National Energy Futures Analysis and Energy Security Perspectives in China

--Strategic Thinking on the Energy issue in the 10th Five-Year Plan(FYP)

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Abstract

A general introduction concerning the population, economics, industry structure and energy supply in China is presented in the paper, which points out that the present technology of energy is unsustainable for China from the point of view of resources and environment. When the perspective of supply of petroleum and natural gas is analyzed, the major problem of energy security in China is the shortage of liquid fuel. China is expecting a significant increase of natural gas production in recent years, but due to its limited share in the energy mix it cannot solve the energy security problem entirely. Some strategic thinking relating to the development of energy in 10th Five-Year Plan is raised. The development of fossil fuel fired power generation, hydroelectric power, nuclear power and renewable energy is analyzed, which leads to the urgent necessity of near term, intermediate term and long-term arrangement of clean coal utilization. The coal will still have the share in energy mix no less than 50% in the coming three or more decades.

The polygeneration system based on oxygen blown coal gasification is emphasized in particular, as this system could provide super-clean energy for diverse sectors of industry, and provides advantages in resource optimization, economic benefits, and effective utilization of energy resulting in obvious environmental improvement. This polygeneration system is one of the most important ways for solving the energy security problem in China. Finally, the role of the government in formulating necessary policy and support measures and implementing the strategies of the 10th Five-Year Plan is proposed.

I. General Introduction

The rapid increase in population brings enormous pressure to energy resources and the environment, since improving the living standard will doubtlessly increase energy use and emissions per capita. China has been carrying out a rather strict birth-control policy for many years, but because of the huge base, the net increase of population is still quite high. Tab.1 is the forecast of the population and the proportion of urban residents.

Table 1. Forecast of population in China*

Year	2000	2010	2020	2050
Population (bil.)	1.3	1.4	1.5	1.45 1.58
Fraction in urban area (%)	32 38	41 50		65 80
*Under stringent control				

As shown in Tab.1, even under strict control, the population of China will reach 1.6B in 2050.

Concerning the structure of energy, the shares of agriculture and industry will decrease gradually, as there are increases in shares within the tertiary sector (finance, insurance and diverse service businesses), which will reach 51~56% in 2050.

Currently, China has about 10 million vehicles, and the number of cars is expected to reach 50 million in 2020 or 150 million by the year 2050. Consequently, the demand for liquid fuel will increase. Tab.2 is the predicted structure of the economy of China in 2020 and 2050.

Table 2. Structure of Economy

Year	2020	2050
Agriculture	13 13.6	7 7.6
Industry	42.9 46	37 41.6
Tertiary	41 43	51 56
Cars:	1car/(10-30 people)	
Total number	50mil 150mil	

Source: Long-term strategic study of Energy, Energy Research Institute, SDPC.

There are already a lot of scenario studies relating to the energy demand for China and although different data are obtained, the discrepancy is not so significant and can be used as references. Roughly, the demands of energy are 2.1~2.5 Btce, 2.5~3.0 Btce and 3.5~4.2 Btce in 2010, 2020 and 2050 respectively. That is, in the coming 50 years, the demand of energy will increase by 3.0 or 3.5 fold in comparison with the demand in the year 2000. Tab.3 is the energy demand scenario provided by diverse organization.

Coal is the primary contribution to the energy mix, with a share of 75%. Serious environmental problems are caused by direct combustion of coal. It is estimated that 87% of SO_2 (it was 20.9million tons in 1998), 71% of CO_2, 67% of NOx and 60% of particulate matter emitted in China in total is from the combustion of coal. The area of the country experiencing of acid rain with pH value of less than 5.6 is increasing; at present, the area is about 40%, mainly in the more developed regions. The social and economical losses from acid rain damage are enormous.

Table 3. Energy Demand Scenarios

Organizations	Date of forecast	Results of forecasting (Bil. tce)			
		2000	2010	2020	2050
Energy Research Institute of SDPC	1996	1.5	2.05	2.55	
Tsinghua University	1994	1.44 1.53 1.39 1.71		2.38 2.68 2.20 2.78	3.48 4.4 3.3 4.2
Former Ministry of Energy	1994	1.44 1.53		2.38 2.68	3.48 4.41
Chinese Academy of Science	1995	1.5	2.1		
Chinese Academy of Engineering	1996	1.66 1.7	2.27 2.4	2.9 3.15	3.57 4.13
IEA	1993	1.39 1.4	2.05 2.09		
EIA	1990	1.25	17.0		
EDMC	1991	1.62	2.64		

Source: Long-term Strategic study of Energy, China Soft Science (1998.7)

China has been searching for alternative energy supply with the aim to reduce the share of coal in energy mix, but originating from the initial condition of China, the share of coal will be still about 50% up to 2050. Tab.4 is the prediction of energy mix structure in 2020.

Table 4. General Energy Mix in 2020

Coal	55
Petroleum	20
Natural Gas	10
Hydro power	10
Nuclear	5

Source: Long-term Strategic Study of Energy in China

Given China's relative lack of resources and huge population, even with the most abundant coal resource the amount of coal per capita is only 50% of the world average, and the petroleum per capita--1/10 of the world average.

Therefore, China should pay great attention to energy and resources conservation, and to have its own specific living style and not blindly copy the style of developed countries. The consumption of energy should be strictly controlled. Tab.5 is energy mix demand per capita.

Table 5. Energy Demand per capita

	Energy demand per capita (tce)			
Organizations	2000	2010	2020	2050
Energy Research Institute of SDPC	1.15	1.46	1.70	
Tsinghua University	1.07　1.32		1.52　1.92	2.12　2.82
Former Ministry of Energy	1.11　1.18		1.64　1.85	2.23　2.82
Chinese Academy of Engineering	1.27　1.31	1.6　1.69	1.95　2.11	2.33　2.7

Source: Long-term Strategic study of Energy in China

The proportion of primary energy mix for electricity generation is an index of economic development, technical advancement, living standard and reasonable utilization of energy. Alongside with the increase of the proportion, the energy intensity (the consumption of energy per unit GDP) will be decreased. In 2000, this proportion in China is 33%, much less than in the USA. Tab.6 is the electricity demand Scenario.

Table 6. Electricity Demand Scenarios

Year	Installed Capacity (GW)	Generated Electricity (TWh)
1995	217	1007
2000	290	1350
2010	450-600	2600-2900
2020	700-1100	3500-5400
2050	1200-2300	6200-12000

As shown, in 2000, 2020 and 2050 the installed capacity per capita is 0.24kW, 0.46kW and 0.8 kW respectively, and the generated electricity is 1120 kWh, 1300kWh and 4130 kWh, which are much less than in the developed countries at the time being (the population increase is shown in Tab. 1) (in 1995, USA-3.8 kW, France-2.0kW, Japan-1.77kW, South Korea-0.69kW per capita respectively). Consequently, the per capita energy consumption in China could only maintain a relatively low level in 21st century.

Tab.7 is the prediction of coal production, since the share of coal in energy mix will decrease gradually, thus the growth of coal production will be rather moderate.

Table 7. Prediction of Coal Production

Year	Production of raw coal (Bt)
1995	1.36
2000	1.4
2010	1.7
2020	2.0　2.1
2050	2.8　3.0

But, if the advancement of clean coal technology could provide super clean fuel for different sectors, the production of coal may have a new motivation.

In summary, the bottleneck of sustainable development in China is the energy and associated environment. The shortage of liquid fuel is the main factor in the energy security. In conclusion, clean coal technology is the key issue of sustainable development.

II. China's present energy technology is unsustainable from the point of view of resources and environment

1. **The continuous increase of energy consumption per capita.** As mentioned, at present, the energy consumption per capita is much lower than other countries (China-1000kgce per capita annually, but USA-11000kgce, Japan, Germany, Russia-about 5000~6000kgce). With the expectation to have better living standard, the energy demand will increase continuously as predicted, it will be 2500~3000kgce per capita annually by the year 2020~2030. It is terrible and difficult to imagine when the emissions will be doubled or tripled.
2. **If the path of present technology continues, the resources and environment can not bear the heavy burden.** For instance, at present the installed capacity per capita is 0.24kW, therefore for the medium living standard of at least 1.0kW, a four-fold increase in the emissions of CO_2, SO_2, NO_x, and TSP will increase correspondingly. Tab.8 is the world average emission level of coal fired power plants.

Table 8. World Emission Level of Coal-Fired Power Plant

Emission technology	unit emission g/kWh		
	SO_2	NO_x	PM_{10}
Average emission level of coal fired power plants in 1997 (USA)	6.1	3.47	0.16
The best emission level of coal fired power plants in 1997 (UAS)	0.46	0.87	0.15
Buggenum IGCC power plant (Netherlands)	0.08	0.22	0.033
Natural gas fired combined cycle	—	0.092	—

The average SO2 emission of coal-fired power plants is roughly 15 to 16g/kWh in China.

Obviously, even for the power with FGD (95% sulfur removal) and de-NOx equipment, the degree of pollution is still quite serious, much worse than IGCC and natural gas fired combine cycles. For China, as predicted, the share of coal in energy mix will be 50% or more, and more than 80% of coal will be used for power generation. Thus, from the point of view SO_2, NOx, TSP and CO_2 emission, the present technology is unsustainable. Further, the low quality gypsum obtained during wet FGD is causing secondary white pollution.

3. **<u>The process of urbanization is irreversible</u>**. The pollution problem in large cities is becoming more and more serious, mainly caused by the exhaust of cars. Though the improvement of the performance of cars is encouraging, still the total amount of exhaust will be huge .We can't be optimistic to the situation of pollution in China's large cities, since among the world's ten worst polluted cities, China has 7 of them, and Beijing ingloriously ranks third.

III. The Energy Security Problem I - Supply of Liquid Fuels

The reserve/exploitation ratio of petroleum in China is 15, much lower than world average (40) and far from the security margin. A few years before, the Chinese petroleum industry laid great expectation on the Tarim Basin, Xinjinang Region, but through more than ten years exploration and exploitation, it was proven that the reserves of Tarim Basin are much less than expected. And they can only be exploited only with high costs because of the desert and transportation. Diverse predictions show that the production of oil in China will be maintained at the present level or will increase a small amount in the near future. Beginning in 1993, China became a net oil importing country; in 1999, the net import of oil was 40 million tones, and it is estimated that the net import will be 100 million tones and 160 million tones by the years 2005 and 2010 respectively. Not speaking about the consumption of foreign currency, the national economy will be greatly influenced by international oil price. At the same time, it is serious from the point of view of energy security.

Many of the oil fields in China now are in the second stage of exploitation. For example, the most important oil field, Daqing, has sustained oil production of 50 million tones which has already had lasted 30 years. In recent years, the oil is obtained by injection of water under high pressure (200kg/cm^2), the outlet substance from the well is an oil/water mixture, the later is 85%, the oil is less than 15%, consequently, the cost is high. Unfortunately, the ratio of water is still increasing, this situation could not be sustained for a long period.

Now Daqing oil field is implementing the program of the third stage of exploitation, that is, the injection of high molecular polymer for reducing the viscosity of crude oil and thus increasing the recovery rate. (At present, the crude oil recovery rate is about 33%, if the rate could be increased 4~5 percentage points, a huge amount of additional reserves could be obtained)

Recently, the imported high sulfur content crude oil is raising another problem, because the existing refinery installation (Fluidized Catalyst Cracking) which is widely used in China can not "digest" this kind of crude oil. This leads to a low quality of obtained diesel fuel and gasoline, with a sulfur content a magnitude higher than international standard . Retrofitting the existing installation needs tens of billions RMB.

From the abovementioned points, China as a large country, the shortage of liquid has inherent potential danger, a strategy for solving this problem is of urgent necessity.

IV. Energy Security Problem II – Supply of Natural Gas

The development of natural gas in recent years is quite optimistic, but can natural gas solve the energy security problem? Natural gas is the best fuel especially for gas/steam combined cycles with very high thermal efficiency up to 58%~60%. With the same heat content, the exhaust of the greenhouse gas CO_2 is 50% less than coal. Therefore, some experts predict that natural gas will solve the energy security problem. In fact, this is not realistic. Theoretically, the total reserves of natural gas in China are 38Tm^3 (among them 22.4 Tm^3 in the West Part, about 59%), but up to now, the proven exploitable reserves are:

Tarim Basin (Xinjinang)	504 Bm^3
ChaiDama Basin (Xinjang)	279 Bm^3
Sichuan Province	537 Bm^3
Sanxi Province	323 Bm^3
Total	1643 Bm^3

Now the Chinese Government has decided to construct a gas pipeline from Xinjinang to Shanghai with length of 4200 km, the diameter of the pipe is 1118 mm, and the transportation capacity is 12~30 Bm^3 annually. The preliminary assessment of capital investment is 120 B RMB. It is a quite huge engineering project, but even so, this amount of natural gas only has the share of 1.2~2.0% of the total energy mix, and will double the portion of natural gas (at present, the share of natural gas is 2%). Another two pipelines are under negotiation and planning, one is from Kazakstan to China with capacity of 20 Bm^3 annually, one is from Siberia with the same capacity. Taking all of these productions of natural gas into account, it will be a great success if by the year of 2030, the share of natural gas could reach 10% of energy mix. Most of the natural gas will be used as gas for large cities to mitigate the pollution, such as cooking, heating and distributed power/heat/cool cogeneration, in some cases for small and medium size industry boilers if necessary. Long-distance transportation leads to higher prices of natural gas, therefore common sense tells us it is not reasonable to use natural gas for centralized large-scale power generation just like in USA and other countries.

The conclusion is: natural gas is not the ultimate solution of energy security, the only way out: produce liquid fuel from coal in environmentally friendly and economically competitive ways.

V. Some Considerations For Increasing the Efficiency and Mitigating the Pollution in 10th FYP

1. Fossil fuel power generation

- Using the opportunity of temporary surplus of electricity supply to phase out the small, serious polluted and low efficiency units (12~100MW). At present, the average coal consumption of energy generation is 407 gce/kWh, about 90g higher than that in developed countries, consequently, the emissions of SO_2, NOx and

CO_2 are 20%~30% higher correspondingly. The high coal consumption is caused by a great portion of small units. In 1998, the average unit capacity was only 50 MW. State Power Corporation already has set a target to reduce specific coal consumption down to 367gce/kWh by the year 2005.

- Development and deployment of domestic large steam power plants with supercritical and further, ultra- supercritical parameters. The worldwide trend for improving the efficiency of steam power plants is implementation of supercritical parameter of live steam (25MPa and 560 or a bit more with the thermal efficiency about 42%). The key barrier is the materials problem, which can bear the high temperature. Through many-year's R&D, China already has the ability for commercialization of this kind of power plants. What about the aerodynamic design of the turbine, a domestic advanced level design system with own intellectual property has already established. Therefore, using this opportunity, an engineering project of construction domestic 600~1000MW with supercritical steam parameter should be arranged in order to accumulate the experiences and to make the technology more mature. At the same time, a concerted R&D effort should be organized targeting the higher steam parameters and higher efficiency (ultra supercritical parameters, 35MPa and 600 , with efficiency about 45%).
- Pay great attention to the flue gas desulfurization installation (FGD) suitable for China. Though the technology of wet FGD is mature and is widely used all over the world, due to the cost of capital investment (about 1/4~1/5 of the total power plant) and high maintenance cost, its deployment in China is quite difficult and slow. The urgent problem is to have a FGD with Chinese features, that is, less cost (50% or less than conventional) and less water consumption. At the time being, almost 98% of the power plants are operating without any desulfurization installation, the harmful environmental impact is obvious.
- Development of circulating fluidized bad combustion boiler (CFBC). CFBC is one of the desulfurization technologies suitable and realistic for China's current condition since it requires low capital investment and maintenance costs. Further, the waste from the boilers could be easily utilized as construction material. At present, the 130t/hr CFBC is getting mature and could be disseminated as industrial and utility boilers. The research institutes and boiler manufacturers already have accumulated sufficient experiences of CFBC, some of the technologies, such as compact quadrangular high efficient separator are at the world advanced level. In order to have a substantial market share domestically and abroad, it is the appropriate time for speeding up the research, demonstration and deployment of large scale CFBC (420t/hr and 700 t/hr).
- Enhancement of construction of integrated gasification combined cycle (IGCC) demonstration power plant. As known, IGCC is one of the best ways for clean coal utilization, doubtlessly, it will be widely used in China in the coming several decades, because of its high efficiency and low emissions. SDPC already has approved the construction of a 300~400MW IGCC power plant in Yantai City, Shandong province and arranged some R&D projects in this direction. But up to now the process is quite slow, such as financing, issuing of favored policy and others. The hesitation is mainly caused by the high capital investment, high risk

and operation availability. During 9th FYP, some research projects have achieved encouraging results concerning the key technologies of IGCC. Except for the high-temperature gas turbine, for IGCC a rather high degree of localization could be obtained.

- Working out the development program of advanced gas turbine system (with inlet gas temperature more than 1300). Not only the clean coal technology, but also almost all of the efficient energy-power transformation system (with efficiency up to 60%~70%) have the gas turbine as the core of the system, so we could say the advanced gas turbine will play central role in the power system in 21st century. There is a significant gap in China's gas turbine technology in comparison with the world famous manufactures. China's future potential domestic market of gas turbines is huge.

  The Chinese industry is simultaneously facing opportunities and challenges. China has the potential opportunity for a large gas turbine market, but up to now the domestic gas turbine manufacturers have not been able to supply the advanced gas turbines to meet the market demand on unit capacity and application needs. In order to shift from "pure" import to partial domestic design and manufacturing and to have a reasonable market share, not totally relying on endless import, a strategic program of gas turbine development should be worked out.

2. Hydro-power, renewable energy and nuclear power

- **Speed up the construction hydropower stations.**

  China is ranking 1st in hydropower reserves, exploitable hydropower is 378GW(1.3 times the installed capacity of China at the time being), the former Soviet Union and Brazil are second and third with exploitable reserves of 270GW and 213GW respectively. Hydropower is a clean energy, therefore greater attention and funding should be paid for its development. The Three-Gorges hydropower station with a capacity of 18GW now is in its full construction; according to the plan, the last hydro turbine (there are 26 units) will be put into operation by the year 2010. The most essential and difficult task is the resettlement of local residents from the place of reservoir (there are more than 1 million). The Three Gorges power station will be the hub of state-united utility grid.

  Though the waterpower reserves in China are abundant, the degree of exploitation is quite low, up to 1996, the ratio of exploited to the exploitable was only 10% (Brasil-21.4%, Canda-52.34%, USA-78.82%). Tab. 9 is the historical data of hydropower-installed capacity and the electricity generated.

Table 9. Historical data of installed hydropower capacity and electricity generated

Year	Installed Capability GW			Electricity Generated TWh/y		
	Total	Hydropower	Ratio	Total	Hydropower	Ratio
1949	2.05	0.36	17.6	4.9	1.2	24.5
1970	23.80	6.24	26.2	115.6	20.5	17.7
1980	65.87	20.32	30.9	300.6	58.2	19.4
1990	137.89	36.05	26.1	621.3	126.3	20.3
1995	217.22	52.18	24.0	1006.9	186.8	18.5
1996	236.54	55.58	23.5	1079.5	186.9	17.3
1997	254.24	59.73	23.5	1134.2	194.6	17.1

Source: State Statistic Bureau

As shown in Tab. 9, because of the long construction periods, the ratio of generated electricity of the hydropower to the total is varying, the average is 17%~18%, and by the end of 1999 the installed capacity of hydropower reached 70GW. Tab. 10 is the rate of increase of hydropower in different periods, if maintaining the 7% average increase rate, the share of hydro power will be definitely increased in energy mix.

- **Development of grid connected large wind farms.**

  The theoretical wind power resource in China is 254GW. Certainly this is a very rough estimation, but take 1/5 of it and there still are 50GW of resource which could replace 150 million ton of coal with consequent elimination of all harmful substances. Tab. 11 shows the wind power resources of wind power of several provinces. As shown, the most abundant resources are found in Inner Mongolia and Xinjiang.

Table 10. Rate of Increase of hydro power in different periods

Year	Installed Capacity		Power Generated	
	Capacity MW	Increase ratio in average	Power Generated TWh	Increase ratio in average
1949	360.0		1.2	
1970	6235.0	14.50	20.5	14.50
1980	20318.0	12.50	58.2	11.00
1990	36045.5	5.90	126.3	8.06
1995	52183.6	7.68	186.8	8.13
1996	55577.9	6.50	186.9	0.08
1997	59730.4	7.47	194.6	4.09

Source: State Statistic Bureau

Table 11. Wind power resources in different provinces

Province	Exploitable in practice (GW)	Province	Exploitable in practice (GW)	Province	Exploitable in practice (GW)
Inner Mongolia	62	Liaoning	6.0	Heilongjiang	17.2
Jilin	6.4	Gansu	11.4	Hebie	6.1
Shandong	4.0	Jiangsu	2.4	Xinjiang	34
Hainan	0.6	Jiangxi	3.0	Zhejiang	1.6
Fujian	1.4	Guangdong	2.0		

Source: New Energy and Renewable Energy in China, White Book, SDPC, 1999

At present, the installed capacity of wind power is only 240MW, a very small portion of exploitable resources. The unsatisfactory development is caused by the high price of electricity generated by wind power. During the period 1997~1998, about 229 units had been put into operation with total capacity 114.2MW, all of which were imported. The high price of imported equipment is the main reason for the high price of wind power, because the wind mill itself accounts for 75%~80% of the unit capital investment. Only localization of the manufacturing of the windmill could reduce the cost of wind power. According to the plan, the capacity of wind power will reach 1GW by the year 2005. At present the 600kW units already have 78% localized production fraction, 9 domestically made units have already been in operation about 2 years and have shown good performance to date. Joint ventures will be organized for 1000kW unit design, manufacturing, installation and operation.

Some important institutional problems should be solved during 10th FYP. One is the introduction of competitive mechanisms for wind farm construction and elimination of the monopoly of state and local power sectors. For example, the implementation of a concession approach similar to that used for offshore petroleum and natural gas exploitation, has already gained great success during last 20 years. The second is the government support policy, the price gap between the electricity generated by wind power and conventional coal-fired power plants will be borne by the customers all over China, rather than locally, which in some cases, means very small grids. Otherwise, more wind power means more deficiency of local grid (because of higher cost and low quality of generated electricity), especially for relatively poor regions such as Inner Mongolia and Xinjiang. The establishment of a Renewable Portfolio standard (RPS) is extremely necessary. The third is to construct a transmission line from wind power-abundant areas to load centers. Unfortunately, the grid in the abovementioned areas are quite small (about 2GW), the portion of the relative random wind power in the grid is limited (5%~10%) due to the stability of power system. Perhaps joint generation of natural gas-fired combined cycles could compensate the randomness of the wind power and to make the transmission load more stable.

- **Concentrate the effort for solving the key problems of utilization of large-scale photovoltaic cells.**

  The barrier of wide application of photovoltaics is the limitation of price. Because of the small scale of photovoltaic industry, the price of every Wp is several tens-fold greater than conventional power generation. Through more than 20 years effort, China already has the foundation for further development. Some good results have been obtained in single and poly silicon cells, amorphous silicon film cells and CdTe, CdS poly crystal film cells. Several grid-connected and stand-alone photovoltaic power stations (the capacity is 25KW to 100 kW) have been constructed in Tibet and other isolate regions. But still the technology gap with the world advanced level is significant. In the 10^{th} FYP, a leap-frogging program for rapid development of photovoltaic industry, targeted to the most advanced photovoltaic technology such as multi-crystal film and dye nano-semiconductor, should be conducted, in order to have a breakthrough within few years by a concerted effort of different research institutes and enterprises.

- **Promotion of modern utilization of biomass**

  China is a country with huge population (especially the residents in rural areas), therefore agriculture is still a very important part of national economy, and the energy supply of the rural areas' residents and treatment of agricultural waste still are central problems deserving public attention. If these wastes are not properly used, not only is it a waste of energy but it can also create a big source of pollution (especially indoor pollution). Tab. 11 is the distribution of stack and their utilization in 1995 and 2000.

Table 11. Stack distribution and Utilization in China in 1995 and 2000(Mt)

	total amount of stocks	back to field as fertilizer and collection loss	as fodder for animals	as the feedstock for paper	available amount for energy use
1995 (whole country)	604.7	90.7	145	14	355
2000 (whole country)	647.9	97.2	177	21	352

Source: China's New Energy and Renewable Energy, White Book SDPC 1999

Take 1.0t stack=0.52tce, the amount of stack available for energy use in China is equivalent 180 million tce. At present, the efficiency of burning stack in the primitive stoves is only 10%~20%, or even less. In recent years, the government forcedly shutdown the small paper factories because of their serious pollution, and farmers can not sell their stack, but for convenience, during the harvest season farmers are burning the stack in the fields directly, which causes an additional pollution problem. As informed in the newspapers, some airports were closed because of the burning of stack in the surrounding fields. The top ten ranking of the amount of stack available for energy use is: Shandong, Henan, Hebei, Jiangsu, Heilongjiang, Jilin, Sichuan, Hubei, Anhui and Inner Mongolia. The Shandong province has the stack of 440 million tones.

From the point of view of technology, the gasification of biomass is not so difficult (how to reduce the tar is the problem), the key is to have a market driven mechanism. If all the expenses are borne by government (construction of gasification station, laying of pipeline, providing cooking and heating equipment…), it is impossible to be widely disseminated. The private capital for this undertaking must be encouraged. The role of government is providing technical support and issuing appropriate policy. For China, the energy density of biomass is low, the stack and straw are highly scattered, collection, transportation and utilization only economically feasible within the circle of 10km diameter for one station. Therefore, unlike the developed countries, the small-scale modern utilization roughly could be classified in three stages:

First stage: air blown gasification, the obtained gas with heating value 4000~6000kJ/m^3 could be used for cooking and heating, one gasification station for 50~100 families. A lower tar gasifier should be developed, and disseminate this kind of utilization during the 10th FYP, and reach a substantial amount.

Second stage: air blown gasification, except for the cooking and heating, the gas could be used for power generation via reciprocating engines, or, heat and power cogeneration. There is a demo in Jilin Province supported by UNDP Foundation and Jilin Provincial Government. If successful, it will serve a good example for other provinces.

Third stage: application of fuel cell and micro turbine combined cycles to increase the efficiency up to 43%.

Modern utilization of biomass will reduce the coal consumption in widespread rural areas with low efficiency and serious pollution, and will greatly benefit the environment (in terms of reduced SO_2 and CO_2 emissions) of whole country.

- **On the basis of localized production of 1000 MW nuclear power, increase the share of nuclear power in energy mix.**

The material of World Energy Council (WEC) indicated, according to the present consumption, the supply of petroleum, natural gas and coal could sustain the demand only 50,70 and 200 years respectively, which is a very incisive problem, for China in particular. There are two important starting points for developing nuclear power in China: one is the energy resources structure, shortage of petroleum and natural gas; the second is environmental problem, mitigation of SO_2, NOx and CO_2 emission and reduction of the share of coal in energy mix. Different opinions, sometime quite controversial, lead to the conclusion that maybe nuclear power is one of the feasible alternatives to fossil fuel. The main problems which must be solved are:

*Reduction of cost of nuclear power plants. For Daya Bay nuclear power plant, the cost of unit installed capacity is more than $2000, much more than an advanced coal fired power plant. The main reason is almost all the equipment was imported (the nuclear island from France, the turbine island from the UK), so localization will reduce the cost significantly.

*Improve the efficiency of utilization of nuclear fuel

*Treatment of the nuclear waste with very long semi-decay period.

The installed capacity of nuclear power should reach 200GW in the period of 20~30 years. Generally, there are three phases: first phase, development of pressurized water reactor, during 10th FYP China should grasp the key technology of design, manufacturing, operation and management of 1000MW nuclear power plant; second phase, development of fast-bleed neutron reactor, and to make this type of reactor commercialized by 2020~2030, for matching with the pressurized water reactors, to form a reasonable nuclear fuel cycling; third phase is nuclear fusion, it can only be realized by the joint effort of scientists and engineers of all the countries in the world (may be by the year 2080~2090), and will solve the human energy problem eventually. Tab. 13 is the preliminary plan of development of nuclear power in China. As shown, the share of nuclear power will be 5% by 2015, for 2050 there are three different data, corresponded to low, medium and high scenarios.

Table 13. Preliminary plan of development of nuclear power in China

	Total Capacity GW	Capacity of nuclear power GW	
2000	290	2.1	0.7
2005	350 360	8.5 9.0	2.5
2015	550 580	27 29	5.0
2050	1200 2300	120/240/360	

Source: Proceeding of workshop, "Sustainable Development Strategy of Nuclear Power in China", Chinese Academy of Engineering, 2000

3. Polygeneration System Based on Oxygen Blown Gasification

As described above, because of the shortage of petroleum and natural gas, in order to solve the energy security and environment problems thoroughly, we must find the way out from the clean coal utilization. Polygeneration based on oxygen blown gasification will provide this possibility.

- **The concept of polygeneration System**

The polygeneration system is proposed from the point of view of comprehensive optimization, which is a highly flexible integrated cross-sector resource/energy/environment system. Fig.1 is the basic framework.

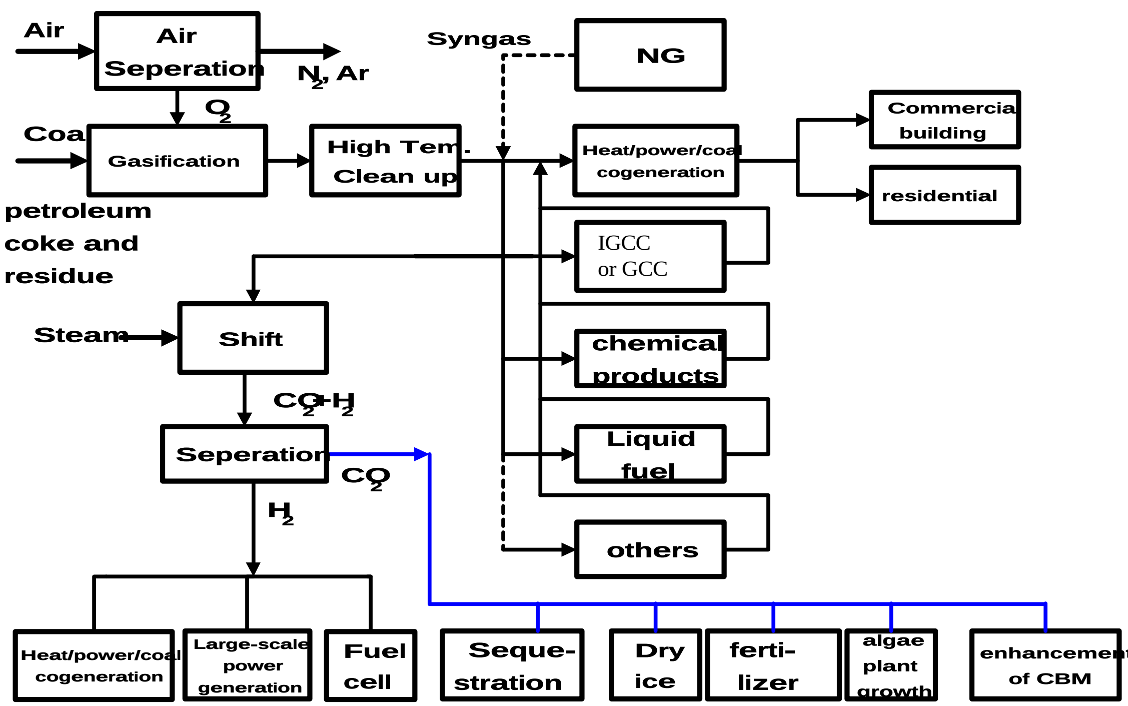

Figure 1. Integrated system for resource, energy and environment

The main points are:

1) Using the coal, petroleum coke and residues as feedstock, through oxygen blown gasification (the syngas content is $CO+H_2$), after cleanup and purification, the pure sulfur could be obtained as by-product.
2) There are diverse ways of utilization for obtained syngas

-----City gas for cooking and heating, for distributed power, heat and cool cogeneration.

-----Large-scale power generation (fuel cell or gas/steam combined cycles)

-----Methanol production via “once through” liquid phase reactor

-----Liquid fuel production (synthetic fuel and dymethyl ether) via “once through” liquid phase reactor

-----Other chemical products (NH_3, urea, middle distillate)

Other part of syngas can be used for hydrogen production via steam reform, the latter can be used as fuel for PEM fuel cells in the engines of cars for large cities with near zero emission, and solve the car pollution problem eventually. From the long term point of view, H2 as the energy carrier, could be utilized as cleanest fuel for distributed power, heat and coal cogeneration for realizing the local zero emission as well.

3) The treatment of separated CO_2

As seen from Tab.1, the combustion of cleaned syngas causes much less pollution than a conventional power plant with the direct firing of coal, if the combustion process is properly controlled. Therefore, the key issue is the treatment of the green house gas CO_2. For the proposed polygeneration system, the separated CO_2 is pure (the purity is 99%), unlike in conventional power plant, in which the CO_2 in flue gas is diluted by large portion of nitrogen. Thus, in this case, CO_2 could be used as a feedstock for different products, such as urea, dry ice… or for enhancement of plant growing and other industrial purposes. In recent years, a Canadian company named Albert is conducting the research and experiment for enhancement of coal bed methane (CBM) production by injecting the CO_2 to the coal seam (the depth is more than 2000 m), since coal as a micro-porous substance has the greater absorption capability to CO_2 rather than to CBM (mainly CH_4). Thus, the valuable CH_4 could be "squeezed" out and the CO_2 is sequestrated. There are a lot of ways for CO_2 sequestration, to deep sea, to depleted oil and gas fields or to saline aquifers. Surely, these kinds of concepts are only on the stage of preliminary study, the detailed technical, environmental assessment should be conducted. But anyway, the pure CO_2 will be much easier to be treated than the CO_2 in the flue gas of conventional power plants.

4) The core of the proposed polygeneration system is the close coupling of the production processes of different products. For instance, the syngas passes through the "once through" liquid phase reactor producing methane (or DME), and the unreacted syngas could be directed to the IGCC for power generation, unlike the stand-alone methane production with subsequent separation and recycling. Therefore, the capital investment, maintenance cost and environment impact will be significantly reduced, and consequently, the price of these products could be reduced as well. Further, because of the co-production, the "peak and valley" of each product (especially power generation) could be adjusted more easily according to the demand.

5) This polygeneration system is "open" and highly flexible. Under the concrete circumstance of China, in the coal abundant areas, this system is quite beneficial, it could implemented step by step, or phase by phase according to the technical advancement and the availability of capital investment, for example, for the first phase, only co-production of power, heat and methanol, the other products could be arranged later.

Fig. 1 only shows the framework of the polygeneration, the material flow, energy flow, information flow and multi-target (technology, economics, resources utilization, environment) optimization for each related subsystems should be arranged through sophisticated study of complex systems, and the local concrete conditions might be taken in account.

- **The benefits of polygeneration system**

The benefits of polygeneration system already have been mentioned in the previous paragraphs, hereunder are some quantitative results, the steam reform of syngas for H_2

production and enhancement of CBM are not included (the data are from US literature), even in this case, the benefits are quite impressive. The outputs of power, heat, methanol and syngas are 400MWe, 400MWth and 400MWeq respectively. The base case for comparison is the stand-alone production of these products by conventional power plant, industrial boilers, traditional technology for methanol production, and coal gasifiers correspondingly.

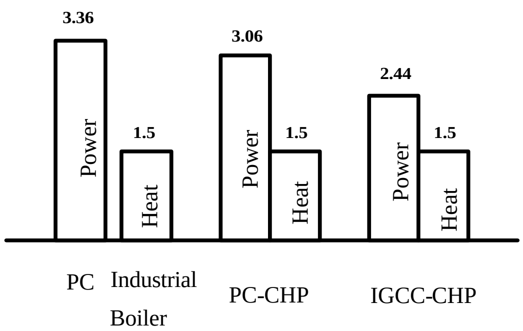

Fig.2 Economic comparison for different cases of heat and electricity production

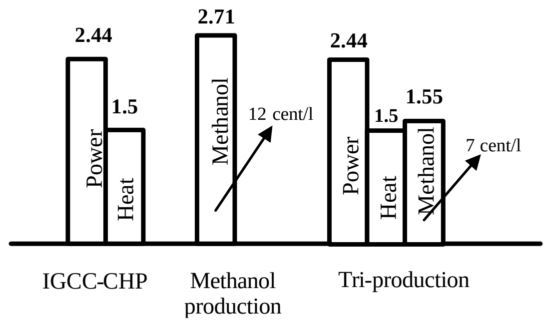

Figure 3 Economic comparison for tri-production of heat, electricity and

Fig.2 is the economic comparison for different cases of heat and power cogeneration. For stand-alone arrangement, the prices of electricity and heat are 3.36cent/kWh and 1.5cent/kWth, for cogeneration, the price of electricity reduces to 3.06cent/kWh while maintaining the price of heat unchanged. For cogeneration using IGCC, the price of electricity reduces to 2.44cent/kWh.

Fig.3 is the economic comparison for power, heat and methanol tri-generation. Using IGCC for heat and power cogeneration, and stand-alone methanol production, the price of latter is 12cent/liter, but for tri-generation, the price of methanol reduces to 7cent/liter while maintaining the unchanged prices of power and heat, the rate of reduction is 40%.

Fig.4 is the economic comparison of power, heat, methanol and syngas quad-generation with stand-alone case. The price of stand alone production of syngas is $4.8/GJ, the quad-generation, because of the scale effect, the price of latter reduces to $2.6/GJ, while maintaining the unchanged prices of power, heat and methanol, the rate of reduction is 46%.

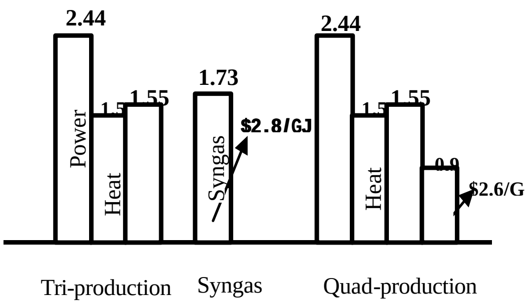

Fig.4 Economic comparison for the production of syngas, electricity, heat and methanol

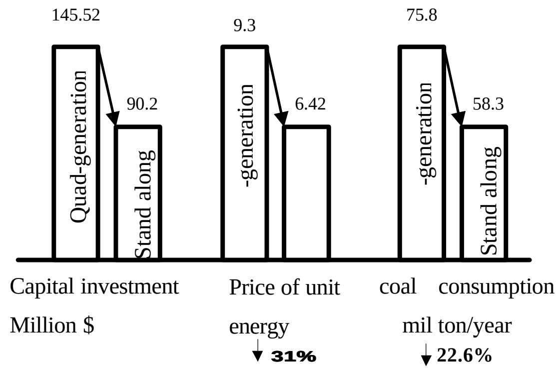

Fig.5 Benefit of investment, energy consumption and environment for quad-generation

In summary, taking the stand-alone production for these four products as base case, quad-generation leads to the following benefits: reductions of capital investment, cost for unit energy and coal consumption are 38%, 31% and 22.6% respectively, correspondingly the reduction of CO_2 emission is 22.6% as well.(Fig.5)

No doubt, the above-mentioned results are rather simplified and should be adjusted according to the concrete situation, but the benefits of polygeneration system (quad-generation is the example) are obvious.

The grand development of the West Part of China is a huge project in 21st century. The target is to put the end of backwardness of western regions, to develop the regional economy, to foster the new educated generation and to improve the living standard of local people. Only export the natural resources are not the way for reaching the aim. A new innovative approach is needed, to make the natural resources to be more value-added, the concept of polygeneration is a good enlightenment.

- **The Policy Support and Starting Steps for the Development of Polygeneration System**

1. Because of the polygeneration is a cross-sector large system, it could be developed only with the support and coordination of different sectors of industry (such as chemical and power generation industries) and the support of central government from the standing point of whole nation's benefits. So, firstly, the boundary between the sectors must be broken.
2. State Development and Planning Commission (SDPC), State Economic and Trade Commission (SETC) and Ministry of Science and Technology (MOST) must have a concerted action and different layers arrangement. For instance, the fundamental study of this system should be conducted via State Key Fundamental Research Program, the industrial demo of the system should be supported by S-863 Program. Besides, a favored policy under the guidance of government should be issued, since every new technology and system will have buy-down process, it is irrelevant to claim unreasonable request from the

very beginning.

3. The power sector must loose the regulation of grid connection; the owner of polygeneration system can sell the generated electricity to the grid at reasonable price.

4. There are two starting options. Firstly, in the coal abundant region (especially coal with high sulfur content) to set a industrial scale demo with co-production of power, methanol and syngas using once-through liquid phase reactor. It could be expended according to the availability of investment, and will serve a impressive example for other regions, for West Part of China in particular. Secondly, in the vicinity of oil refinery to construct a polygeneration plant using the high sulfur content residues as feedstock, thus to solve the problems caused by high sulfur content crude oil.

5. Utilizing the achievement obtained by many research institutes and enterprises in China, to organize a coordinated team for designing and construction of polygeneration system with own intellectual property.

6. Clean utilization of coal and mitigation of CO_2 emission are the global issue, support and donations from the international organization, such as UNDP, World Bank, Asia Development Bank, GEF, are desirable.

7. International Partnership and Cooperation with foreign famous enterprises, universities and research institutes.

8. Just from now on, to arrange a sophisticated and detailed study of the feasibility of polygeneration system.

- **Some concluding remarks for polygeneration**

1. The oxygen blow gasification is the **key enabling way** for high efficient, low emission utilization of abundant coal resources in China. It has the potential for CO_2 reduction;
2. "Once through" liquid phase reactor (production of methanol, F-T liquid fuel and DME) and advanced membrane separation technology (organic, non-organic, metallic, and related catalysts) are the **key enabling technology** for the liquid fuel production and further transferring to hydrogen energy system;
3. Polygeneration is the **key leap-frogging strategy** for enabling China to make a transition to the super-clean energy carrier (syngas, methanol, F-T liquid fuel, DME and hydrogen), to meet the requirement of diverse customers;
4. Polygeneration is the **key enabling measure** to solve the energy security problem under the circumstance of the shortage of petroleum;
5. Polygeneration is the **key enabling approach** to make the IGCC more competitive in the sense of price, efficiency, availability and environment, it is also very important for future high efficient distributed cogeneration of power, heat and coal;
6. Concerted arrangement, coordinated actions of different industrial sectors, purchasing of electricity generated by polygeneration at reasonable price by utility are the **key policy** for development of this kind of system;

7. Polygeneration is the **key option** for development of West Part of China, much higher value-added utilization of abundant natural resources, improvement of economy and ecology of those west regions.

VI. Recommendations of the relative policy and support measures for 10th Five-Years Plan in the energy field

1. Increase the funding of R&D in the energy field. Because the energy sector is a field of industry requiring long-term evolution, the formation of any new system needs several decades or more, therefore, to have a long-term program and consistent funding is extremely necessary. Any new technology in energy field needs quite a long period for maturation, there is a "learning curve" and "buying down process" during which government support is indispensable, such as for IGCC, wind power, polygeneration, and fuel cells.
2. The process of the formation of a comprehensive program, the "one dragon" consideration must be taken in account. That is, not only the technology itself must be considered (including fundamental research and applied research), but also the consequent development and demonstration, the issuing of the favored policy, creation of market, commercialization strategy, involvement of enterprises and large-scale deployment. In other words, government and enterprises must keep in mind RD^3 (Research, Development, Demonstration and Deployment), and to handle the whole chain. The diverse government organizations (SDPC, SETC, MOST and other ministries) and diverse programs (National Key Fundamental Research Program, 863 Program, S-863 Program, High-Tec Development Program, State Grant Engineering Project) should concentrate their efforts towards a concerted solution of several important problems, (similar to the CCT Program and the ATS Program in USA.)Some leap-frogging technologies need essential government support in order to have significant breakthroughs, such as large scale CFBC, polygeneration, nanocarbon tubes for hydrogen storage, PEMFC, SOFC, dye nano semiconductor photovolaic cell, l000 MW nuclear power plant with domestic intellectual property, etc. For these leap-frogging technologies, some special authorized steering committee which can control the budget, assign the human force, space and equipment, could be established for reinforcing the coordination.
3. The convenience of grid connection must be given to renewable energy and distributed power/heat/cool cogeneration with obvious economic and environmental benefits. Market driven mechanisms should be applied for promoting the deployment of renewable energy, such as Renewable Portfolio Standard (RPS) and the concession approach of wind power development. It is extremely desirable to put in the practice of concession approach of wind power development as a demonstration in Inner Mongolia , Xinjinang or Zhang Bei area

of Hebei Province .

4. The direction of utility reform is deregulation or decentralization, and the elimination of the monopoly of the State Power Corporation. The external cost (caused by environment damage) of power generation should internalized, and a reasonable price system established for electricity, which would leads to the encouragement of the small, medium and large capacity IPPs (independent power producers) to sell the generated electricity to the grid at reasonable prices.

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