Review of Assumptions as to Changes in the Electricity Generation Sector in Nautilus Institute's Clean Coal Scenarios Report

Xie Shaoxiong

The "Clean Coal Scenarios Report" has properly set the goal of describing and evaluating two scenarios for the development of the Chinese electricity sector between now and the year 2020. The importance of the Report is not to give any "optimal" path for the sustainable development of the electricity sector in China but to illustrate the potential role of clean coal technologies as well as the limitations of those technologies for the electricity sector in addressing environmental problems in China. To accomplish this goal, assumptions as to changes in electricity generation seem to be more important than the analysis itself. The author of this paper intends first to comment on some general assumptions underlying the Report and then to list some specific assumptions as to electricity generation. Before doing this, it seems reasonable to the author to give a brief overview of Chinese power generation.

With the rapid growth of the power industry since reform and its opening up over the past two decades, China now possesses the second largest power industry in the world. By the end of 1999, the nation's total installed generating capacity reached 299 GW, with a total generation of 1233 TWh. Of the total installed capacity 223 GW was thermal, accounting for 74.8%, and the remainder came mainly from hydro. The electricity generated by thermal power totaled 1005 TWh, accounting for an even higher percentage (81%) in 1999. Along with the effort made to upgrade the power industry, the number of large generating units with higher steam parameters and more efficient power plants has doubled and quadrupled, coming to be the main power sources of China's power industry. At the end of 1998, in the field of thermal power, there were 398 generating units each with a capacity of 200 MW or more , among which are 20 units of 500-660 MW, 41 units of 320-362.5 MW, 148 units of 250-300 MW, and 190 units of 200-210 MW, totaling 106.2 GW in capacity, and accounting for 51% of the nation's total installed thermal capacity. As a result, technical-economic indexes have been distinctly improved. In 1999, national net coal consumption for electricity generation was decreased to 399 g/kWh, 28g/kWh less than in 1990. In the meantime, environmental protection, availability of thermal generating units, clean coal combustion, and automation of thermal power plants have seen progress. It should also be noted that with the development of pollution control technology and the strengthening of environmental protection management in the power industry, good progress has also been made in mitigating the pollutants emitted from thermal power plants. Coal consumption by thermal power plants in China increased from 119.78 Mt in 1980 to 481.87 Mt in 1999, while the fly ash discharges not only did not increase, but, on the contrary, decreased somewhat due largely to the success in comprehensive utilization of fly ash and slag. Furthermore, with a number of new large units coming into operation, together with the improvement of the coal quality supplied to these power plants, the quantity of fly ash and dust discharged increased not so much in recent years. After bringing fly ash discharges under effective control, sulfur dioxide has emerged as the major pollutant, and the atmospheric pollution caused by sulfur dioxide emissions has been, in turn, the major environmental issue facing the power industry . Although effort has been made to reduce the average sulfur content of the coal consumed by thermal power plants, total annual SO_2 emissions are still increasing (see Table 1).

Table 1: SO_2 emitted by thermal power plants between 1980 and 1997

	1980	1997
Average annual sulfur content of coal (%)	1.2	1.11
Annual SO_2 emission (Mt)	2.87	6.83

Source: Electric Power 1999, China Electric Power Information Center

Presently, the shares of coal burned in thermal power plants with sulfur contents below 1% and above 1% account for 59.29% and 40.71% respectively. According to the difference in distribution of S-contents of coal in China, several flue gas desulfurization (FGD) processes have been investigated with positive results over the past years. Now China has more than ten thermal power plants equipped with FGD facilities using different FGD technologies, among which five are situated in Sichuan and Chongqing in southwest China, where the sulfur content is higher than 1% and desulfurization seems to be a must today. In addition, China has also engaged in retrofitting old power plants by employing conventional lime/gypsum wet type desulfurization technology. The old condensing-type thermal power generating units (unit capacity below 50 MW) with a total capacity up to 31 GW are in the process of being replaced by new larger ones, and some 5745 MW was closed down in 1999. With the increasingly strict requirements of environmental protection and the rapid development of clean coal technology for power generation, China's power sector is paying great attention to the development and implementation of clean coal technology to be used in the years to come.

With the above brief introduction of China's electricity generation, I am coming back to my comments on the "Clean Coal Scenarios Report".

General view

The Alternative scenario in the Report has been designed primarily to show the impact of a significant effort to decrease electricity sector emissions of sulfur oxides. As sulfur oxides have come to be the top pollutant and as desulfurization is a top priority in dealing with pollution problems in China's electricity sector and the country as a whole, efforts to decrease these emissions as made in the Report deserve high consideration. However, in an overall point of view sulfur oxides emissions from the electricity sector do not account for the largest fraction of the total from all sectors in China (35% of the total from all industries and an even smaller percentage of the total from the whole country for the year 1997). So, it seems more reasonable to deal with SOx emissions issues not only specifically from thermal power plants, but also broadly from all sectors (described as "demand-side sources of emissions" in the Report). While desulfurization of coal by the electricity sector is going to be more urgent as more coal (in both absolute and percentage terms) is to be converted to

electricity through combustion in the years to come, it is advisable to keep in mind that electricity generation from burning coal even with conventional technologies (such as flue gas desulfurization and some less expensive facilities used in China) has already been more efficient in use and cleaner in dealing with SOx emissions compared with direct burning of coal in other sectors, where no desulfurization measures have been adopted for those low-efficiency boilers scattered over the country.(see Table 2).

Table 2: Efficiency of Small-size Boilers in China (1995)

	Number of units, (× 1000)	Capacity, (× 1000 tons/hour)	Coal consumption (Mt)	Average nameplate efficiency (%)	Average operation efficiency (%)
Total	499.4	1200	277.64	66.68	63.11
Industrial use	229.0	700	213.98	67.35	62.43
Non-industrial use	270.4	500	63.66	66.11	61.26

Source: Energy Research Institute, SDPC China

Table 3: Efficiency of Household Stoves

Type of Stoves	Efficiency, %
Coal-fired	15-20
Gas-fired	
Natural gas	55-60
LPG	55-60
Methane	55-60
Electricity	
Electric	60-65
Microwave	55-60

Source: Energy Research Institute, SDPC China

Therefore, converting as much coal as possible into electricity is in itself a contribution to the alleviation of SOx emissions and other air pollutants (only 40% of coal production was converted to electricity in China in 1999 compared with 93.2% in the US in 1997) (see Table 4). Furthermore, to reduce the huge quantity of coal consumed by numerous small boilers and countless household stoves which use coal at low efficiencies and traditionally in a most polluting way, to replace coal by electricity and, wherever possible, by direct use of cleaner fossil fuels like natural gas by pipeline and/or in the form of LNG, would not only benefit China with the clean environment for which people in many cities and vast rural areas thirst, but would also contribute to the energy conservation of the country.

Table 4: The Structure of Coal Consumption in Some Countries (1997)

	China	USA	Germany	Japan	UK
Consumption (Mt)	1392.5	917.0	251.5	134.9	63.1
Structure (%)					
Electricity	39.7	93.2	90.9	39.3	74.6
Coking	13.9	3.0	5.2	44.3	12.8
Industries	36.5	3.5	3.5	16.0	9.8
Household, Business and other	9.9	0.3	0.4	0.4	4.8

Source: State Statistics Bureau; Coal Information IEA, 1998

In addition to a moderate desulfurization measure for coal-fired thermal power plants, energy efficiency improvement measures combined with the accelerated development of clean electricity sources (hydro and other renewable sources) with multi-environmental benefits seem to be more plausible.

With regard to the assumptions as to changes in the electricity generation sector in the Report, the following aspects are reviewed:

1. General pattern of growth in generating capacity by type

Coal–fired capacity will continue to provide the great bulk of power supplies, but its share in the total supply will decrease slightly. This is mainly because up to 75% of China's hydropower resources are distributed in the west, and so far only about 8% have been developed. The development of China's western regions will give a big push to the development of hydropower. More electricity generated by hydropower stations can not only meet the increasing demand of the region with the development of the economy and the upgrading of people's living standard, but can also be transmitted to eastern regions through long distance transmission lines.
This, in turn, will help contribute to long-term hydropower development. In contrast to estimates from other sources such as IEA's Outlook on World Energy, 1998 and "Prospect of Energy Demand and Supply in China" by China International Engineering Consultants, August 1999, the assertion, "The combined share of coal and washed coal in fuel for electricity generation declines somewhat over time, but is still well over 80% of fuel input by 2020" (page 44, Report) seems debatable (see Tables 8 & 11).

2. Assumptions for future electricity consumption

As it is well accepted that raising the share of electricity in total primary energy consumption is the effective way of achieving a sustainable energy development, the growth rate of electricity consumption will definitely be higher than that of total energy consumption. With the slowing down of the economy in recent years as well as a result of energy efficiency improvement and changes in industrial structure, the growth rate of electricity consumption has also declined. Historically, the industrial sector consumed more than 70% of the total electricity consumed in the country. The decrease in the industrial growth rate resulted in the decrease of electricity consumption growth by industries, particularly by those electricity-intensive consumers in the industry. The growth rate of electricity consumption in this sector decreased from an average of 9% for the Eighth-Five-Year-Plan period to 5.78, 2.9%, and 1.1% for 1996, 1997, and 1998, respectively. However, residential and services sectors played an important role in achieving the overall growth of electricity consumption in the country in recent years. The overall electricity consumption growth rates of 10.1% for the "Eighth-Five" period and 6.9%, 4.4%, and 2.8% for 1996, 1997, and 1998, respectively, in the country were achieved largely due to the contribution of residential and services sectors (at an annual growth rate of 16.9% in the Eighth-Five period and 10-12.5% in recent years for the residential sector, and 13.5% and 8.7-9.3% in the same periods for the services sector). With the continuous and moderate growth of the whole economy, overall electricity consumption is projected to maintain a moderate growth rate (3.5-4.5%), while the residential, services, and communication sectors still have the strongest growth rate (at 9-10% for residential, 8-9% for services annually), along with the improvement of living standards and enhancement of distribution networks in both urban and rural areas in the period from 2000 to 2010. Electricity consumption in agriculture varies a lot depending on weather conditions, but is predicted to grow at 4-5% annually, while industries are predicted to differ in their electricity consumption according to different effects of the ongoing structural reform. Based on the analysis of some experts in different industries, the growth rate varies between 2% and 3% for mining, industry, and construction before 2010. Although it is still hard to predict precisely to what extent the implementation of the strategy of launching a campaign to develop western areas will increase electricity consumption nationwide within ten to twenty years, it is seems certain to the author that China may enjoy an even higher growth rate than that predicted by experts based on the following facts: overall per capita electricity consumption is low compared to that of industrialized countries (see Table 5); the difference in per capita electricity consumption between urban and rural inhabitants is very large; the percentage of electricity consumption by service sector and residential users is far behind industrialized countries. These, altogether, give great potential to the increase of future electricity consumption. This, fortunately, could be supported by the most updated statistics from the State Power Corporation, saying that "pulled forward by the recovery and growth of the economy both at home and abroad, China's electricity sector enjoyed a high growth rate in electricity consumption up to 10% in most regions and even higher than 14% in the economically developed coast regions like Shanghai, Jiangsu and Shangdong in the period from January to July, 2000 compared to the same period in the previous year. In some areas like the Hebei grid in north China, serious power shortage even occurred at peak hours this summer.

Table5: Comparison of per capita electricity generation,1997

	China	USA	Japan	OECD	World
KWh	919	13739	8132	8021	2090

Source: China Energy Research Society

In order to cope with future increases in electricity consumption, China will continue to pursue the policy of mainly relying on its own energy resources, in particular, coal and hydro, to develop its power industry. As a carbon-free source of electricity, nuclear can provide huge quantities of electricity without causing any air pollution and, therefore, can play an important role in the Chinese power industry. Now, nuclear electricity development is just at the beginning stage in China. What affects its further development is lack of funds and technology. It seems that a large-scale nuclear development plan would not be implemented unless nuclear equipment manufacture is localized and hence nuclear electricity can be competitive with thermal and hydro. Emphasis is increasingly being given to renewable energy sources, particularly wind. China's wind energy potential is very rich (estimated at 253 GW). However, by the end of 1999, only 268 MW of wind power was developed , representing a very small percentage (less than 0.1%) of the total installed generating capacity in the country. Efforts are being made to accelerate the process, and it is anticipated that several GWs will be developed within ten years. This author does not expect renewable energy to play a substantial role in China's electricity market until distributed generation shows its strong viability in the traditionally monopolized power industry and until powerful support is given by the Chinese government. With China's entry into the WTO and progress to be achieved in carrying out reform and opening up policy, international cooperation in electricity sector would be widened. China will not ignore any important energy resources, including electricity from other countries, if it is economically feasible and safe in supply for China. Potential electricity exchange with neighboring countries has already been taken into consideration on some occasions.

3. Specific assumptions for electricity generation infrastructure

3.1. Generation Efficiencies

The efficiencies of existing coal-fired power plants vary a lot due to equipment supplied by different manufacturers and different operating conditions (type of coal, maintenance, seasonal change of ambient temperature, etc.). The per-kWh net coal consumption by the same size generating sets (for example, 200 MW sets) varied in the range of 360 g to 420 g in 1998. So, it is good to understand that the gross energy efficiencies of different thermal power plants assumed on page 30 in the Report are designed efficiencies for those plants instead of the real ones. As the gap in generation efficiency between China and advanced industrialized countries is going to be narrowed and even filled in twenty years with more technology transfer to local manufacturers following the import of advanced equipment from abroad and also through China's own R&D efforts, I predict that the advanced international efficiency level can be used as the efficiency of power plants to be built in 2010 to 2020.

3.2. Generation capacity additions

The rate of introduction of high-efficiency coal-fired generation (IGCC+SCPF) will increase only slightly by 2005 due to the temporary supply surplus in some areas and, more importantly, the very high price in building. In the author's point of view, only a few demonstration clean-coal power plants will be built within ten years. Firstly, what kind of clean coal technology (CCT) is more suitable to China's situation is still something to be demonstrated by projects. Secondly, the development of a specific CCT, say IGCC, cannot be determined solely by the electricity sector and needs coordinated action among industries. It appears, with the deepening of the reform in the power sector, that more power and coal companies may join in symphony, and more coordination work may be needed. But the role of government at both central and provincial levels in making decisions about which clean coal technology is to be adopted should be highlighted. It also seems to the author that right signals and accurate information in the clean coal technology field from industrialized countries may also play an important role in helping China make choices.

3.3. Generation auxiliary power use

According to the Statistics of the State Power Corporation, the nation's averaged auxiliary power use of both thermal and hydropower plants is 5.61% and those for hydro and thermal are 0.43% and 7.01% in 1999, respectively. The nation's averaged auxiliary power has shown a steady decrease in recent years due to the change in structure of installed generating capacity and the decommissioning of smaller size generators (unit size at 50MW and below). But the figures still differ a lot among plants from the lowest 4% for some imported 600MW units to the middle 7- 8% for most indigenous 200MW and the highest 10% for some old units. The assumed 8% of gross generation (for existing coal-fired plants) in the Report is acceptable.

3.4. Renovation and retirement of existing plants

For the purpose of continuously improving energy efficiency in thermal power generation, large, high steam-parameter generating sets are replacing and will continue to replace the old and obsolete ones built in the 1950s and early 1960s. Over the past two decades, newly installed generating capacity was mainly 300 MW and 600 MW sets. By the end of 1998, the number of 200 MW and above generating sets reached 467, with a total installed capacity of 126 GW, representing 51.88% of national total installed capacity, compared to only 18 200 MW and above generating sets, totaling 4.32 GW, representing only 7.6% of national total installed capacity in 1978. In the field of thermal power plants, as mentioned earlier in this paper, there are 398 generating units each with a capacity of 200 MW and above, among which 20 units being of 500-660 MW, 41 units of 320-362.5 MW, 148 units of 250-300 MW, and 190 units of 200-210 MW, totaling 106.2 GW in capacity, and accounting for 51% of the nation's total installed thermal power capacity (see Table 5). Where conditions are mature small thermal generating sets (below 100 MW each) are progressively being shut down. All new standard coal plants to be built in the so-called "Two Areas under Control" (acid rain control area and sulfur dioxide pollution control area) will have FGD systems by 2010 . As to coal fired power plants to be built outside the "Two Control Areas" and the coal to be used with sulfur content less than or equal to 1%, according to permissible total discharge amount and total control amount of the area as well as the requirements of local environmental quality for the area, the decision will be made on whether or not to adopt desulfurization measures after the Environmental Impact Assessment is reviewed. The assumption on page 34

in the Report, "All existing coal-fired plants (with a total installed capacity over 200 GW in 2000!) that did not originally have FGD have been retrofitted with FGD by 2020," seems not quite plausible because, firstly, it is not easy to retrofit 10 GW each year in a period of 20 years, and secondly, it would be more feasible to build new standard coal plants with FGD to replace those old and obsolete ones (those built in the 1960s and 1970s) instead of retrofitting them with FGD.

Table 6: Size mix of thermal power generating units 1998

Unit size (MW)	Number of units	Share (%)
200-210	190	17.88
250-300	148	21.03
320-362.5	41	6.66
550-660	20	5.47
900*	2	0.85
199 and below		48.12

*Two 900 MW nuclear power generating units included in this table
Source: Electric Power 1999, China Electric Power Information Center

3.5. Transmission and distribution losses

According to statistics of State Power (see Table 7), line losses (T&D losses) declined continuously from around 10% in the 1970s to less than 9% in the 1990s. In the most recent ten years it fluctuated above 8%, with a high (8.77%) in 1995, and a low (8.13%) in 1998. To what extent it can decline by 2010 is not clear, since how much distribution losses historically "lumped" with sectoral electricity use of most large industrial and some rural wholesale consumers will be taken into line loss category in statistics is still uncertain. Furthermore, transmission losses do not seem to decrease much with the ongoing effort to form an integrated network nationwide. So, in this author's judgement, the figure (7.5%) assumed for 2010 in the Report (on page30) may be a little low.

4. Key ongoing energy/environment-related changes in China

The Report lists nine important policy uncertainties that would affect the energy and environmental situation in general and the electricity sector in particular (page 8). Besides these, the author considers that more issues should be taken into account:

- The new development of clean coal technologies and the advancement of IGCC. The possibility of technology breakthrough in other means of electricity generation based on coal gasification and hydrogen (such as decentralized generation systems with more efficient and environmentally-friendly technology) within twenty years.
- The influence on promoting competition and broadening international cooperation in the energy field of China's entry into the WTO, the prospect of joint exploitation of natural gas in neighboring countries and importing more liquid fuels and gaseous fuels from the international market.

- The market mechanism (competition) is going to be introduced in electricity generation in the years to come. If real competition rather than one in name occurs, what would be its implications for the electricity producers in terms of their interest in producing environmentally sound electricity to the public? What would be its effect on adopting a clean coal technology strategy in the electricity sector?
- The implications of carrying out the strategic plan to develop electricity generation in China's western areas in terms of both its growth-rate and its mix. To what extent hydro, oil, and gas resources will experience accelerated development. How much the total share of electricity generation from hydro and gas would increase by 2020.
- Global warming issue concern
  What would be the evolution of UNFCCC? The possibility of developed countries' commitment to UNFCCC in ten or more years. Furthermore, what progress would be achieved within twenty years in explaining on a more scientific basis the real cause of global warming and its relationship to greenhouse gas emissions, in particular carbon dioxide emitted from burning fossil fuels. This would exert some influence on the Chinese energy sector in the process of implementing a clean coal technology strategy in China.

Table 7: Major Electricity Tech-economic Indices (1952-1998)

Year	Annual average utilization hours of electricity generation capacity	Auxiliary use of electricity in power plants (%)	Line losses (%)	Generation standard coal consumption (grams/ kWh)	Delivery Standard coal consumption (grams/kWh)
1952	3800	6.17	11.29	727	
1957	4794	5.99	6.61	604	
1962	3554	7.87	8.73	549	605
1965	4920	6.98	7.31	477	518
1970	5526	6.54	9.22	463	502
1971	5810	6.68	9.48	465	505
1972	5746	6.68	9.43	464	504
1973	5530	6.26	9.53	457	496
1974	5010	6.19	9.91	450	488
1975	5197	6.23	10.13	450	489
1976	4869	6.34	10.32	449	487
1977	4947	6.41	10.19	446	484
1978	5149	6.61	9.64	434	471
1979	5175	6.54	9.24	422	457
1980	5078	6.44	8.93	413	448
1981	4955	6.40	8.98	407	442
1982	5007	6.32	8.64	404	438
1983	5101	6.21	8.53	400	434
1984	5190	6.28	8.28	398	432
1985	5308	6.42	8.18	398	431
1986	5388	6.54	8.15	398	432
1987	5392	6.66	8.48	398	432
1988	5313	6.69	8.18	397	431
1989	5171	6.81	8.18	397	432
1990	5041	6.90	8.06	392	427
1991	5030	6.94	8.15	390	424
1992	5039	7.00	8.29	386	420
1993	5068	6.96	8.52	384	417
1994	5233	6.90	8.73	381	414
1995	5216	6.78	8.77	370	412
1996	5033	6.88	8.53	377	410
1997	4765	6.68	8.20	375	408
1998	4501	6.66	8.13	373	405

Source: State Power Corporation

Table 8: Electricity Generation Projection (1995-2020) in China (TWh)

	1995	2010	2020
Coal	767	1729	2612
Oil	63	168	257
Gas	2	65	123
Nuclear	13	72	127
Hydro	191	457	726
Other Renewable Energy	0	7	11
Total	1036	2497	3857

Source: World Energy Outlook, 1998 (IEA)

Table 9: Capital costs and efficiencies of power plants (1995-2020) ($/kW, %)

	1995	2020
Coal-fired		
Cost	750	750
Efficiency	35	38
Gas steam combined cycle		
Cost	450	450
Efficiency	50	55
Gas turbine		
Cost	275	275
Efficiency	35	39
Nuclear		
Cost	2000	2000
Hydro		
Cost	2000	2000
Wind		
Cost	1000	1000

Source: World Energy Outlook, 1998 (IEA)

According to our statistics, the capital cost of coal-fired thermal power plants has been rising over the past twenty years. The average capital cost of thermal power plants with 300 MW units rose from around 1400 yuan/kW in 1986 to almost 4000 yuan/kW in 1994, with an average annual rise of 14%. This was mainly due to the price rise of equipment, increase of construction cost, and additional cost for upgrading design standards. In recent years this rising tendency has been under control. A target has been set at roughly 3400-3600 yuan/kW for new coal-fired thermal power plants with indigenous 600 MW units and 3500-4000 yuan/kW for those also with indigenous 300 MW units in China. What would be the capital cost for those coal-fired power plants to be built in 2010-2020 seems uncertain to us.

Table 10: Major power Industry Data (1985-1998)

	1985	1990	1995	1996	1997	1998
Installed Generating Capacity (GW)	87.05	137.89	217.22	236.54	254.24	277.29
-Hydro	26.42	36.05	52.18	55.58	59.73	65.07
-Nuclear	-	-	2.10	2.10	2.10	2.10
Electricity generation (TWh)	410.7	621.32	1006.9	1079.4	1134.2	1157.7
-Hydro	92.4	126.35	186.8	186.9	194.6	204.3
-Nuclear			12.8	14.3	14.4	14.1
Coal consumption per kWh supplied (gce/kWh)	431	427	412	410	408	404
Coal consumption Per kWh Generated (gce/kWh)	398	392	379	377	375	373
Auxiliary use of electricity in plants (%)						
-Hydro	6.42	6.90	6.78	6.88	6.80	6.66
-Thermal	0.28	0.30	0.37	0.51	0.51	0.47
Line losses (%)	7.78	8.22	7.95	7.94	7.81	7.71
Annual utilization hours of generating Capacity	8.18	8.06	8.77	8.53	8.20	8.13
-Hydro	5308	5036	5121	5033	4765	4501
-Thermal	3853	3800	3867	3570	3387	3319
	5893	5413	5454	5418	5114	4811

Source: State Power Corporation

Table 11: Generating Capacity and Electricity Generation in Percentages (1980-2010)

Year	1980	1985	1990	1995	1996	1997	2010
Installed Capacity	100	100	100	100	100	100	100
-hydro	30.85	30.34	26.14	24.02	23.50	23.50	
-thermal	65.15	69.66	73.86	75.01	75.61	75.68	
-nuclear				0.97	0.89	0.82	
Electricity Generation	100	100	100	100	100	100	100
-hydro	19.40	22.50	20.33	18.55	17.32	17.15	23.68-22.04
-thermal	80.60	77.50	79.67	80.18	81.35	81.58	68.71-69.32
-nuclear				1.20	1.33	1.27	3.51-3.66

Source: An Outlook on China's Energy Demand and Supply (Research Report by China International Engineering Consultants,1999)