*Pre-feasibility Study Report on 1.6 million t/a Indirect Coal Liquefaction Project of Taixi Group Corporation*》

Direct coal liquefaction plants were once put into commercial operation only in Germany before World War II. After the war, no large scale direct coal liquefaction plants have been in commercial operation until now worldwide. Research results at home and abroad have proved that investment for a direct coal liquefaction plant is lower than an indirect one. Results of feasibility study have indicated that total investment for a direct coal liquefaction project with capacity of 1.5 million t/a is estimated at 9 billion Yuan in China. With an internal rate of return of 10.89%, the payback period of the project will be 12.6 years, the proportion of oil products will be 50-60% and the cost of oil products will be 1,400-1,500 Yuan/a[2].

The first production line of the direct coal liquefaction in China will be put into operation in 2008 and the first production line of indirect coal liquefaction in China will start construction before 2010. It is expected that by 2020 coal liquefaction technology will be up to the commercialized scale to some extent in China.

- Producing methanol and di-methyl ether from coal

It was put forward only over the last few years internationally to produce methanol and dimethyl ether from coal as fuel substitutes. Such proposal has aroused rather big echoes in China. Currently, basic research and pre-feasibility study are under way from the initial conceptual design in the country and commercialized demonstration plant has not started yet.

The technology of producing methanol from coal has been well proven. The two-step method of producing dimethyl ether from coal (coal-methanol-dimethyl ether) has been well proven, too. The one-step technology from coal (coal-dimethyl ether) needs to import abroad. Both technologies have close relationship with the selection of coal gasification technology. As fuel substitutes, methanol and dimethyl ether involve a lot of technical issues (such as engines and gas stations) that are now under research. To what degree the issues will be solved will directly influence the development of producing methanol and dimethyl ether from coal and the industrialization process. There are still many uncertain factors whether the said technology can be put into commercial application before 2020 and detailed argumentation needs to make quickly.

b) Development options for future fuel oil substitutes

In 2000, total fuel oil consumption of China's power sector was 20 million t approximately (accounting for half of total fuel oil consumption of the country), among which total annual fuel oil consumption by oil fired generating units was 7.6 million t approximately and about 40% of the consumption can be possibly replaced with CWM. Considerable fuels can be replaced with CWM in the petroleum and petro-chemical sector as well as the numerous oil-fired industrial boilers in cities of China. In building materials, 3 million t/a of fuels has been consumed to produce sheet glass and sanitary wares for buildings, part of which can possibly be replaced with CWM. If only the fuels consumed by oil fired boilers (kilns) are considered to replace with CWM, by 2020 the potential capacity of fuel oil substitution with CWM will be 3 million t/a and 6 million t/a of CWM will be needed.

In view of the development of coal liquefaction technology, it is predicted by organizations concerned that the coal liquefaction industry will be in shape to a certain scale in China by 2020 (with a period of 15-20 years). By that time, 25 million t/a of fuel oil would be able to supply via coal liquefaction, equal to 35 million t/a of crude oil. It will not only help to develop the technology for strategic reserves but also replenish the short supply of petroleum domestically to some extent. Since there are various uncertain factors in the development of coal liquefaction, the development options proposed in the study are calculated only according to 1/3 of the above predicted value.

In comprehensive consideration of factors such as maturity, economy and environmental impact of coal liquefaction and CWM technology, three options like high, medium and low options are put forward for the development of fuel oil substitution technology. For the short term, CWM will be mainly employed to replace oil in the options. As for the medium and long term, coal liquefaction technology will be developed in order to increase the output of oil products. In the meanwhile, demonstration projects should be carried out to prove and develop technologies of producing methanol and dimethyl ether from coal for clean fuel substitutes or energy carriers, see Table 5-23 for details. The three options differ mainly in terms of different speed of commercial application of CWM and coal liquefaction technology.

Comparing the three options, it is considered that the Medium option is more suitable for the conditions in China and will be recommended as the development options (see Fig. 5-6.). If employing the Medium option, by 2010 and 2020, 1.5 million t/a and 3 million t/a of oil will be substituted with CWM respectively in China and 33 million t in total in the period of 20 years. By 2010 and 2020, China will be able to produce 1.6 million t and 11.2 million t of oil products and chemical feedstocks respectively by employing coal liquefaction technology (including direct and indirect liquefaction). By 2020, 8 million t/a of oil will be substituted in total and 6 million t/a of chemicals will be produced simultaneously.

Investment for the Medium option for development of CWM and coal liquefaction technology will be respectively 3.2 billion Yuan and 116 billion Yuan. Accumulative investment in the period of 20 years will be 119.2 billion Yuan.

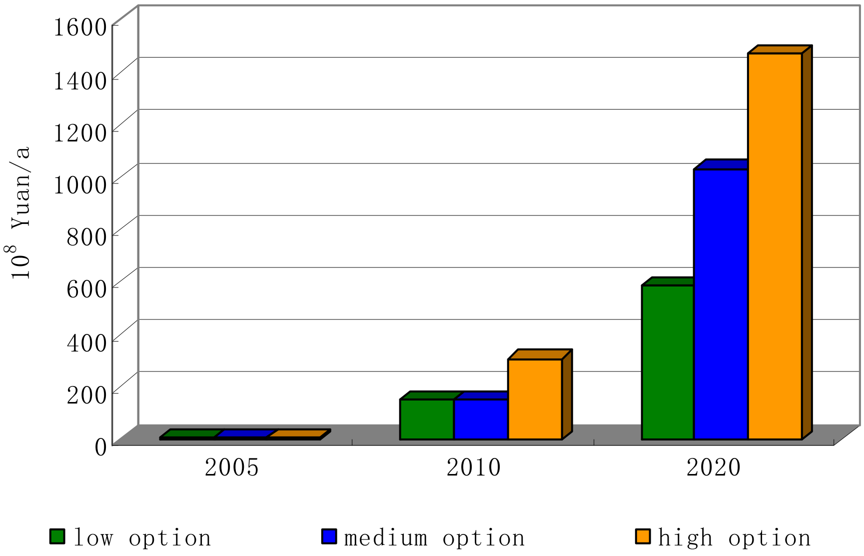


Fig. 5-6 Investment demand options of fuel oil substitution in next 20 years

Table 5-23 Recommended options for development of fuel oil substitutes by phases

Stage	2005						2010						2020					
Option	Low option		Medium option		High option		Low option		Medium option		High option		Low option		Medium option		High option	
Technology	CWM	liquefaction	CWM	liquefaction	CWM	liquefaction	CWM	liquefaction	CWM	liquefaction	CWM	liquefaction	CWM	liquefaction	CWM	liquefaction	CWM	liquefactio n
Scale(10,000t/a)	150	Early stage study	200	Early stage study	300	Early stage study	200	160	300	160	600	320	300	640	600	1120	800	1600
investment[1] (M Yuan)	4.38		5.84		8.76		5.84	145	8.76	145	17.52	290	8.76	580	17.52	1015	23.36	1450
SO_2 emission[2] (10,000t/a)	0.72		0.95		1.43		0.95	0.17	1.43	0.17	2.86	0.35	1.43	0.69	2.86	1.21	3.82	1.73
PM emission[3] (10,000 t/a)	0.57		0.77		1.15		0.77	0.38	1.15	0.38	2.30	0.76	1.15	1.51	2.30	2.65	3.06	3.78

Notes: 1. Investment for CWM technology includes investment for producing CWM and upgrading investment for oil-fired boilers;

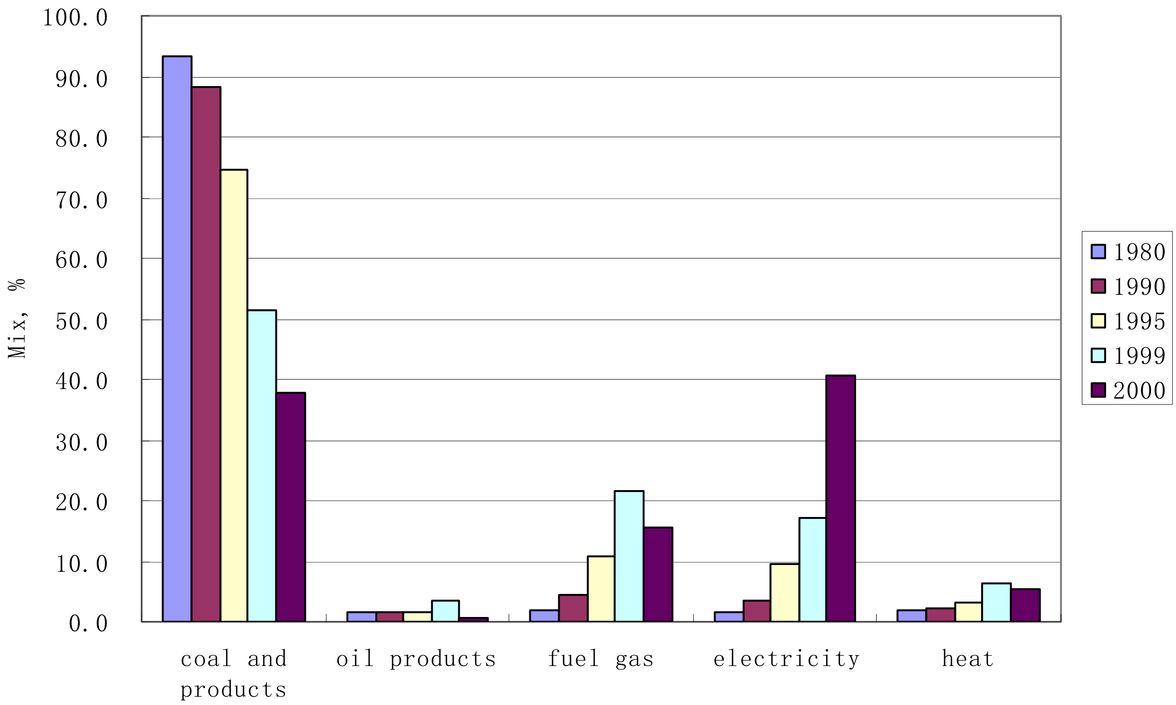
2. Emission of SO_2 in CWM is the value with desulfurization efficiency of 40%;

3. Emission of PM in CWM is the value with de-dusting efficiency of 94%.

5.4 Household use

5.4.1 Household fuels and relevant policies

The energy consumption mix in China has changed from only relying on coal to taking coal as the major energy supplemented with many other energy resources. Direct combustion of bulk coal and briquette is still the usual way for the residents to take. In 2000, household coal consumption was 79.07 million t in the country.



Notes: 1. Natural gas, LPG and pipeline gas, etc. are included in fuel gas;

2. Source: *Energy Policy Research*, 2002 (1); China Statistical Yearbook 2002

Fig. 5-7 Changes of commercial household energy mix in china

Changes of energy mix of household consumption in China are shown in Fig. 5-7. The proportion of coal in household energy mix tends to decrease and in recent years the figure is on a quick decline. The proportion of clean energy such as gas, electricity and heat is increasing year by year.

At present, the consumption of bulk coal as household energy has dropped tremendously in proportion. The consumption of bulk coal in the country has been more than 13 million t/a, accounting for 16% of the total household coal consumption and mainly focused on coal mining cities, mining areas and rural areas.

a) Energy consumption in cities

Since 1950s, big cities in China started to consume honeycomb briquettes in large quantity. There are more than 2,000 production lines for civil briquettes in the country currently. Sales of civil briquettes has been up to 56 million t/a, accounting for more than 80% of the total coal consumption in towns and cities of China. In recent years, the proportion of clean fuels (such as LPG and natural gas in household fuels has been increasing rapidly while the consumption of civil briquettes has been in slow growth.

City gases include coal gas, LPG and natural gas. By the end of 2000, 84.15% of residents in 665 cities all over China had been available to consume various gases with the 176 million of population, of which, the percentage of artificial gas, natural gas and LPG is respectively 23%, 13% and 63%[50].

With the rapid development of China's economy and the increasingly strict requirement to the environment, each city in China is expanding the proportion of clean energy sources in civil energy consumption according to their own economic conditions and energy availability. Beijing, Shanghai and the coastal areas with developed economy where environmental requirements are strict are considering taking natural gas, LPG and LNG as major commercial and household fuels, and solving the problems of heat supply in winter and industrial heating with natural gas fired boilers, CHP generation using coal-fired CFB and central heating system instead of scattered coal-firing boilers. Those regions with less developed economy and in short of natural gas are popularizing in succession briquettes, low sulfur coal and coal-saving furnaces as main household energy sources. Cogeneration with coal-fired CFB and central heating systems are major heat supply technologies in these regions. All big cities have delimited coal forbidden zones in city centers.

Some cities with favorable conditions are developing the solar and geothermal energy resources used for civil consumption, heat supply, medical treatment and baths, etc. Solar energy heaters have been developed very well in China. By the end of 2000, China had had up to 26 million m^2 of solar water heater, ranking the first in the world[51], equivalent to save 3.64-5.46 Mt of coal approximately, reduce 36,400-54,600t of PM emission, 65,500-98,300t of SO_2 emission and 1.77-2.65 million t of CO_2 emission[52]. In 2000, Tianjin Municipality had 6 million m^2 of heating area from geothermal energy. Beijing had developed 8.8024 million m^3 of geothermal water, equivalent to saving 75,000 t of coal and reducing 750t of particulate emission, 1,350t of SO_2 emission and 36,400t of CO_2 emission each year[j].

b) Energy consumption in rural areas

Non-commercial biomass energy sources like straw are still the major domestic energy in rural areas in China. Coal has taken the second place among household energy consumption there. In recent years, rural energy such as small-scale hydropower stations, biogas, energy-saving furnaces and firewood forests have been developed considerably. In some economically developed rural areas or those with good availability of energy have started to supply biogas, briquette and LPG. Please see Table 5-24 for proportion of energy consumption in rural areas. By 2000, 417,200 biogas tanks had been built in the suburb of Chongqing Municipality for 374,900 households, with total biogas capacity up to 112.1 million m^3 and the average capacity per household was 299m^3, equivalent to 80,000 tce. Besides, Chongqing had 33,300 customers using stoves with briquette[53].

It is anticipated that by 2020 household fuels in cities will be mainly composed of clean

[j] Emission factor of coal in household energy: SO_2 1.8kg/t.coal, CO_2 0.68t/tce, particulate10kg/t.coal

household energy or fuels, such as natural gas, LPG, LNG and thermopower. In rural areas and coal mining communities, there'll be still some consumption of coal

Table 5-24 Household energy consumption mix in rural areas in 2002

Total energy consumption （Mtce）	Straw	Firewood	Coal	Electricity	Product oil	Others
453.47	31.20%	25.14%	34.70%	5.46%	1.87%	1.63%

Source: Energy Policy Research, 2003 (6)

5.4.2 Existing problems in household energy

a) Development of household energy will be unbalanced due to difference of energy availability and economic conditions in different regions

In China, 77% of coal resources are distributed in the north of Qinling and Huaihe River; 85% of oil resources are distributed in north of Yangtze River and 82.5% of hydropower resources are distributed in the west of the country. However, major energy consumers are located in the eastern and middle part of China. The unbalanced distribution of resources decides the long-existing phenomenon that coal has been transported from north to south and from west to east. With big difference of energy availability in each region, prices of various energy sources differ a lot. Table 5-25 shows a comparison of energy supply in Beijing, Shanghai and Chongqing Municipality.

Table 5-25 Energy availability and economy in Beijing, Shanghai and Chongqing

		Beijing	Shanghai	Chongqing
Energy demand and supply features		Capital, host for Olympic Games 2008; Energy mainly imported.	Major energy consumer. Energy mainly imported.	Big energy consumer, producing high sulfur coal, NG and hydropower
Available energy		Oil products, NG, coal, part renewables	Oil products, NG, coal	Oil products, NG, coal, hydropower and biogas
Prices of major energy sources	Coal (5,000kcal/kg)	260Yuan /t	330Yuan /t	160Yuan/t (self-produced high sulfur coal) >300Yuan/t(imported)
	NG (8,450kcal/m^3)	1.8Yuan/m^3	2.1Yuan/m^3	1.2Yuan/m^3
	Heavy oil (9,200kcal/kg)	1,500Yuan/t	1,500Yuan/t	1,500Yuan/t
	Light oil (10,000kcal/kg)	2,200Yuan/t	2,200Yuan/t	2,200Yuan/t
Energy price ratio at same heat value		NG>oil products & Heavy oil >coal Nearly 4 times of NG as much as coal.	NG>oil products & Heavy oil>coal Over 3 times of NG as much as coal.	Oil products & Heavy oil> NG>coal

Source: Survey data by CCERC

Energy availability, environment and economy are major factors that every city needs to weigh the pros and cons when selecting energy utilization technologies and clean energy. As the capital and host of Olympic Games 2008, Beijing will manage to use natural gas as much as possible to ensure environmental quality. Its utilizing amount of natural gas will be increased from 1 billion m^3 in 2000 to 6 billion m^3 in 2008. Shanghai will choose to use multiple energy sources. Not only utilization ratio of natural gas will be increased through the West-to-East natural gas pipeline, but also CCT will be strongly developed, for instance supercritical generating technology in Shanghai. Chongqing will try to use natural gas and hydropower as much as possible and in the meanwhile increase the proportion of converting coal to electricity and heat, and the proportion of coal in the end energy mix will be reduced from 64.6% in 2000 to less than 50% in 2010.

b) Many cities have been forced to forbid coal combustion under environmental pressure

Through various measures, the smoke emission in China has been initially under control in recent years. The emission has been reduced from 17.44 million t in 1995 to 10.59 million t in 2001. However, particulate matters are still the major pollutants affecting city air quality. In 2001, the average annual concentration of particulate matters in 64.1 % of cities in China was beyond the National Class II Standard for Air Quality. Among the 341 cities covered by the statistics made in 2001, 19.4% of them did not meet the National Class II Standard for Air Quality in terms of SO_2 emission and 9.7% of them were beyond the National Class III Standard for Air Quality.

On September 1, 2001, the Chinese government promulgated the Law on Atmospheric Pollution Control and 47 cities were listed as key cities allowing each local government to delimit coal forbidden zones in its urban areas where only clean fuels were allowed to burn. Pressed by the environmental requirement, many other cities had started to reorganize boilers burning bulk coal and practise coal forbidden programs in downtown areas in turn. Small boilers, hot water boilers were switched to burn clean fuels such as oil, gas and electricity without exception and all of surrounding areas of cities were forbidden to burn bulk coal. Medium-sized boilers would use clean fuels such as industrial briquette, oil and gas step by step.

c) Non-commercial energy sources are still playing major roles in rural consumption

Firewood and straws are conventional fuels in the daily life of peasants, accounting for 56% of the total energy consumption in rural areas of the country in 2002%. Direct combustion of large amount of biomass resources has therefore destroyed the rural ecology. Over consumption of firewood has decreased the area of forest vegetation and has caused heavy water losses and soil erosion. The content of organic matters in agricultural land has been reduced as large amount of straws can’t return to the soil, resulting in great decrease in effect of increasing production with fertilizer.

Since large amount of non-commercial biomass energy will be consumed continuously in rural areas for a long period of time, gasification technology, power generation through gasification and compact shaping with biomass should be actively developed. Besides, the utilization efficiency of biomass energy can be improved if direct combustion of firewood and straws will be changed gradually. In most of the rural areas, it is possible that cooking will be directly transited to use LPG and biogas while heating will have to experience the stages from non-commercial biomass energy to coal and then to other clean energy. In the years to come, coal consumption in rural areas will be increasing.

d) Indoor pollution gradually becomes chief environmental issue in household energy

Currently, more than 60% of residents in China are still relying on burning solid fuels. Direct burning of coal, firewood and straws will not only pollute the surrounding environment, but also lead to serious indoor air pollution and endanger people's health severely. Air pollution, especially indoor air pollution, can cause diseases of respiratory system in high proportion. Diseases of respiratory system have been currently considered the chief source of disasters to cause death in rural areas and take the third place to cause death in cities

The problem of indoor air pollution out of household energy consumption has aroused concerns of all walks of life step by step. Since it is closely related with people's health, both the governmental departments and the public should attach further importance to indoor air pollution. Clean energy and advanced furnaces should be strongly popularized in cities and towns. Clean energy sources such as firewood and coal-saving furnaces, briquette and biogas should be promoted in rural areas.

5.4.3 CCTs and economic evaluation for focused development

We can see from Table 5-26 that coal still has the absolute superiority in price among household fuels. Oil products, natural gas, LPG and gas come after it. Electricity is the most expensive energy among household energy sources, 10 times as high as raw coal at equivalent calorific value.

In terms of household energy consumption currently, annual emissions of dust 791,000t, SO_2 1.423 million t and CO_2 38.41 million t have been produced from coal combustion only. According to Table 5-27, it is predicted that by 2020 in household energy consumption, coal consumption will be 100 million t approximately in China, a slight increase compared with the current consumption. Emission of various pollutants will be also increased slightly upon then.

Therefore, among household energy sources, the development of coal should be restricted and clean energy sources such as electricity, heat, natural gas, LPG and coal gas should be encouraged to consume. However, when taking factors such as economy and energy availability into consideration comprehensively, coal will be accounting for a considerable proportion in household energy in the undeveloped regions and the vast rural areas in a long period of time ahead. In order to follow the adjustment tendency of energy mix as well as the increasingly stricter environmental requirements in China, the development of household energy should tend to this way: The consuming proportion of natural gas, LPG (LNG), especially heat and electricity should be further increased in cities and their surrounding regions with allowable economic capacity while the consumption of high quality coal with low ash and low sulfur content and energy-saving briquettes should be gradually increased in poor areas and rural areas. The consuming proportion of clean energy sources like biogas and small hydropower should be also increased in these areas.

Table 5-26 Comparison of prices of various fuels

No.	Fuels	Unit	Price (Yuan/)	Heat value (LHV) (kcal/)	Price Yuan/ Gcal	Price Yuan/ GJ
1	Shanxi coal	kg	0.15	5000	30	7.17
2	North China low sulfur coal	kg	0.25	5000	50	11.94
3	East China low sulfur coal	kg	0.30	5000	60	14.33
4	Crude oil	kg	1.50(AP*)	10000	150	35.83
5	Imported heavy oil	kg	0.75(AP)	9200	81.2	19.39
6	Domestic Heavy oil	kg	1.10(AP)	9200	119.57	28.56
7	Imported diesel oil	kg	1.50(AP)	10302	145.6	34.78
8	Domestic diesel oil	kg	2.30(AP)	10302	223.26	53.32
9	Imported LPG	kg	1.54(AP)	11650	131.8	31.48
10	Domestic LPG	kg	1.96(AP)	11650	168.24	40.18
11	City gas	m^3	0.90(AP)	4500	200	47.77
12	Electricity	kWh	0.45(AP)	860	523.26	124.98
13	Russian NG	m^3	1.00	8400	119.05	28.43
14	Shaanxi-Gansu-Ningxia NG	m^3	1.31	8400	155.95	37.25
15	Imported LNG	m^3	1.50	8400	178.57	42.65

Note: AP*: Average Price

Source: Proposal on China's Natural Gas resources Survey and Direction of utilization, October 1999, China Energy Network.

Table 5-27 Development forecast on household energy sources

Year	Total energy consumption （100 Mtce）	Ratio of household energy consumption to total (%)	Household coal consumption （10,000t）	Ratio of household coal consumption to total household energy consumption (%)
2000[a]	13.0	11.5	7907	37.9
2020	19.0[b]	16.9[b]	10000	22.9

a Based on China Statistical Yearbook 2002

b Based on the low option (scenario C) of Scenario Analysis on China Energy Demand in 2020, Energy Research Institute

5.5 With regard to coal washing

5.5.1 Requirements for steam coal quality in China's current environmental standards

a) Emission standard for power plants

It was specified in the Emission Standard of Air Pollutants for Thermal Power Plants GB13223-1996 issued in 1996 that when sulfur content in coal is ≤1%, the maximum concentration of SO_2 emission is 2,100 mg/m^3; when sulfur content in coal is >1%, the maximum concentration of SO_2 emission is 1,200 mg/m^3.

The new Emission Standard of Air Pollutants for Thermal Power Plants GB13223-2000 was issued at the end of December, 2003 and was put into effect on January 1, 2004 (Please see Table 5-28). The maximum concentration of SO_2 emission required by the new Standard will be: 1) before 2010, 2,100 mg/m^3 for old power plants built before 1996 and 400 mg/m^3 for new power plants; 2) after 2010, 1,200 mg/m^3 for old power plants built before 1996 and 400 mg/m^3 for new power plants. 3) After 2010, the maximum concentration of smoke emission will be 200 mg/m^3 for old power plants and 50 mg/m^3 for new power plants. The new standard is clearly stricter than the former one.

Table 5-28 Emission Standard of Air Pollutants for Thermal Power Plants

(GB13223-2003)

Phase		Phase I		Phase II		Phase III
effected time		2005.1.1	2010.1.1	2005.1.1	2010.1.1	2004.1.1
PM (mg/m^3)		300[1] 600[2]	200	200[1] 500[2]	50 100[3]	50 100[3]
SO_2 (mg/m^3)		2100[4]	1200[4]	2100	400	400
effected time		2005.1.1		2005.1.1		2004.1.1
NOx (mg/m^3)	V_{daf}<10%	1500		1300		1100
	10%≤V_{daf}≤20%	1100		650		650
	V_{daf}>20%					450

Notes: Phase I: Thermal power plants newly built, expanded or modified before Dec. 31, 1996;

Phase II: Thermal power plants newly built, expanded or modified between Jan. 1, 1997 and Jan. 1, 2004;

Phase III: Thermal power plants newly built, expanded or modified starting from Jan. 1, 2004.

1) Thermal generating boilers in built-up urban areas above county level execute such limit;

2) Thermal generating boilers outside built-up urban areas above county level execute such limit;

3) Thermal generating boilers of mine mouth power plants burning coal with specially low sulfur content (less than 0.5%) in non-two control zones in the west execute such limit;

4) The limit is the average value of thermal generating boilers of the whole plant during Phase I.

If the existing boilers are required to meet the national standard for pollutants emissions, then the control of SO_2 must be strengthened and the desulfurization devices must be installed or only coal with very low sulfur content (sulfur content is required to be <0.6% before 2010 and <0.2% after 2010.) can be burned. In the meanwhile, high efficient de-dusters (or burning coal with low ash content) and low-NOx combustion technology should be employed.

To match with the new Emission Standard of Air Pollutants for Thermal Power Plants, the State has issued policies requiring that all new power plants must install desulfurization devices, old plants must add desulfurization devices step by step and those old plants without desulfurization devices must burn coal with low sulfur content (or prepared coal).

b) Emission standards for industrial boilers

Table 5-29 Emission Standard of Air Pollutants for Boilers (GB13271-2001)

Items		PM (mg/m^3)		SO_2（mg/m^3）	
Boilers	Function zone	phase I	phase II	phase I	phase II
Natural ventilation	Class I	100	80	1,200	900
	Class II, III	150	120		
Others	Class I	100	80		
	Class II	250	200		
	Class III	350	250		

Notes: Phase I, before Dec. 31, 2000; Phase II, after Jan. 1, 2001.

By the end of 2000, the State issued Emission Standard of Air Pollutants for Boilers GB13271-2001, specifying the max. concentration of SO_2 emission of 1,200 mg/m^3 in phase I and the max. concentration of SO_2 emission of 900 mg/m^3 in phase II. The required concentration of PM emission is tending much stricter. Please see Table 5-29 for details.

If they could meet the standards for pollutants emission of Phase II, the industrial boilers currently in operation must install desulfurization devices or burn coal with sulfur content less than 0.5% and in the meanwhile employing high-efficient de-dusters (or burning coal with low ash content).

5.5.2 Analysis on demand for washed steam coal in China

Steam coal (indicating coal for combustion in power station boilers, industrial boilers, kilns and household consumption) in China includes solid fossil fuels such as lignite, long flame coal, non-caking coal, weak caking meager, anthracite and natural coke, etc. A considerable amount of gas coal and other coking coal is also included in steam coal in practical application.

a) Steam coal resources and production in China

Table 5-30 shows average quality of steam coal resources in major mining areas of China.

Table 5-30 Quality indexes of steam coal resources in major mining areas of China

Item	Meager coal	Anthracite	Weak caking coal	Non-caking coal	Long flame coal	Lignite	Unclassified coal	Natural coke	Subtotal
% of steam coal	7.68	15.88	9.64	20.72	21.92	17.91	6.03	0.22	100.00
Ad %	19.51	17.93	15.57	13.48	17.66	16.52	15.21	21.50	16.97
St,d %	1.67	1.24	0.89	0.60	0.75	0.55	0.80	0.80	0.85
Qgr,ad MJ/kg	27.89	27.82	27.59	27.11	24.39	19.99	26.56	25.09	26.03

Sources: *Steam Coal Blending, aut*hored by Chen Wenmin, etc.

The average sulfur content in steam coal resources in China is 0.85% approximately. If power plant boilers and industrial boilers are not equipped with desulfurization devices, quite a amount of steam coal can’t be burned directly with these boilers. The coal must be prepared before burning. Only when the sulfur content in coal is reduced to <0.5% or 0.6%, can the current environmental standard be met with these boilers. Besides, sulfur content in some coal (for instance S>1.5%) is still higher than 0.7% even after preparation. Desulfurization devices must be then employed when burning such coal otherwise the environmental requirement will be very difficult to meet.

According to the regional distribution of coal in China, high quality steam coal is located mainly in northwest, north and northeast China, accounting for 83.27% of the total steam coal resources of the country. Since coal produced in these regions has been transported to other places in large quantity, it is necessary that the coal be prepared in order to improve quality of the coal. With big coal consumption, coastal areas of southeast China have small output with poor quality. Coal with high sulfur and ash content is mainly distributed in Hainan, Guangdong, Guizhou, Sichuan, Hunan, Hubei and Zhejiang province, Guangxi Autonomous Region and Chongqing Municipality. These regions mainly rely on coal from other places and local coal plays a supplementary role only. To meet the requirement of environmental protection, coal produced locally in these regions must be washed (see Fig. 5-8 for details).

The average sulfur content of the current commercial steam coal in China is 1.0% approximately (see Table 2-2 for coal quality), which differs a lot in terms of the requirement of environmental protection. Since less than half of the commercial steam coal for city consumption can meet the above-mentioned requirement of environmental protection, it is very necessary to stress the preparation of steam coal

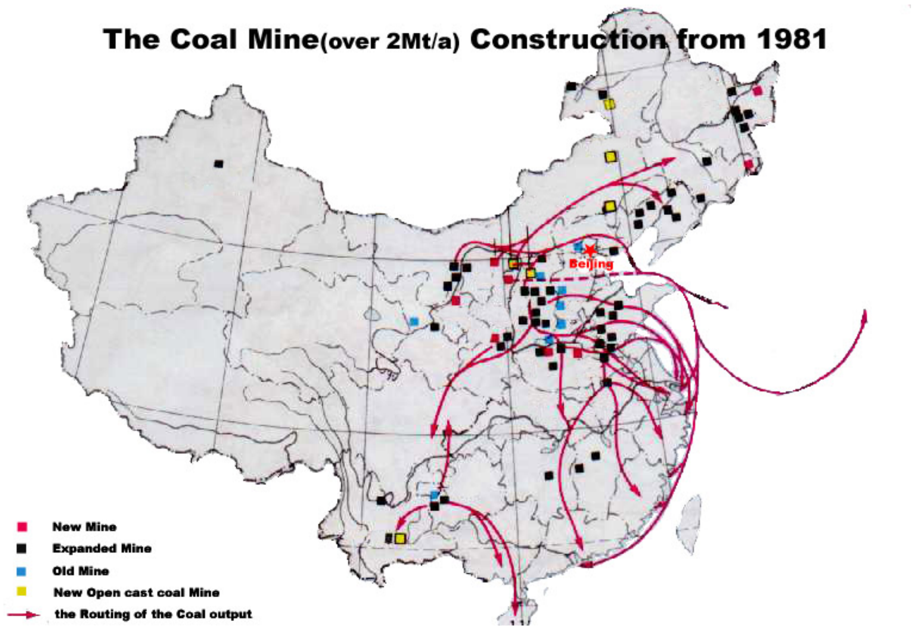


Fig. 5-8 Construction of coal mines over 2Mt/a since 1981

b) Steam coal preparation and application of washed coal in China

The increasingly strict requirements of environmental protection have promoted the gradual expansion of the washed steam coal market in China (see Table 5-31). In 2002, the amount of raw coal washed in China was 456 million t with raw coal washing rate of 33%, among which the amount of steam coal washed was 145 million t. However, the washed amount of steam coal accounted for only 12% of the total amount of steam coal and the availability of steam coal preparation plants was 56% only. There is a great deal of difference between the current rate and the expected one.

Table 5-31 Production structure of coal preparation in China

Item	1980	1985	1990	1995	2000	2002
Raw coal washed (100 million t)	1.14	1.43	1.91	2.02	3.37	4.56
Washing ratio (%)	18.4	16.4	17.7	15.6	33.7	33.0
Among which: Steam coal washed (100 million t)	0.23	0.36	0.64	0.71	1.07	1.45

Source: China Coal Industry Statistics Yearbook, Beijing: China Coal Industry Publishing House

The technology (jigging, floatation and heavy medium) for steam coal washing has been mature in China. The introduction of technologies such as heavy medium and the autonomous intellectual property of these technologies step by step have provided good conditions for further development of steam coal washing. Investment on the current technology for steam coal washing and its operating cost are not that high, yet the price of coal after washing will go up, 1.2-1.4 times as much as that of raw coal.

Results of the research in former chapters have proved that burning of washed steam coal with sulfur content less than 0.6% for power plant boilers will not only meet the current environmental standards, but also help to improve efficiency of boilers, reduce coal consumption and decrease wear and tear of boilers. Its operating cost is equal to that of installing FGD. Washed steam coal with sulfur content less than 0.5% for industrial boilers and household consumption will be able to improve combustion efficiency, meet the current environmental standards and solve the difficult issue of desulfurization for small and medium-sized boilers and household consumption. It is the most rational choice technically and economically.

One of the major reasons that is curbing the development of steam coal washing and processing in China currently is that the market for better quality coal is in short. Although both the national and local governments have issued policies stressing and encouraging coal preparation and processing again and again, some large and medium-sized cities have even required forcibly that sulfur content in steam coal be less than 1.0% or less than 0.5%. However, consumers are more willing to use cheap raw coal. The existing low emission fees and the loopholes in management have made it possible that users keep on consuming raw coal.

c) Development trend of coal preparation in China

The orientation and development trend of coal preparation in the future in China should be comprehensively improving coal quality nationwide and providing suitable coal for different clients. Here goes the detail:

- Cleaned coal must be good enough to guarantee output and quality of iron and steel. The current design capacity of coking coal preparation plants in the country is 387 million t/a, basically meeting the demands of the coking coal market. Later on, coking coal preparation should be focused on further improving quality of cleaned coal for coking and further reducing its ash, sulfur and water content;
- Steam coal washing must be actively developed focusing on sulfur removal and providing coal with low sulfur content for decentralized consumers (mainly industrial boilers for industrial heating and city heating). In addition, coal with low ash and sulfur content should be supplied for the existing power plants without desulfurization devices (those with FGD or with in-bed desulfurization CFB can burin coal with higher sulfur content.);
- Steam coal washing must be developed focusing on both desulfurization and de-dusting. In China, pollution of SO_2 has been under effective control in quite some cities yet the problem of pollution of particulates, especially respiratory particulates, is still very difficult to solve. Among the 343 cities within the monitored “SO_2 and Acid Rain Control Zones”, respiratory particulates in 63.2% of these cities are beyond the National Class II Standard

for Air Quality. It's time to take serious consideration for control of ash content in fuel coal.

The suitable development scale of steam coal preparation in China should be determined according to the demand of market, quality of raw coal and washability of raw coal:

- Not necessary to wash raw coal with low sulfur and ash content;
- Sulfur content in washed coal will still be more than 1.0% for raw coal with sulfur content of more than 1.5%, which can't meet the requirements of environmental protection when burning directly. Such raw coal should supply those power plants with desulfurization devices to reduce the cost of power generation;
- There is some coal that is very difficult to wash or unsuitable for washing (lignite, for instance) among coal resources. Such coal should be converted in situ or utilized to generate electricity by those plants with desulfurization devices;
- Washing of steam coal with sulfur content of 0.8-1.5% and ash content more than 20% should be stressed;
- Sulfur removal rate of coal washing is generally between 30-40% (mainly removal of inorganic sulfur). If the State requires that average sulfur content in steam coal at the market should be less than 1.0%, at least 20% of the steam coal needs to be washed (new coal-fired units equipped with desulfurization devices can consume coal with higher sulfur content). If the State requires that ash content in steam coal should be ≤20%, at least 45-60% of the steam coal needs to be prepared.

d) Demand of washed steam coal in China in 2020

If the total coal demand in China in 2020 is estimated at 2.2 billion t, the demand for steam coal of the country will be more than 1.8 billion t (among which demand for power generation will be 1.4 billion t, industrial boilers 300 million t and household consumption 100 million t).

Requirements for washed coal in terms of desulfurization are as the following:

Washed coal for power generation: By 2020 total demand of coal for power plant boilers will be 1.4 billion t approximately. According to the requirements of the State, new power plants built after 2003 can burn raw coal directly to reduce operating cost as they must be fully equipped with desulfurization devices.

Old power plants built before the end of 1996 can burn coal with low sulfur content (<0.6%). Installed capacity of these old power plants accounts for 29% of the total coal-fired generating units of 2020. If some of these plants are installed with FGD, the demand for washed coal will be 300 million t approximately. If all plants switch to washed coal, the total demand for prepared coal will be 400 million t approximately.

Coal for industrial boilers: The total coal demand for industrial boilers will be 300 million t approximately by 2020. If boilers with larger capacity (accounting for 20% approximately) will be equipped with desulfurization devices, 240 million t of coal must be washed for the rest boilers.

Coal for household consumption: The total coal demand for household consumption will be 100 million t approximately by 2020, mainly briquette. To guaranty environmental quality, half of this part of coal for briquette will use methods of sulfur capture and the other half must be washed before briquetting.

All in all, by 2020, the demand for washed steam coal should be at least 600-700 million t in terms of sulfur removal, accounting for nearly 33-40% of steam coal demand in that year. Since some big cities and regions have strict requirements on environment, coal with low sulfur content will be still consumed while using FGDs because of the low efficiency of some desulfurization devices, which caused increasing demand for washed steam coal. If ash content will be further required, the total demand for washed steam coal of the country will be up to 800 million t approximately in 2020, accounting for 45% of the total demand for washed steam coal that year.

The current washing capacity of raw coal is 580 million t in China and the washing capacity of steam coal is only 200 million t approximately. There's a big gap between the currently available capacity and the amount of washed steam coal and the actual demand. The potential to further develop the market of washed steam coal is very big.

In addition, steam coal blending technology can effectively balance the coal quality, give full play of each single variety of coal, guarantee stable quality of fuel coal and meet the demand of customers as has high quality. For instance, the blending of Shenfu coal with specially-low ash and low sulfur content and other steam coal with rather high ash fusion can not only complement the advantage of each coal mutually, but also can have low ash and low sulfur coal that will meet the environmental requirements as well as improve the burning conditions of boilers. Coal for power plant boilers and industrial boilers will be the maximum potential market to develop the technology for steam coal blending.

To turn the potential market into the real market demand, there must be relevant policies and measures to ensure it, such as the strict environmental restrictions, stimulations by the State policies for the demand side (customers), reform of the State on the existing ways of supply and sales, etc. (at present, there are too many intermediate links among coal supply and sales and coal supply is in disorder, which is not favorable for the development of steam coal preparation.) Policy-oriented requirements only on the development of coal preparation technology can't play its due role of stimulating the growth of steam coal preparation.

6. Proposals on Development Strategy for CCT in China

6.1 Guiding ideology

To ensure realization of the general target of quadrupling the GDP of the year 2000 by 2020, it is necessary to change entirely coal utilization modes in China for implementing the energy strategy of "development of a multiple of energy resources with coal as predominant primary energy, increase of energy utilization efficiency and reduction of pollution" by promotion of effective and cleaner coal combustion technologies, development of oil substitute technology and by solving three big problems of low coal utilization efficiency, serious environmental pollution and high proportion of coal in the end energy consumption mix. The aim is to set up a clean coal technology development system with Chinese character based on the energy resources and economic conditions to achieve a concerted development of energy, environment and economy in a long period in China.

6.2 Target of development

The demand for coal will be 2.2 billion tons in 2020. Under the condition that coal will constitute over 60% of the consumption mix of the primary energy sources in 2020, total emission of SO_2 from coal combustion will be reduced by around 60% as compared to 2000. The environmental status and energy utilization efficiency will be much improved. The specific goals are as follows:

a) All-round development of advanced, effective and low pollution clean power generation technology that may satisfy the increased demand of national economy development for electric power, and at the same time the emissions and coal consumption for power generation will reduce to a great extent.

b) Accelerated development of advanced coal gasification technology to support the demand of modern chemical production for feed gas from coal that will lay a good foundation for medium- to long- term development of poly-generation system and coal-based substitute fuel technology.

c) Development of coal liquefaction technology for strategic reserve of oil substitute technology.

d) Adoption of advanced small- to medium- sized coal combustion technology to replace completely the out of date technology. The aim is to improve coal utilization efficiency, to increase the operating efficiency of industrial boilers in average by 10%, and to reduce the pollutants emission by over 1/3.

e) Development of household fuels toward cleaner and multiple sources. Priority is given to household purpose in supply of good quality energy sources. Coal supply system and mode will change fundamentally and the quality of steam coal on the whole will be improved.

6.3 Proposals on development measures

Based on the above-mentioned techno-economic assessment of clean coal technologies for different users and analysis of market demand, the arrangement of future CCT development for several categories of users, including power generation, industrial boilers, chemical production and fuel oil substitution, household use, etc, and measures to be taken are proposed as follows:

6.3.1 Clean power generation technology

a) Applicable technologies and their techno-economic conditions

- Supercritical and ultra-supercritical coal-fired generating units are well-established and internationally commercialized technologies. Their power generation efficiency is higher than 40%. The installed capacity of a single unit may reach 1,000MW. The unit investment of 600MW of a subcritical unit with FGD is 4,098Yuan/kW, and that for a 600MW supercritical unit with FGD is 5,493Yuan/kW. Emission of SO_2 may reduce by 90%. Taking into all around consideration of fuel cost in the twenty-year operation, the overall input will be greatly lower than IGCC and PFBC, and only about half of natural gas generating unit (using high-efficiency GTCC technology). They are suitable for long-term development.
- Circulating fluidized bed (CFB) boiler technology is well established. The maximum capacity of a single unit is 300MW. It is adaptable to a wide variety of fuels. Its thermal efficiency is comparable to that of PC boiler with desulfurization unit. The rate of in-bed desulfurization may reach over 90%, and emission of NOx is low. The capital cost is comparable to PC boiler with FGD unit, which is suitable for combined heat and power generation (CHP) and burning of inferior coal.
- As for the retrofit of the existing coal-fired generating units, that they are equipped with FGD units is the most economic approach for emission reduction, under the condition of meeting the environmental requirements, which should be applied and popularized. Taking a 300MW power plant as an example, the sum of investment for FGD and the operating cost within fifteen years after retrofitting is equivalent to that of burning washed coal, and 10.48% of that of switching to natural gas.
- The research of the second-generation PFBC-CC technology, characterized by high efficiency and adaptability to a great range of coals, should be followed. Research of IGCC should combine with poly-generation technology.

b) Recommendations on the arrangement and measures of future development of advanced coal combustion technology

- Application of the advanced technology will be encouraged by guidance of government's policies and constraints of environmental protection. Specific development of technology will be driven by market, and decision made by the enterprises themselves.
- New coal-fired generating units: The supercritical and ultra-supercritical PC generating

units (with FGD units), which is well established and internationally commercialized, will be the major generating units in the future, supplemented by CFBC generating units.

- Refurbishment of existing coal-fired generating units: If conditions permit, the existing coal-fired generating units should be equipped with FGD units consecutively. If FGD units could not be installed in some old plants due to limitation of space at site or other reasons, these plants must use low sulfur coal (or washed coal, with sulfur content <0.6%). At the same time dust removal and denitration should be improved.
- The government should arrange demonstrations on IGCC and second generation advanced PFBC to accumulate experiences. It is necessary to consider that the demonstrations are carried out in combination with poly-generation technology.
- It is expected that the installed capacity of coal fired generating units will increase from 232 GW in 2000 to 577GW in 2020. The quantity of coal for power generation will increase to around 1.4 billion tons. To meet the environmental requirements, it is necessary to adopt clean power generation technology. Proposal study has indicated that if 100% to 80% of new generating units apply supercritical generating-units plus FGD units; that 0-10% apply large-sized CFB boilers; that 0-10% apply ultra supercritical generating units plus FGD units in different phases; and meanwhile if about 50% of existing generating units are equipped with FGD units consecutively, the total emission of SO_2 from coal-fired power stations in 2020 will not only not increase but also may reduce by 5.648 million tons per annum. The total reduced emission of SO_2 within 20 years may be 39.30 million tons. Coal consumption may reduce by 1.77 billion tons and reduce emission of CO_2 by 6.45 billion tons within 20 years due to progress of technology and improvement of efficiency. The gross investment for advanced technology will be 1966.3 billion Yuan RMB, which is 480.4 billion Yuan more than the proposal when all the generating units are sub-critical. It is suggested that the government make reference to this proposal in considering the arrangement of development.

6.3.2 Industrial boiler refurbishment technology

a) The applicable technologies and their technical and economic conditions

- Pollution reduction technologies for industrial boilers are: CFB plus in-bed desulfurization, de-dusting and desulfurization technology; use of different fuels (washed coal, sulfur capturing briquettes, CWM, natural gas, heavy oil and electric power,) etc.
- After considering the environmental factors, the ratio of operating cost of industrial boiler from bulk coal, washed coal, sulfur capturing briquette, CWM, heavy oil and natural gas is 1: 1.1: 1.2: 1.45: 2.3: 3.1.
- From the viewpoint of reducing the consumption of fuel oil and from environmental protection, it is not suitable for industrial boilers to use heavy oil.
- From long-term point of view, the trends of development of coal-fired boilers are:

application of large-sized boilers, central heating, combined heat and power generation, central desulfurization and dust removal.

b) Suggestions on the arrangement and measures of technology development of industrial boilers in the future

- The government will control the trend of development of industrial boilers by macro control, stringent environmental constraints, intensified supervision of medium- and small-sized coal-fired enterprises, phasing out of the out-of–date technologies, and by encouraging application of advanced technologies. The development of specific technology for industrial boiler depends on combined effect of governmental guidance and market drives.
- Different regions will develop technologies for industrial boilers that are suitable to local conditions after overall consideration of availability of energy sources, demand of environment and economic conditions, and make all-round arrangement of refurbishment of industrial boilers.
    - For IB <10t/h: to switch to briquette or natural gas according to availability of local energy.
    - For IB ≥10t/h: to supply step by step excellent quality coal with a sulfur content <0.5%, or to adopt central desulfurization, to improve dust removal and to develop gradually to the large-scale technologies..
    - For IB>35t/h: to introduce CFB technology, central heating, and combined heat and power generation.
- New industrial boilers should be developed to large scale, high efficiency and cleanness through adoption of effective measures.
- It is necessary to improve the operating and automatic level of existing industrial boilers, and quicken the step of eliminating the out-of-date coal-fired industrial boilers. Control will be exercised from the boiler-manufacturing source. Re-use of eliminated equipment should be stopped resolutely.
- It is expected that by 2020, the number of coal-fired industrial boiler will decrease from current 0.53 million to about 0.4 million in China. The gross capacity will decline from 1.20 Mt to around 1.05 Mt. The total quantity of coal to be utilized will be around 300 million tons. To meet the demand of environment, all the new boilers should adopt various advanced technologies and technical transformation of the existing industrial boilers must be undertaken at the same time. The study on proposals has indicated that if the industrial boilers in the first class regions mainly utilize clean energy sources, like natural gas; if those in the second and third class regions mainly adopt CFB plus in-bed desulfurization, sulfur capture briquette, washed coal (low sulfur coal) plus retrofit of boiler, central heating and CWM technology appropriately, and if the retrofit of industrial boilers is to be accomplished within 17 years in China, the average efficiency of industrial boilers in the country may increase by nearly 12%, the emission of SO_2 may

reduce by 2.71 million tons per annum, emission of particulates by 1.78 million tons per annum, emission of CO_2 by 80.91 million tons per annum, the environmental problems due to pollution of SO_2, smoke and particulates will be eased to a great extent. The investment for retrofit of existing industrial boilers in this country will be 124.3 billion Yuan, and the operating cost compared to that before retrofitting will increase by 27.2 billion Yuan per annum. However, four years after retrofitting of industrial boilers in this country, the overall economic benefits to be obtained may make up the retrofit investment. By 2020, the cumulative overall economic benefits may reach approximately 50 billion Yuan. It is recommended that the government consult this scheme in deliberation of arrangement of the development.

6.3.3 Chemical production and fuel oil substitute technology

a) Applicable technologies and their techno-economic conditions

- Chemical production
  - The merits of natural gas for chemical production are good quality products, less environmental pollution, and less investment. When the price of natural gas is less than 1.0 Yuan/m^3, the cost of synthetic ammonia workshop is lower than that using coal gas as feedstock. Priority is given to chemical production by using natural gas, if natural gas is available and if conditions permit.
  - Limited by natural gas resource, regional distribution and its price, it is necessary to develop energetically synthetic ammonia and other chemicals mainly by coal gasification in future several years in China.
  - In the long run, it is suitable for China to develop advanced coal gasification technologies including pressurized fixed bed, pressurized entrained bed, and pressurized fluidized bed, such as Lurgi, Texaco, Shell, etc. The traditional fixed bed gasifiers should not be developed any longer, and should be eliminated gradually.
  - From long-term point of view, the speed of development of coal gasification should be quickened, not only because it is a feed gas for chemical production, but also because it is the gas head of poly-generation technology and also the gas source for producing hydrogen energy and fuel cell as well.
  - From long-term point of view, the poly-generation technology, the source of IGCC, is the trend of development for chemical production in the future, which is characterized by flexible product combination, a multiple of products, graded use of energy, low investment and low operating cost.
- Substitution of fuel oil:
  - CWM, as fuel of boiler, is a well-established technology. About 2 tons of coal and water mixture (CWM) may replace one ton of fuel oil. In the current stage, it is the first option to replace fuel oil used by oil-fired boilers. This technology should be disseminated in the near future in China. As compared with PC boiler, CWM boiler is not so competitive economically from long-term point of view. This technology may be developed appropriately.

- Coal liquefaction is suitable for China to develop as a strategic reserve technology and as a supplement for making up partial shortage of oil. The result of feasibility study has revealed that the investment of an indirect coal liquefaction plant with a capacity of 1.6 million tons per annum is 14.5 billion Yuan, and the production cost of oil products is about 1,800 Yuan/ton. The investment of a direct coal liquefaction plant with an annual production capacity of 1.50 million tons is about 9 billion Yuan, and the production cost of oil is about 1,400-1,500Yuan/ton. The cost of production is comparatively low when building coal liquefaction plant in China.
- China should consider development of methanol and DME (Di-Methyl-Ether) technology from coal as substitute fuel or energy carrier from long-term point of view.

b) Suggestions on arrangement and measures of future development

- Suggestions on arrangement of chemical production
  - Priority is given to development of chemical production based on natural gas in regions where natural gas is sufficient, easily accessible, and at lower price. In other regions, chemical production based on advanced coal gasification technology will be developed.
  - The government will speed up elimination of out-of date coal gasification technologies and small sized chemical fertilizer enterprises through policy guidance and environmental constraints.
  - The government will speed up R&D and commercial demonstration of a variety of large advanced coal gasification technologies, so that China will possess autonomous intellectual property of commercialized technologies as soon as possible.
  - The government needs to put more efforts on research of poly-generation technology, so as to reduce further its cost and promote its commercialization.
  - In the development of chemical production, we take synthetic ammonia production as an example. It is expected that China will produce 40 to 45 million tons of synthetic ammonia by 2020. Considering factors, like, elimination of small-sized synthetic ammonia installations, China needs a new capacity of 8 million tons per annum. Of the new capacity, if the proportion of natural gas and coal will be 50% respectively, and if the advanced coal gasification technologies, such as pressurized fixed bed, pressurized entrained bed and pressurized fluidized bed gasification technologies will be applied to produce feed gas, the total quantity of natural gas needed will be 2.9 billion m^3/annum, and that of coal will be 5.3 million tons/annum. Emission of SO_2 and investment for the new capacity may reduce greatly. It is recommended that the government refer to this scheme in arranging the development.
- Suggestions on arrangement of development of fuel oil substitution technology:
  - In the near future, CWM technology will be developed appropriately as the first option for substitution of fuel oil. CWM boilers or advanced coal-fired boilers will be chosen for replacement of those oil-fired boilers to be renewed.
  - The government will enhance R&D of key technologies and establish commercialized technology with autonomous intellectual property in building demonstration plants of

direct and indirect liquefaction of coal.

- The government shall make an overall comparison and authentication of using methanol and DME from coal to replace fuel oil technology, which is based on energy system, and arrange R&D of this technology.
- By 2020, the oil substitution capacity of CWM may reach 6.0 million tons per annum, i.e. CWM may replace 3.0 million tons of oil per year. If coal liquefaction technology (including direct and indirect coal liquefaction) will achieve preliminary success in commercialization and obtain strategic reserve technology of making oil from coal, the demonstration plants may produce 11.2 million tons of oil and chemical feedstock. These two may replace 8 million tons of oil per year. At the same time the 6 million tons of chemicals to be produced in the same period may replace several million tons of oil indirectly. The investment of this proposal is 11.92 million Yuan in total. Of which, the investment for developing CWM technology and for coal liquefaction is 3.2 billion Yuan and 116.0 billion Yuan respectively. It is recommended that the State refer to this proposal in considering arrangement of these technologies in China.

6.3.4 Household fuels

a) Applicable fuels and their economic conditions

- From environmental point of view, the proportion of different clean energy sources for household use, like natural gas, LPG, LNG, and town gas should be increased step by step.
- From economic point of view, among the household fuels, coal is in a superior position in terms of price, and the next is oil products, natural gas, LPG and town gas. The price of electric energy is the highest among all the household energy sources, or near 10 times as high as raw coal of equivalent calorific value.
- Limited by resource conditions and economic constraints, coal will keep its predominant position in household use. With development of economy, predominance of coal in household fuels will transfer from cities to villages to replace large quantity of non-commercial energy consumption currently used in the countryside, such as biomass.

b) Suggestion on arrangement and measures of future development of household fuels

It is forecast that coal consumption among household fuels in 2020 will reach around 100 million tons. The measures for control of pollutant emissions are as follows:

- Energy used in cities: The proportion of natural gas, LPG, LNG and electricity for household living will rise further. For heat supply in winter seasons, coal-fired combined heat and power generation, and central heating plus follow-up desulfurization units will be popularized, and dispersed small-sized coal-fired boilers will be replaced or eliminated step by step.
- Energy used in countryside: The proportion of small hydropower, biogas and kindle-saving

stoves will further increase and consumption of superior quality coal (washed coal and low sulfur coal) and briquette will go up.

- The State will reform its mechanism for energy supply for household purposes into a new coal supply system. Under the new supply system, priority will be given to supply of superior quality energy for commercial and household purposes, supply of bulk coal for household use will be canceled gradually, washed coal will be required to be used for household purposes; low sulfur and low ash good quality coal will be supplied in priority to medium- and small- sized industrial boilers and other medium- and small-sized end users, and inferior quality coal will be sent to boilers in the power plants for central handling step by step.

6.3.5 Steam coal washing

a) The development need and techno-economic conditions

- In accordance with newly issued “The Atmospheric Pollutants Emission Standard for Thermal Power Plants” and “The Atmospheric Pollutants Emission Standard for Industrial Boilers”, the sulfur content of steam coal supplied to power plants and industrial boilers should be controlled within the range of 0.5 % - 0.6 %, if they are to meet the standards without equipping FGD units. That is about half of the steam coal currently produced should be washed. But, at present, only about 12 % of the total steam coal output is washed, and only 56% of the capacity of the steam coal preparation plants is utilized.
- The technology for steam coal washing is well established, however, the price of the washed coal is 1.2 to 1.3 times as high as raw coal. Currently, the market of washed coal is not good, which needs stimulation of policies and stringent constraints of environmental protection.
- Power station boilers burn washed coal with sulfur content <0.6% may satisfy the current environmental standard and may also improve boiler efficiency, and reduce coal consumption and wear of boilers. Its operating cost is equivalent to installation of FGD unit. Industrial boilers and household use burn washed steam coal (with sulfur content <0.5%) can reach the current environmental standard, and may also solve the problem of medium- and small sized boilers as well as in household use where desulfurization is not applicable, which is most reasonable both from technical and economic point of view.

b) Suggestion on the arrangement and measures of development of steam coal washing

- The government will devote main efforts to washing and processing of steam coal through energetic policy support, while guaranteeing coking coal washing and quality of iron and steel. The aim of steam coal washing is mainly desulfurization as well as ash removal, so that a multiple of products of steam coal with a diversity of specifications will be supplied.
- In the future five to ten years, emphasis will be laid on building and modification of coal preparation plants for steam coal. For newly built steam coal preparation plants, it is encouraged to develop complete technology and installation for modular type of plants

with heavy medium cyclone as the core, in order to promote construction of high-efficiency coal washing plant with excellent quality. For existing coal preparation plants for steam coal, efforts will concentrate on improving the technical level so as to meet the demand for a multiple of products and higher quality. The small coal preparation plants, which adopt out-of-date technologies and equipment, resulting in great waste of resources and bringing about serious pollution of environment, will be eliminated step by step.

- The government will enhance combined development of coal washing & blending, briquetting, CWM through macro adjustment and restructuring of coal market, so as to achieve integration of production, processing, sales, distribution of coal. It is hoped that all steam coal will be washed or processed by other methods, such as, blending screening, etc. step by step before long distance transportation.
- It is forecast that by 2020 the demand for steam coal in China will exceed 1.8 billion tons. From desulfurization point of view only, at least 700 million tons of steam coal should be washed. Some large cities and regions have more stringent requirements on environmental protection. If this factor is taken into consideration, some part of steam coal needs ash removal. Thus, the total demand for washed steam coal in this country will be around 800 million tons, or 45% of the total demand for steam coal in that year in China. Half of the washed steam coal will be used by old power plants without FGD units (built before 1996, the State allows them burning low sulfur coal), the rest of washed steam coal will be used by industrial boilers and for household purposes. By 2020, the State will set up a new framework of production, supply, sales and distribution of coal through reform of transport & sales of coal and combined development of coal washing & other coal processing technologies, so that 90% of steam coal will enter the market after washing or processing. However, to achieve the goal of the proposal, it needs strong support from the State's policy and stringent constraint of environment to stimulate the demand of the users for washed steam coal. Policy guidance alone is not sufficient to promote the development of steam coal washing.

6.3.6 Suggestions on development of CCT-related industries

The following new industries will come into shape based on development of clean coal technologies:

- Integrated industry, including steam coal washing, processing, distribution and after-sale service;
- Environmental protection industry including clean coal technologies and desulfurization;
- Municipal heat and energy supply contract service industry
- Coal conversion industry including coal liquefaction and coal-derived synthetic substitute fuels;
- Clean coal technology engineering service and consulting industry, etc.

If the above-mentioned all-around clean coal technology development scheme is realized, the environmental pollution due to coal combustion in China will be effectively solved by 2020. As compared with emission of SO_2 in 2000, it may reduce by about 9 million tons and PM emission by about 2.million tons in 2020. When compared with the existing technologies of the similar scale, the above-mentioned schemes can reduce emission of CO_2 by more than 500 million tons in 2020. The State will achieve tremendous overall benefits through development of clean coal technologies. It is recommended that the State take reference to this scheme when considering arrangement of the technology development.

7. Recommendations on Policies & Measures for CCT Development

Coal is a predominant energy source in China, and it has been occupying an important position in the consumption mix of primary energy in China. Based on forecasts from many sources, coal consumption will be over 60% of the total consumption of primary energy, and its total consumption will exceed 2 billion tons in 2020 in China. That is to say, the status of coal predominance in the energy mix in China will not change in a considerably long period of time. China should accelerate development of clean coal technologies and achieve clean and effective utilization of coal according to characteristics of its own resources; meanwhile it should strengthen adjustment of energy mix and increase consumption of clean energy sources.

Up to now, the clean coal technologies have made rapid progress in five technical domains in China. The State has also formulated a number of policies. However, in comparison with policies, measures, and practical experiences in the foreign countries, China is now facing obstacles in three aspects, that is the associated policies, laws and regulations; management system or mechanism; and technical development, such that the clean coal technologies have not yet been sufficiently and effectively disseminated and utilized.

After a detailed analysis of above-mentioned problems, this sub-project focused on economic assessment of technologies used by four coal utilization sectors. A proposal for development of clean coal technologies in the future in China is put forward based on the needs of different sectors. In order to achieve the target of development, the following policies and mechanisms are necessary to push forward the campaign.

7.1 Strengthen the unified control for CCT development

- To resume the activities of the former National Leading Group for CCT Dissemination and Planning on the basis of the current Energy Department of the National Development & Reform Commission (NDRC).
- To reformulate a national CCT development plan, which will sort out the focusing points and sequence of priority, and make a united arrangement and control of development of clean coal technologies in whole country.
- It is requested that all the places realistically make the local energy development plan and CCT development plan according to the national environmental target and based on availability of indigenous energy resources, economic capability, etc. It is permissible that

all the places will develop technologies suitable for local conditions to avoid impose uniformity on all regions.

7.2 Work out a united policy system for CCT

- To work out united national policies for CCT development, which will combine organically the CCT, environmental protection, energy conservation and high tech development, etc.
- To work out specific implementing regulations for relevant existing national laws and policies, e.g. " Atmospheric Pollution Law", " Coal Law", and some national macro statutes and policies for effective enforcement of law, regulations, rules and policies.
- The State provides necessary incentive policies to large-scale commercialized project of clean coal technology.
  - To set up special funds for technology development, or fund-raising channels and to provide low interest loan to commercialized projects of clean coal technology. Projects with environmental benefits greater than economical benefits, will be included into the national key technical updating projects, which may enjoy special loans for energy conservation, loan for technical innovation of the enterprises, extension of the payback time for funds paid. To finance for procurement of household equipment for support to domestic equipment and technology.
  - Preferential taxes should be given to clean coal technology, which is of great importance to environmental protection and social benefits, such as zero rate of investment direction regulatory tax, transitional reduction and exemption of VAT and income tax and proper reduction and exemption of land holding tax.
  - The imported equipment and technology necessary for national-level large-sized demonstration projects of CCT may enjoy reduction or exemption of import tariff and VAT for imports.

7.3 Formulate reasonable national standards

- In view of the fact that most of coal-fired equipment follows a general emission standard, it is necessary to formulate some reasonable special standards for all the coal-fired equipment as supplements of the general standard.
- Current unreasonable emission standards and coal quality standards should be revised and refined and the instructive coal quality standards for small users should be changed into mandatory standards.
- To work out a new guiding standard for steam coal pricing, so that premium steam coal has a higher price. There must have a greater difference between the good and inferior quality of steam coal.
- The development of advanced technologies will be guided by environmental standards, but not by restrictions on fuels or coal combustion technologies.

7.4 Strengthen development and early-stage research for key technologies by the government

- The government will enhance arrangement and support to R&D of large-sized key technology and equipment, such as, ultra supercritical boiler, steam turbine, flue gas cleanup system, large CFB boiler, coal gasification, coal liquefaction technologies, etc., so that China will get hold of autonomous intellectual property of technologies as soon as possible.
- For development of technologies of long-term strategic importance, the Government should arrange necessary first phase research, e.g. relevant fundamental research on poly-generation technology, overall comparison and authentication as well as first phase research on coal-based methanol and DME to substitute fuel oil based on energy system, etc.

7.5 Make more investment for R&D and commercial demonstration by the Government

- The State needs to put more investment in R&D of key CCTs. The government will set up funds for R&D of fundamental and universal technologies and build R&D bases. The State will arrange subsidiary funds for digestion and absorption of the key technologies introduced. The competition mechanism will be introduced in all the phases like R&D, small-scale test, pilot test and demonstration, etc. so that the research institutes, universities and colleges and the enterprises may give full play of their superiorities.
- The government will increase investment in demonstration projects of CCTs. For projects with good environmental protection benefits, heavy investment and certain risks, such as coal gasification and coal liquefaction, the government will give financial support. Low interest loan will be given to enterprises that undertake demonstration projects. Preferential policy will be given to draw investment from non-governmental organizations and enterprises in order to promote demonstration and commercialization of new technologies.

7.6 Enhance environmental drives and environmental monitoring of coal-fired users

- All the big coal users (including non-power sector) are requested to install FGD units and continuous emissions monitors (CEMs). The government has specific requirements on operating rate and serviceable rate of equipment, and will inspect their operation periodically and non-periodically. At the same time the government will make efforts to strengthen the establishment of the environmental quality monitoring network.
- Supervision and management of medium- and small-sized coal-fired users will be strengthened. For example, the environmental enforcement departments and industrial management departments will supervise and inspect jointly whether the in-bed desulfurization technology is applied in CFB boilers of the power plants that burn coal rejects; and whether continuous emission monitors is installed in large- and medium-sized industrial boilers. The management of coal supply to medium- and small-sized users should be strengthened. An energy contract management mechanism and socialized service system suitable for Chinese conditions should be set up, so as to realize specialized and socialized management for heat supply.

- It is necessary to continue to restrict and eliminate the out-of-date medium- and small-sized coal utilization equipment and technologies, and to strengthen law enforcement.
- It is necessary to introduce as soon as possible the trade system of SO_2 emission. The environmental carrying capacity is regarded as a scarce resource for free trade in the market. It is allowed to raise the charge standard of SO_2 emission in areas with stringent requirements on environment to persuade the polluting units to apply actively the CCTs.
- It is necessary to introduce as soon as possible the SO_2 emission trading system. The environmental capacity should be regarded as a scarce resource for free trade in the market. It is allowed to raise the level of SO_2 emission fee in areas with stringent requirements on environment to persuade the polluters to apply actively the CCTs.
- Propaganda on CCTs should be strengthened to enhance public consciousness of environment and awareness of CCT development, and environmental supervisory capacity. It is necessary to raise the vocational level of enforcement staffs and their capability of guiding the enterprises through various modes like training, etc.

7.7 Set up and perfect coal supply market mechanism

- The State shall continue to strengthen environmental constraints and penalty on emissions in excess of regulations. At the same time, the users which utilize low sulfur coal or washed coal (with sulfur content $<0.5\%$) are allowed to continue to burn coal if they can meet the current environmental standards，so as to promote the development of washing and processing of steam coal. The government shall make efforts to realize standardization and serialization of steam coal products under the guidance of policies, measures and standards to achieve provision of a variety of high quality steam coal products with multiple specifications. The unprocessed coal is not allowed to enter the market as a product.
- The existing coal supply system should be changed step by step. Priority will be given to industrial boilers, medium- and small-sized coal users, commerce and household use by supplying good quality low sulfur and low ash coal. The inferior coal will supply to boilers with FGD units in power plants for central treatment.
- The existing coal consumption and distribution modes should be reformed. The links of coal sales should be reduced through improvement of policy-making and management. The coal supply system should be rectified and sorted out. A new coal supply system, which integrates production, supply, sales, transport and distribution of coal, will be developed.

7.8 Set up a mechanism for CCT development with enterprises as the main body

- The State, as a main body of policy-related investment, shall devote its efforts on support to earlier-phase R&D and commercial demonstration of key technologies. At the same time the State shall encourage through policies the enterprises to be the main body of operative investment in commercial development of CCTs.
- The government shall through policies encourage investment from a multiple of main bodies, all types of combination and cooperation among different industries and trades (e.

g., combination of coal, electricity and chemical production), development of modern complexes for coal processing, conversion and utilization, and development of large CCTs projects in combination with making plans for building large-sized energy and coal complexes.

- The government will adopt a strategy of "grasping the large". It encourages that the large sized enterprises or groups, to expanding investment horizontally or vertically. That is to say, it encourages them to enter into the domain of coal production, utilization and conversion trans-regionally, conglomerately and cross ownership systems. The phenomena of separation of coal upstream and downstream industries, such as, separation of coal mining and electric power industries as well as separation of coal mining and chemical industries, and self- closed circulation, which have formed in long periods in the past, should be overcome. The superiorities in resources, production, technology and funds between the upstream and downstream as well as among different regions could supplement each other, which may enhance competitiveness of enterprises and promote technical progress, and result in a superior conglomerate, consisting of a number of medium- and small-sized enterprises headed by a large enterprise.
- The government shall encourage the large enterprises to set up technical development centers, so that they will form an important part of CCTs R&D and an important base for commercialization of new technologies.

Appendix

Table A1 Major CCT Development and Demonstration Projects of in China

Type of technology	Classification of project	Name of project	Main contents and targets
Coal washing	Key R&D Program in 9^{th} Five-Year period	Study on effective & advanced key coal washing technologies	Automatic jig, large screen-moving jig, $120m^2$ press filter, $400m^2$ press filter for cleaned coal, large flotation column, etc.
		Research on coal washing, processing & utilization technology for typical high sulfur coal area	Commercialized demonstration of total heavy medium cyclone process with a single system capacity of 0.90Mt/a.
CWM	Key R&D in 7^{th} Five-Year period	Preparation and combustion of CWM.	
	Key R&D in 8^{th} Five-Year period	Research on CWM technology	
	Key R&D in 9^{th} Five-Year period	Research on key techniques of CWM industrialization	
CFBC	Key R&D in 7^{th} Five-Year period	R&D on 35t/h CFB boiler[54]	
	Key R&D in 8^{th} Five-Year period	Improvement of 75t/h CFB boiler[62, 55]	
	Special project in 8^{th} five Year Plan	Demonstration of 75t/h CFB boiler project	Development and application of 75t/h CFB boiler
		R&D of 220t/h CFB boiler	
	National Special project	Demonstration of 220t/h CFB boiler project	Development of domestic 220t/h CFB boiler. Localization and commercialized demonstration & application of imported technology
	Key R&D in 9^{th} Five-Year period	Study on 125MW CFB boiler design option[56]	Design and research of 125MW（410t/h）CFB boiler with autonomous intellectual property.
	Key R&D in 10^{th} Five-Year period	Commercial demonstration of CFB boiler and industrialization of the tecnology[62]	Commercial demonstration and industrialization of 100MW（reheating）CFB boiler.
Ultra super-critical units	Hi-Tech R&D (863 program) in 10^{th} Five-Year Period	Ultra-supercritical coal-fired generation technology[57]	Development of boiler, gas turbine, power plant system and associated flue gas cleanup technology of ultra-supercritical power generating unit with autonomous intellectual property
PFBC	Key R&D in 8^{th} Five-Year period	Study on PFBC-CC and its equipment	Overall commissioning of 15MW PFBC pilot plant made by the end of 2000.
	Key R&D in 9^{th} Five-Year period	Testing of a PFBC-CC pilot plant and research on key technologies.[58]	
IGCC	Special project in 8^{th} Five-Year period	Pre-feasibility study of developing IGCC technology in China[59]	
	Special project in 9^{th} Five-Year period	Research on dynamic characteristics of IGCC key technologies[67]	Research on key technologies, such as, IGCC process, gasification, gas clean-up, gas turbine, waste heat system, etc.
	Key R&D in 10^{th} Five-Year period	IGCC Power plant design integration and dynamic charateristics[65]	Software & emulator of IGCC plant. To master design technology of IGCC plant system with capacity > 300MWe and the dynamic characteristics of IGCC system during building the demonstration plant.
Coal gasification	Key R&D in 6^{th} Five-Year period	Building up, commissioning and testing different coals for pilot Φ650 pressurized Lurgi gasifier	
	Key R&D in 7^{th} Five-Year period	Building up, commissioning & testing different coals for Φ100 pressurized fixed bed test-gasifier	
		Building up, commissioning and testing different coals for Φ100 pressurized fluidized bed test-gasifier	
		Mathematical model for Lurgi Pressurized gasifier	
		Development of process and equipment for Φ1600 two stage water gas gasifier	

	Key R&D in 8th Five-Year period	Semi-commercial test of underground coal gasification in Xinhe No.2 shaft in Xuzhou.	
		Commercial demonstration of CWM gasification and gas cleanup	
	National special project in 9th Five-Year period	New type of CWM gasifier (opposite-nozzles)	
	NSFC project in 9th Five-Year period	Research on CWM gasification mechanism	
	National Basic Research Priorities (973) program of 10th Five-Year period	Fundamental research on process of coal pyrolysis, gasification and high temperature purification	To propose gas cleanup mechanism at high temperature & scale-up theory for building large gasification system; to complete a conceptual process software package.
	863 program in 10th Five-Year Period	New type CWM gasification technology	Setting up commercial demonstration equipment for CWM gasification with autonomous intellectual property.
		Dry PC pressurized gasification technology	Technology development for dry PC pressurized gasification & buildup of pilot equipment with autonomous intellectual property.
		Research on stable control of underground coal gasification	
Coal liquefaction	Key R&D in 6th & 7th Five-Year period	Research on technology for direct coal liquefaction	
	CAS project in 9th Five-Year period	Key technology for producing 10,000 tons of coal based synthetic fuel and development of industrial software	
	863 program in 10th Five-Year period	Indirect coal liquefaction	To ease tense situation of oil shortage and to set up important industry within few years.
		Key technology for direct coal liquefaction	
		High- efficiency catalyst for direct coal liquefaction	
Fuel cell	CAS project in 7th Five-Year period	R&D of PEMFC	Research on Direct Methanol Fuel Cell (DMFC)
	Key R&D in 8th Five-Year Period	Research related to SOFC	
	Key R&D in 9th Five-Year period & CAS project	Fuel cell technology	Incl. PEMFC, MCFC & SOFC. 5kW PEMFC for electric automobile is listed as key point of development.
	863 program in 10th Five-Year Period	Development of PEMFC automobile	An important special research project.
Poly-generation	863 program in 10th Five-Year period	Research & demonstration of key technologies for cogeneration of power and methanol from coal gasification	Joint-venture project “new type gasifier with a capacity of 1,000 tons of coal” in Yanzhou Coal Group
FGD	Key R&D in 8th Five-Year period	Technology for clean coal combustion and conversion	PC low NOx technology and desulfurization technology
	Key R&D in 9th Five-Year period	Commercialization of new technology for recovery and clean-up of SO_2 waste gas	Pilot test of NADS process for SO_2 recovery in the flue gas from 10,000 Nm^3/h level of coal-fired power plant; waste gas cleanup from smelting plant---Commercial demonstration of unsteady state of SO_2 conversion
		Technology development for desulfurization of boiler combustion and cogeneration of heat, power and gas	Listed as an important special research project.
	973 program in 9th Five-Year period	Fundamental research on prevention and control of pollution due to coal-combustion	
	863 program in 10th Five-Year period	Control technology for flue gas emissions from coal-fired power plant[65]	Development of commercial technology for flue gas desulfurization and denitration that can comprehensive use of resources

Table A2 Major introduction projects of clean coal technology

Type of technology	Year	Source	Location	Description
CFB technology	End of 80's	Riley, USA	Beijing Boiler Plant	Circofluid boiler, and a number of 75 t/h CFB boilers were produced
	Beginning of 90s	FW, USA	Gaoba Power Plant, Neijiang, Sichuan[60]	One 410t/h CFBC boiler with 100MW units, using high sulfur anthracite from Sichuan. It was put into normal operation from 1996.
		Ahlstrom , Finland	Liaohua Thermal Power Plant in Panjin[68]	One 220t/h CFB boiler
		Ahlstrom , Finland	Thermal Power Plant of Dalian Chemical Corporation[68]	Two 220t/h CFB boilers
	Now under construction approved in 2000	Alstorm, Sweden	Baima Power Plant in Sichuan	One 1,025t/h atmospheric CFB boiler and key associated equipment, with a domestic 300MW gas turbine unit
Supercritical units	1992	ABB, Sweden	Shidongkou No.2 Power Plant	2×600 MW, single reheat, in operation.
	1994	Former-Soviet Union	Nanjing Thermal Power Plant	2×300MW, single reheat, in operation.
	1996		Yingkou Power Plant	2×300MW, single reheat, in operation.
	1995		Panshan Power Plant	2×500MW, single reheat, in operation.
	1998 (1 unit) 1999 (1 unit)		Yimin Power Plant	2×300MW, single reheat, in operation.
	1999 (1 unit) 2000 (1 unit) 2001 (1 unit)	Mitsubishi, Japan	Houshi Power Plant	3×600MW have been put into operation.
	2000	Russia	Suizhong Power Plant[61]	2×800MW have been put into operation.
		Siemens, Germany	Waigaoqiao Power Plant	2×900MW are under construction.
		Mitsubishi, Japan	Houshi Power Plant	1×600MW is under construction.
Coal gasification technology	1987		PLA Chemical Fertilizer Plant in Yunnan	2720mm，10 gasifiers for synthetic ammonia have been put into use.
	1993	Texaco, USA	Lunan Chemical Fertilizer Plant in Shandong	2 gasifiers, 1 operating & 1 stand-by. Daily capacity of single is 400t of coal. Pressure is 2.8MPa.
	1995	Texaco, USA	Shangahi Chemical Fertilizer Plant	4 sets, 3 operating, & 1 stand-by. Daily capacity of a single is 500t of coal. Pressure is 4.0MPa
	1996	Texaco, USA	Weihe Chemical Fertilizer Plant in Shaanxi	3 sets, 2 are operating, and one stand by. Daily capacity of a single is 820t of coal. Pressure is 6.5Mpa
	2000	Texaco, USA	Huainan Chemical Fertilizer Plant	3 sets without stand-by. Daily capacity of a single is 500 t of coal. Pressure is 4.0MPa.
	Under construction, to be in operation the next year.	Texaco, USA	Heilongjiang Haolianghe Chemical Fertilizer Plant	Three sets, two operating, one standby. Daily capacity of a single is 500 t of coal, and pressure is 4.0MPa.
	In design stage	Texaco, USA	Jinling Petro-chemical Plant	4 sets, 3 in operation, & 1 stand-by. Daily capacity of a single is 1,000t of coal, Pressure is 4.0MPa
	In design stage	Shell, Holland	Dongtinghu Nitrogen Fertilizer Plant in Hubei	Daily production capacity is 2,000tons.
FGD technology	2 sets in 1st phase in 1992, 2 sets in 2nd phase in 1999	Mitsubishi, Japan	Chongqing Luohuang Power Plant	Four 360MW units have been put into operation, using wet limestone/gypsum FGD system.[62]
	1994	EPDC.& Mitsubishi, Japan	Huangdao Power Plant, Shandong	One 200MW has been put into operation, using rotary spraying drying FGD system[70]
	1996	EPDC & Hitachi, Japan	Taiyuan the First Thermal Power Plant	1 300MW has been put into operation, using simple wet limestone/gypsum FGD system[70.]
	1998	Ebara Co., Japan	Chengdu Thermal Power Plant	One200MW set has been put into operation, using electron beam FGD system [70]
	1998	IVO, Finland	Xiaguan Power Plant in Nanjing	Two125MW sets have been put into operation, using CDSI FGD system[63]
	1999	ABB, Norway	Western Power Plant in Shenzhen	One 300MW set has put into operation, using seawater scrubbing FGD system
	2000	Stainmuller, AG Germany	Beijing 1st Thermal Power Plant	2×100MW sets have been put into operation, using wet limestone/gypsum FGD system[64]
			Hangzhou Banshan Power Plant	2×150MW sets have been put into operation, using wet limestone/gypsum FGD system[74]
			Chongqing Power Plant	2×200MW have been put into operation, using wet limestone/gypsum FGD system[74]
	2002	Wolf, Germany	Guangzhou Hengyun Power Plant	One 200MW set has been put into operation, using semi-dry FGD system

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