Prospects for and impacts of diversifying fuel use away from coal

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Abstract

China has the largest population in the world, producing and consuming massive amounts of energy. It is apparent that the current energy mix of China will need to be restructured to meet the recent challenges brought on by a surge in the economy, fierce international competition and the increasing pressure of population, resources and the environment.

The level of development of a country is usually measured by indicators such as; 1) per capita energy use, 2) composition of energy production, 3) energy intensity, and 4) environmental impact of energy production. China has a long way to go to reach these targets. Despite a high rate of energy production there is a downward trend in energy production per capita. The structure of primary energy production and consumption has changed dramatically from coal dominance to a mix of coal, petroleum, gas and hydropower, with coal still making up the lion's share. In the foreseeable future, China will compete with the rapidly growing economies in Asia for energy imports. It is predicted that there will be a notable imbalance between primary energy production and consumption. Therefore, serious energy shortfalls may arise in China without significant restructuring of both energy supply and demand. The current social-economic situation, future energy and environmental pressures, resource distribution and the globalization of trade justify this restructuring.

Energy diversification, efficiency and flexibility will be key factors for meeting the ever-increasing energy demand necessary to sustain economic growth in China. The energy restructuring should allow for both domestic and international markets. China will remain an oil and natural gas constrained country in terms of both population size and GDP, with no move away from the dominance of coal in the near future. While China is at a disadvantage in petroleum and natural gas production and exportation, it has a leading edge in making use of international markets and imports. It is imperative that China highlights this advantage in the pursuit of a more diverse energy supply. Considering the predominance of coal in China, maximum diversification of fuel should be pursued in all industries and sectors. It is clear that a coherent and successful policy for the development of clean and efficient energy mix should be crucial to China's sustainability. China's coal-dominated energy structure, with a 75% share in the primary energy supply, is the source of the current environmental, transportation and CO_2 emissions problems. By the year 2020 even if the increasing rate of CO_2 emissions can be kept well below that of economic growth with effective measures for energy conservation, the total emissions of CO_2 may still exceed the current American

level, making China the largest CO_2 emitter in the world. The potential challenges posed by global climate change justify the formulation of a sound energy development strategy for China as soon as possible. The chronic shortage of petroleum and natural gas should move clean coal combustion technologies and high-efficient coal use into the spotlight as a long run solution. Considering the pressure from CO_2 emissions, the long-term energy strategy should allow for the development of natural gas, hydropower, nuclear, solar, wind, and renewable energy. The establishment of a new energy structure and system will entail a decade-long effort including R & D, demonstration projects, commercialization, and large-scale dissemination. Therefore, the planning and R&D must start immediately to ensure timely acceptance and use of new cleaner, more efficient technologies.

1 Present Situation

China has the largest population in the world that produces and consumes massive amounts of energy. Facing intense economic development and international competition as well as the three great pressures of population, resources and the environment, the energy structure of China must meet severe challenges with fresh choices and adjustment. The energy strategy of the 21st century will undergo adjustments according to sustainable development strategies and modulations of the economic and industrial structure.

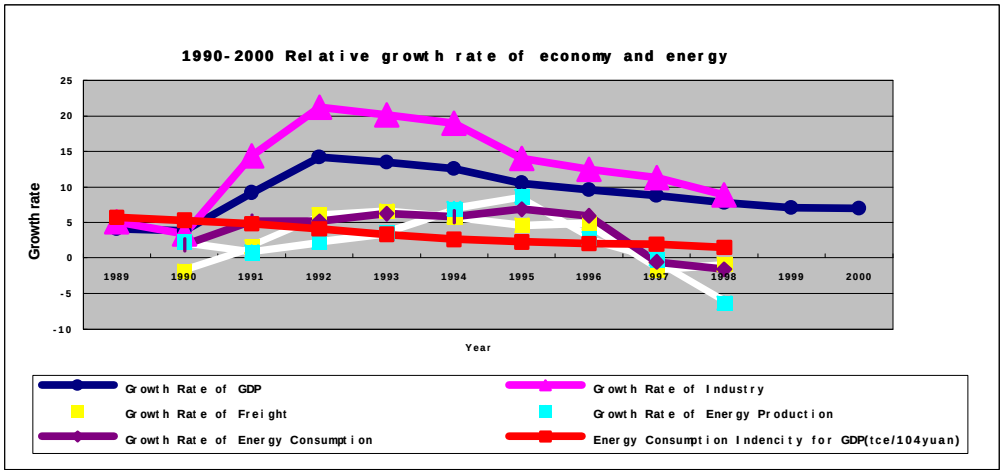
In 1998, the GDP of China was 7939.57 billion yuan, the population was 1.248 billion and the energy production was 1.24 Gtce (Giga tons coal equivalent). In the same year, the energy consumption was 1.36 Gtce, coal production was 1.222 Gt, crude oil production was 0.16 Mt and electricity generation was 1167 GkWh. Energy consumption per capita in 1998 was 1.09 tce and the energy intensity per unit GDP was 1.713 tce/10 thousand yuan. Internationally, a country's level of development can be measured by per capita energy consumption, energy supply diversity, energy conversion efficiency and/or impacts of energy on the environment. China does not measure well using these indicators. Although energy production is increasing, it is projected to decline in the future. Presently, the structure of primary energy production is changing, moving from coal as the single source to a multi-energy structure including oil, gas, hydro and nuclear power. Nevertheless, the energy structure of China still emphasizes coal, which accounts for 75% of energy production. Adjusting the energy structure is an important issue in light of China's growing economy. Energy production will need to be diverse, flexible, efficient and consistent with the adjusting economic and industrial structure. The present energy structure is a severe threat to the economy and environment, and becomes the critical factor preventing the sustainable development strategy of China from being implemented successfully. Relative to total population and GDP, China is still a country lacking oil and natural gas and it is impossible to change this situation. In the near future the reliance on coal will not change, requiring industries to adopt energy policies to raise energy efficiency, reduce consumption and air pollution and ensure environmental security. The predominance of

coal also creates problems in the regional and global environment and results in high emissions of CO_2. By 2020, although China will adopt powerful energy conservation and substitution measures to lower CO_2 emissions, China will most likely surpass the US as the largest emitter of CO_2 in the world. The issue of global climate change brings severe challenge to China's energy strategy. The establishment of a new energy system, from formulating strategy, to research and development, to experimental demonstration projects, to commercialized application and formation of a completely new energy industry requires decades. It is necessary to formulate a technology program in advance; simultaneously, the impact on society and the economy is considerable, which is also the background of our study.

2 Challenges of Energy Structure Pluralism

China has many energy sources including raw coal, crude oil, natural gas and hydropower. However, with the current balance of energy supply and demand and the obvious imbalance of energy production and consumption in the future, the potential for an energy crisis in China cannot be overlooked. If energy supply is not increased, with a concurrent reduction in demand, China will experience severe energy shortages. Economic development will impact the structure of energy supply and demand. In spite of the fruitful energy resource there is an imbalance in the geographical distribution of energy resources. Energy consumption per capita and electric utility efficiency are lower than world averages and the reliance on coal results in regional and global environment pollution and climate change. Integration into the global economy and involvement in WTO will affect energy trade and security. China faces severe challenges in how the energy structure will meet the forecasted demand of national economic development and optimally adapt to adjustments in the national economic structure.

Correlation of economic development with increases in energy consumption



Graph 1. Relative Growth Rate of Economy and Energy

The economic growth in the 1990's proved that the declining returns from economic development are not a short-term phenomenon. The growth of GDP was as follows: in 1992, 14.2%; in 1993, 13.5%; in 1994, 12.6%; in 1995, 10.5%; in 1996, 9.6%; in 1977, 8.8%; in 1998, 7.8% and in 1999, 7.1%, which shows a continual decline. The economic downturn resulted from an essential change in the economy, which is not credited to the Asian Financial Crisis. The external crisis merely made this slowdown more obvious and the change more pronounced in 1998 and in 1999. In past decades the rapid growth of the Chinese economy was attributed to shortages which brought a great deal of investment demand. As a result various entities invested actively, including foreign investors, the national government and village and town enterprises. Rapid investment brought about gains in productivity and economic growth. Since the early 1990's these gains which brought about the severe productivity surpluses had reached a plateau. An inspection of industry in 1995 indicated that the productivity utility rate of 50 per cent of the principal industrial products was less than 60%. Such extra productivity definitely affects industrial investment demand and alters the pattern of supply and demand. These severe productivity surpluses prevented rapid economic growth and formed the imbalance between increased productivity and demand growth.

In addition, advances in information technology reduce the demand for traditional industries. Though the process of industrialization is not yet complete, the information economy has already appeared, and advances to science and technology have accelerated. At the same time when science and technology advancement and the information economy create rapid growth, they reduce the demand for energy, raw material and transportation required by traditional industries. This will reduce energy consumption, material consumption and transportation per 10 thousand yuan GDP. For instance, in 1994 and 1995, industrial energy consumption increased by 6.9% and 8.7% respectively, with a corresponding increase in industrial production of 18.9% and 14%; while in 1997 industrial energy consumption declined by –0.2% and in 1998 by –6.4%. In 1995, the energy consumption per 10 thousand GDP was 2.3 tons, in 1996, 2.0 tons, in 1997, 1.9 tons, and in 1998, it was 1.5 tons. In the past freight volume was highly correlated with economic growth rate, but recently it has not been so strongly correlated. In 1994, the freight volume including railway, roadway, waterway and airway increased by 5.8%; this indicator was 4.6%, 4.9%, -1.6%, and -0.6% in 1995, 1996, 1997, and 1998 respectively. This data shows that with scientific and technological advancement and structural adjustment the dependence on and demand for traditional industrial sectors and materials may rapidly decline. It is required to adjust the energy structure quickly because of the alleviating of economic development. Figure 1 shows the above tendency in detail.

Resource Situation and Energy Structure

The energy resources of China are relatively bountiful. The Ministry of Minerals and the Ministry of Coal have made forecasts of the coal, oil, natural gas and hydro resources in China. The estimations are based on a great number of inspections and

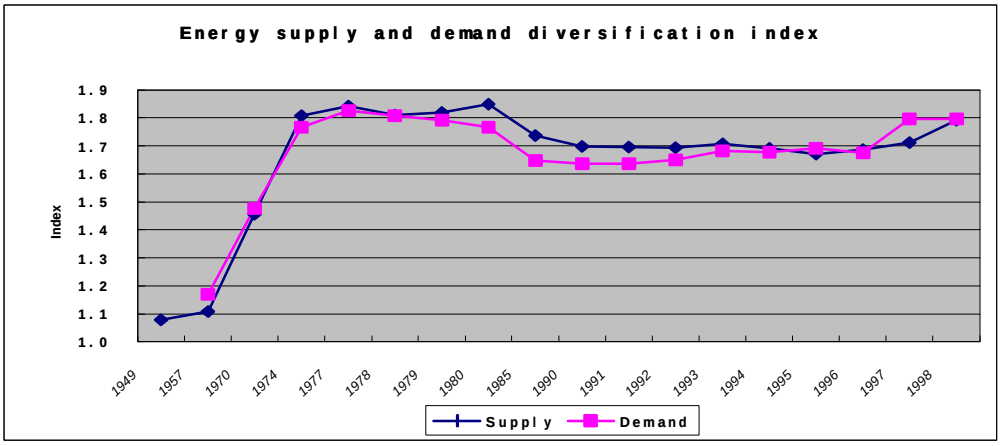
explorations, and the Ministries claim that the energy resources of China amount to 4001.7 Gtce, with coal comprising 90% of the total. By the end of 1990, the proved storage of China's energy resource was 155.1 Gtce, in which coal was 52.6%, water was 43.33%, and oil and gas were only 4%. Energy storage capacity in China is significantly less than world averages; China has 45% of the world average of coal storage, 55% of the world average hydro storage, 11% of the world average oil storage and 5% of the world average natural gas storage. The energy consumption per capita of China is greatly lower than the average level of the world. In 1980 Chinese energy consumption per capita equaled 30% of the world average while in 1994 it equaled 45%. In 1994 the United States consumed 5.46 times as much energy as the world average while Japan consumed 2.69 times as much. In the high-income countries energy consumption was 3.45 times the world average, and in medium-income countries energy consumption equals the world average.

With respect to per capita energy consumption and energy storage Chinese energy resources are significantly lower than world averages. According to the World Bank the crude oil storage of China is 2.43% of the world total while the natural gas storage is 1.20%. Recently some critical oil fields, such as Daqing in China, have neared the limits of their reserves. The crude oil production of Daqing oil field has remained constant over the last 21 years at 50Mt per year. China has not discovered any other large oil fields like Daqing. After 2000 it is possible that oil and natural gas supplies will undergo a crisis. It is apparent that, relative to population and GDP, China is a country with insufficient oil and gas reserves and that this situation is permanent. China has no comparative advantage with respect to oil and natural gas production and export. China does have some comparative advantages in international markets and exports, but this requires great quantities of foreign exchange. According to the World Bank it is estimated that the raw coal storage of China accounts for 10.97% of the world total, while that of the United States accounts for 23.04%. China's hydro resource accounts for 13.22% of the world total, while the United States has 2.58%. It is clear that China has comparative advantages in coal and hydropower production and export. On the whole, however, it is inevitable that with the current energy infrastructure China will face an energy resource shortage in the future.

Although the estimations of China's energy resources are not quite consistent, it is concluded that the energy resource of China is plentiful and that coal comprises the largest share. Based on the survey results of relevant geological sectors, the accumulated proven reserves of coal account for 19.2% of the world total. Oil and natural gas resources are rather low; therefore, it is undeniable that the exploitation and development of China's energy resources (especially natural gas) has large potential and it is necessary to increase domestic resource exploitation and development. In order to meet the energy demand for China's national economic development, it is necessary to import foreign oil and gas resources to make up the increasing demand for domestic high quality energy. In the long term however, it is appropriate to base the energy structure on coal.

Impacts of Energy Supply and Demand Change on Energy Structure

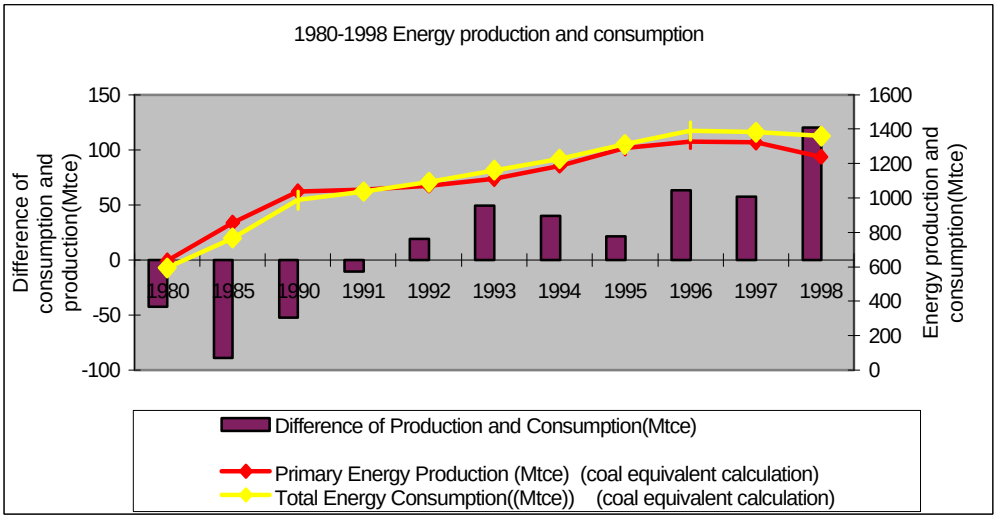
In graph 2, we adopt a diversification index to reflect features of a country's energy structure. The index is defined as the reciprocal of the squared sum of the proportion of each energy type: when only one kind of energy is used, the index equals 1.0. When two or more energy resources are employed the index is greater than 1.0 and a larger number signifies a greater diversity of energy supplies and a higher level of energy security. China has one of the lowest diversification indices in the world.



Graph 2. Energy Supply and Demand Diversification Index

In the ten years of the "sixth five-year" plan and the "seventh five-year" plan (1980-1990) after the economic reform, the energy supply structure of China was basically stable; the structure of energy consumption and known resources remained constant. From 1980 to 1991 the energy consumption diversification index was lower than the energy production diversification index, although the volume of energy production was larger than that of energy consumed (graph 2). In economic terms, however, there appeared to be an energy shortage. During this time the proportion of coal used in energy production increased to 74.2% from 69.4%, whereas in energy consumption coal use increased to 76.2% from 72.2%. Energy production from oil decreased to 19.0% from 23.8%, and oil consumption decreased from 20.7% to 16.6%. However, during the "eighth five-year" period, notice that the trends in energy production structure and the energy consumption structure appear to have changed. In energy production structure, coal proportion increased from 74.2% to 75.5%, while oil production decreased from 19.0% to 16.7%; while in energy consumption structure, coal decreased from 76.2% to 75%, and oil consumption increased from 16.6% to 17.3%. The change between the two energy varieties was not great, nonetheless, the trends in energy production and consumption foreshadow the development in the future. This data indicates that China has made the transition to an open market system, dependant on energy imports, from the traditional and relatively independent closed energy system (Graph 3). This change also indicates that coal alone cannot meet the demand for a high quality energy resource. It is imperative that China make a policy to

employ domestic and international resources to meet developing energy demands. The trends over the last decades have shown that China has moved from a self-sufficient, closed energy economy, to an importer of energy from abroad. If this trend continues



Graph 3. 1980-1998 Energy Production and Consumption

demand will far outweigh supply and the structure of China's energy system will exist in a state of imbalance. If policies are not enacted which address this issue, severe energy supply shortages will appear.

Energy Trade and Global Economic Systemization

In recent decades, China implemented a completely autarkic energy strategy which considered quantities of imported energy, especially imported oil and natural gas, as a severe threat to national economic security. Although China is a country with an insufficient oil resource, it has remained a net exporter of oil. In 1980 China exported 21.6% of domestically produced oil and in 1985 it reached the peak at 36.3%, since then oil exports have continuously declined. In 1993 China became a net importer of oil and in 1995 imported 4.5% of domestic production. Since the 1990's increases in oil demand have greatly exceeded increases in oil supply. From 1980 to 1990 oil consumption and production grew together at 2.8% and 2.7%, respectively. During "the eighth five-year" period there was a serious imbalance between oil production and consumption. From 1990 to 1995 oil consumption increased by 6.4% per annum, while production decreased. This resulted in expanding the gap between oil supply and demand. In 1993, China became a net importer of oil by importing 9.88 Mt. With the expansion of China's population and rapid economic growth China has and will continue to have a growing appetite for oil. With oil import volume increase annually, China became a net import country on crude oil in 1996.

Since 1993 when China became a net importer of oil the international market has increasingly influenced the domestic market. Domestic prices have fluctuated with

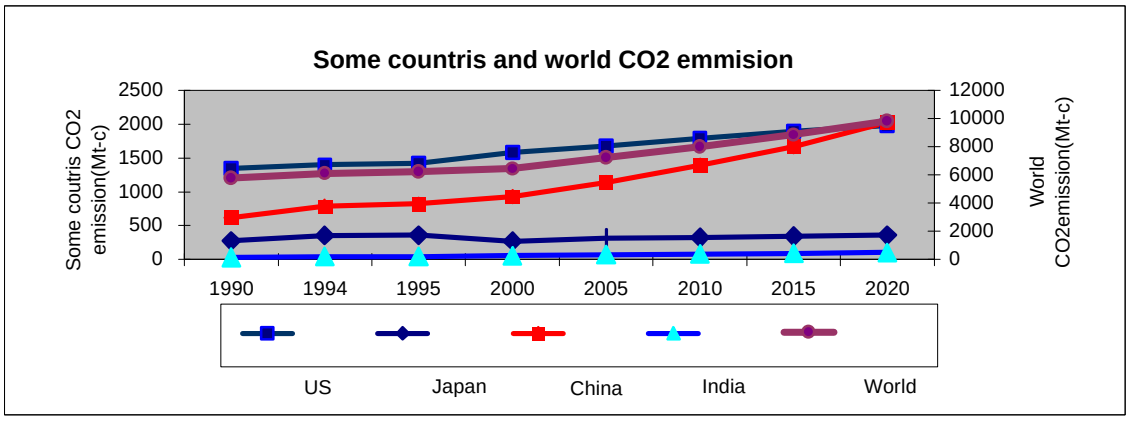
those of the international market, especially in June of 1998. Because the two prices were correlated when the price of international oil increased domestic oil production and refining within China was affected. In 1980 China imported 4% of total energy consumption, and 1% in 1994. Moreover, both developing and developed countries with insufficient energy supplies are net importers of energy: in 1994 Korea imported 86% of it's required energy, 21% in India, 81% in Japan, and 19% in the United States. Energy imports in relation to total imports of these countries greatly outweigh China's energy imports: in 1994, the net energy import value for Korea was 18%, 30% in India, 21% in Japan, 10% in the United States, but only 6% in China. Therefore, China should utilize the international energy market and import oil and natural gas in great quantities. In the future oil demand will far outweigh oil supply and this will continue to be the situation in China's oil market.

According to the latest estimations by IEA, as well as our own research, growth in oil consumption and production will be consistent with the "Eighth Five-Year" plan. Oil exports from China will decline and imports will increase rapidly. China will become one of the principal oil importing countries, which will significantly influence world oil production and trade. In spite of the great quantities of oil imported China remains a fairly self-sufficient energy supplier because of the minor role oil plays in the national energy strategy. Although oil imports continue to rise they are still below the levels of many developing and developed countries. China is in a position to import energy because: i) China has the fastest growing export market in the world, resulting in prodigious purchasing power, ii) energy imports into China make up only 6% of total imports, which may be increased by great margin. Under these circumstances energy imports will not create a national security problem. Henceforth, increasing oil imports will require the development and construction of infrastructure such as oil docks and oil containers. An efficient storage system for oil and natural gas must be built so that sufficient reserves can be kept on-hand to respond to price shocks and temporary crises. China should participate in the exploitation and development of foreign oil and gas resources, contract foreign projects, and find a stable crude oil market to ensure a supply of oil and natural gas into the future. Because this increase in oil consumption is foreseeable and increasing gradually, the world's oil industry will increase investment accordingly. Total oil production will grow and there will not be an obvious increase in oil price. As a growing consumer of oil, China creates an excellent opportunity for international oil companies and oil producing countries.

China's entrance into the WTO is relevant to the energy industry as the country will enjoy the most-favored-nation clause, and the special considerations for developing countries. Customs taxes will be reduced, export subsidies abandoned and non-custom-tax measures will be gradually abolished. These changes will make the energy products of China more competitive in the international marketplace and the domestic market will be opened to international energy products. Therefore, competitive pressures and opportunities coexist. The energy industry must make efforts to develop both domestic and foreign resources and markets. China must export coal,

which is labor-intensive and plentiful, and import oil and natural gas resources, which are capital-intensive and scarce. Domestic businesses should be encouraged to invest in oil fields and oil processing bases abroad and foreign traders must be encouraged to develop the oil and natural gas resources of China. These measures will ensure the stable and diversified energy supply necessary to support the rapid growth of the Chinese economy.

Environment Situation and Energy Structure



Graph 4: CO_2 Emission of Some Countries and the World

Since the reform and the opening of China, China's economy has grown significantly. Meanwhile rapid urbanization and industrialization have greatly damaged China's environment. According to the World Bank air pollution in China, especially particulate pollution, resulted in 54 billion dollars of health related illnesses in 1995, almost 8% of China's GDP. Acid rain is also rapidly expanding, damaging 1 million km^2 more than in the 1980's. In 1995 China was the second largest emitter of SO_2 and had the third largest CO_2 emissions (Graph 4). Coal burning is the principal cause of air pollution and acid rain and accounted for 85% of SO_2 emissions and 70% of CO_2 emissions. China is the only large country in the world which primarily depends on coal for energy production. In 1996 China consumed 1.4 GT of coal, which provided 75.4% of the primary energy in China. This accounted for 29% of the world's coal consumption. From 1978 to 1996, coal consumption in China doubled. With the developing economy, a rising population and an increasing standard of living energy demand will rapidly increase. If China continues it's current course future energy demands will be met with coal, resulting in severe environmental consequences. Therefore, China should implement a sustainable development strategy focused on reducing emissions from coal firing, reducing coal consumption and diversifying the primary energy source by substituting renewable energy sources for coal.

Coal is used for electricity generation, industrial purposes and residential heating. If coal consumption continues to rise SO_2 emissions will rise as well. China is now the largest emitter of SO_2 in the world, emitting more than 20 Mt per year for the past decade. This pollution causes severe acid rain. Presently, acid rain extends south of the

Changjiang River and east of the Qingzang Altiplano. In the 1980's 30% of the territory had precipitation with a pH lower than the international standard of 5.6. Acid rain in the Middle China region has exceeded that of the Southwestern region, which had the most serious in pollution in 1980's. The frequency of acid rain precipitation is over 90%. SO_2 pollution in many cities is very severe. The current average concentration of SO_2 in 62% of all cities exceeds level II of the National Environmental Air Quality Regulations, and daily average concentrations can exceed level III. In recent years coal fired generation expanded rapidly. In 1998 the installed generating capacity grew by 9.07%, reaching 277 GW. Electricity production however only grew by 2.07%, to 1157.7TWh. In which, coal fired power installation capacity was 209.88GW, 75.7% of total installed capacity, and generation volume was 938.8TWh, 81% of total electricity generation. It has been calculated that in 1998, SO_2 emissions from fossil fuel power plants in China was 7.8 Mt, 37.3% of the whole country's SO_2 emissions. Firepower plants belonging to the State Power Corporation, with a capacity of 6000 kW, consumed 280 Mt of coal containing 1.03% sulfur and resulting in 23.9% of China's SO_2 emissions.

In 1997, SO_2 emissions from industry added value per dollar of China's industry was 0.759 ton, 0.5 ton higher than that of Australia, 0.66 ton more than that of France, 0.69 more than that of Japan, 0.56 more than that of Korea, 0.57 more than that of Singapore, and 0.24 more than that of the average level of medium income countries.

With the development of China's economy environmental pressures are mounting. China has the largest population in the world, there is much land in agricultural production and many industries are run at low productivity from villages and towns. It is urgent for China to achieve industrialization and modernization. Hence, the consideration on resources, technologies and consciousness is insufficient, inevitably resulting in the non-economical activities which depend on resource. The economy of China is developing very rapidly but GNP per capita is still very low, which restricts the financial ability to protect the environment. Due to the problems listed above it is in our best interest to adjust the energy and economic structure in order to avoid conflicts between energy production and the fragile and sensitive environment.

Challenges of Industrial Energy Consumption

Some of China's industries are extremely energy intensive and emit high levels of pollutants. Because of different processes and pollutants it is necessary that both energy and industrial adjustment occur simultaneously.

China's steel industry produces over 100 Mt annually; this steel is produced by more than 1600 steel plants. There are only 17 steel plants in China that produce over 1 Mt of steel per year. The steel industry employs 3 million people, but the steel output per person is only 4.5% Japanese output. The energy consumed per ton of steel produced is 976 kgce (kilograms coal equivalent), 48.7% higher than that of Japan. With respect to

output, the ratio of board and tube of the main steel production countries is over 60% while it's only 38% in China. Production and fabrication equipment in China lags behind the rest of the world. Only 10% of the equipment is of international top quality, 20% is of domestic top quality and 70% is of lower qualities. Compared to the steel industry in developed countries the Chinese steel industry lags 10 to 15 years behind.

The oil refining capacity of more than 50% of the oil refining plants in China is below 0.2 Mt. With respect to production level, there are tens of thousands of employees working in ethane plants with an output of 0.3 Gcal/t, whereas it is hundreds in the similar kind of enterprises abroad. The international average of energy intensity for oil refining is 14 kgce/t while in China it is 22 kgce/t. The international average energy intensity of ethane production is 5 Gcal/t while in China it is 9 Gcal/t. With respect to product structure, the number of products manufactured by large-scale oil and chemical enterprises in developed countries reaches thousands, while in China it is only 1800. The ratio of plastic to steel is 1:9 in foreign countries, but 1:30 in China. Table 1 shows the energy intensity of some products.

Table 1 Intensity comparison of some products of 1980 and 1997

1980	**Average in China (1)**	**Average of developed countries (2)**	**(1-2)/2*100%**
Power plan gce/kWh	**448.0**	**338.0**	**32.5**
Steel kgce/t	**1201.0**	**705.0**	**70.4**
Cement (Large/Medium) kgce/t	**203.8**	**135.7**	**50.2**
Ethylene kgce/t	**2013.0**	**1100.0**	**83.0**
Vehicle by freight L/100tkM	**8.7**	**3.4**	**155.9**
1997	**Average in China (1)**	**Average of developed countries**	**(1-2)/2*100%**
Power plan gce/kWh	**408.0**	**324.3**	**25.8**
Steel kgce/t	**976.0**	**656.0**	**48.8**
Cement (Large/Medium) kgce/t	**181.3**	**124.6**	**45.5**
Ethylene kgce/t	**1210.0**	**870.0**	**39.1**
Vehicle by freight L/100tkM	**7.6**	**3.4**	**123.5**

The rapid increase of transportation vehicles and oil consumption will pose a problem in the near future. It is not possible to substitute oil as a fuel for planes and powerboats. The number of vehicles in China is increasing rapidly, in 1985 there were 3 million, 10 million in 1994, 34.33 million in 1997 and 40.89 million in 1998. The proportion of private vehicles owned in China will continue to grow. Based on the present situation of China, private vehicle ownership will increase and public transportation will be developed. The need to reduce the dependence on foreign oil while balancing the conflict between roads, land and population will constitute a major challenge to the energy structure.

It is clear from the above analysis that the gap between some Chinese industries and industries in developed countries is large. Therefore, China should move away from a myopic concentration on industrial output and work to improve the quality of economic development while adjusting the industrial structure. China should raise the technology level of industry as well as adjusting the energy structure.

3. Energy Structure Adjustment, Diversification Possibilities and Potential Problems

Currently coal comprises 25% of the global primary energy source, oil is over 40% and natural gas is over 25%. In 1998 primary energy consumption of China was 1.36 Gtce, second only to the United States. In China 70% of primary energy comes from coal, with oil and natural gas accounting for the other 20%. This ratio is unique for a country that consumes as much energy as China.

Industrialization occurs when a county uses oil as it's primary energy source. Therefore, by the beginning of 21st century, it is necessary to raise the proportion of oil consumed in China. However, China is a developing country with a young economy, a fruitful coal resource, and insufficient oil reserves per capita. It is impossible to depend on imported oil to support national economic development. In the coming decades coal will remain the dominant source of energy in China, while the dependence on foreign energy resources will continue to grow. Oil security includes national supply and the global market, in which supply is limited in quantity, and the market will have volatile prices. Although global oil supply is larger than global demand, China will still be susceptible to regional oil shortages. The effect of volatile global oil prices on a developing economy such as China's cannot be underestimated. According to experts, the overall oil demand of China in 2000 will reach 200 Mt. China will produce 158 Mt, exporting 10 Mt of oil resulting in over 40 Mt. of oil imports. As the 21st century begins, demand for oil in China will increase by approximately 30% per decade and by 2020 consumption will have reached 350 Mt, resulting in 150 to 200 Mt. of imports.

Under these circumstances diversifying the energy structure is the best method to reduce the risks associated with energy prices and pollution. China must diversify its

utilization and exploitation of domestic and foreign energy sources, pursue different channels for importing and exporting energy commodities and diversify transportation energy requirements. China must carry out a sustainable development strategy. China has low per capita energy consumption which will be increasing as the economy grows, but the environmental consequences of simply increasing coal consumption are not acceptable. Therefore, the sustainable development strategy must not only reduce consumption of coal but also pursue sources of high quality energy such as oil, natural gas, hydropower, nuclear power and alternative energy. China should be researching clean coal technologies such as coal gasification and liquefaction as well as end of pipe remedies like sulfur and nitrogen removal.

A. Principal Substitution Possibilities and Problems with Coal

Hydro Power and Nuclear Power Technologies

China's exploitable hydropower resource is 378.5 GW, 80% of which is distributed in the southwestern region and 11% of which has been utilized. According to the policy "self-construction, self-management, and self-utilization", more than 60,000 small hydropower stations have been constructed within China. These small hydropower plants play an important role in developing rural and local economies.

China has prioritized the development of hydropower. The Three Gorges Plant will have an overall capacity is 18.4 GW and is set to start generating in 2003. China has adopted the policy that the price of electricity from both hydropower and power generated from fossil fuels will be the same. This supports the Three Gorges project and facilitates the rolling development of hydropower. Developing hydropower and sending western electricity to the east have played an important role in the national strategy of developing the west.

In order to address the environmental problems resulting from local energy shortages and the emissions of coal power plants China has accelerated the construction of nuclear power stations in the eastern and coastal regions. The first pressurized water reactor with a capacity of 300 MW was successfully installed in Qinshan in July, 1992. Two sets of pressurized water reactors (PWR's) with a capacity of 600 MW each have been ready for installation in the second phase of Qinshan. Two PWR's in Daya Bay (2×900MW) were brought on-line in 1999; two PWR's were installed in Lingao (2×100MW), two heavy water reactors were installed in the third phase of Qinshan (2×700MW), and two PWR's in Lianyungang (2×1000MW) are currently in construction. It is estimated that by 2006 there will be 20,000MW of installed nuclear capacity, constituting 3% of energy production.

In “Energy Policy in China” it is illustrated that nuclear power is a clean, safe and reliable source of energy for the power industry. Developing nuclear power in China will have beneficial effects on energy security, the environment and the stability and growth of the economy. The Chinese government claims that we must address issues of nuclear proliferation, pollution and security.

Renewable Energy

China is a country with abundant renewable resources. It is estimated that the exploitable wind energy resource is 0.25 TW, distributed in the coastal regions of Inner Mongolia, Sinkiang, and the Gansu provinces. There is excellent solar insolation over 2/3 of the nation’s area. Biomass energy resources are estimated at 650 Mtce, which equals half of China’s overall energy consumption. Biomass resources include agricultural wastes such as straw (47% of estimated resource) and firewood (20% of estimated resource). There are 3200 discovered terrestrial heat regions and the proved storage of 40 terrestrial heat fields equals 3160 Mtce. There are 18000 km of coastline with 6500 islands, 4.7 million km^2 of ocean, and a rich ocean energy resource.

There are 800 million people living in rural China. These people consume 600 Mtce of energy annually, half of which is renewable. The utilization of renewable energy has been noted in the “Energy Policy in China”, the “21st Century Agenda” and the “Ninth Five-Year Plan and Perspective Target Compendium”. In 1995 the State Council approved and issued the “New and Renewable Energy Development Compendium in China” stating the importance of “developing and spreading clean energy, such as solar energy, wind energy, terrestrial heat energy, tidal energy and biomass energy according to different conditions locally.” The report also set a goal of “extending and applying new energy technologies, and increasing the exploitation and utilization of various new and renewable energy to 390 Mtce by 2010.” In 1999, the State Development and Planning Commission (SDPC) and the Ministry of Science and Technology (MOST) jointly issued the “notice on Further Support in Renewable Energy Development”, which offers a 2% subsidy to renewable energy projects. Projects receive priority on loans with special interest rates. The SDPC has begun to carry out the “Wind Plan” to accelerate domestic production of wind power equipment, the “Sunshine Project” to bring electricity to non-electrified rural areas, and the “Construction of Hundreds of Counties” project to integrate environmental design into the construction of hundreds of villages and counties.

During the periods from the “Sixth Five-Year” to the “Ninth Five-Year” (1980-1999), the Nation facilitated the exploitation and utilization of renewable energy aggressively. Nearly 200 million yuan were invested in research and development through national technology projects and nearly 2000 million yuan were provided as loans through such projects as the Torch Project, the Spark Project and Technology Reform.

Renewable energy projects:

i) Wind energy: China began to utilize wind energy in the end of the 1970's. There are presently 21 wind farms, with an installed capacity of over 226 MW. One-quarter of these turbines are installed in Sinjiang. Research and development of large-scale wind turbines has lead to the domestic production of a 250 kW wind turbine. By the research and development of large-scale wind engine and the working on nationalization, 250 kW wind engine units have been homebred completely and 70% of 600 MW has realized the nationalization.

ii) Solar energy (PV generation): Battery production began in the mid 1980's and current production reaches 4 MW/year. The herd people of the Western regions for lighting utilize the majority of the batteries. There are over 13 MW of photovoltaics installed throughout China.

iii) Solar heat utilization: China utilizes more energy for solar thermal services than any other country in the world. In 1998 the output of solar thermal heaters was 4 M-m^2 and the total area collecting heat is 15 M-m^2. The high-efficiency vacuum tube technology is produced at an advanced level.

iv) Terrestrial heat energy: Since the 1970's, China has utilized terrestrial heat sources to generate electricity. The largest power station, Yangbajing, located in Tibet has an installed capacity of 25 MW.

v) Biogas: Since the 1970's China has established 6.9 million methane digesters in rural areas. A straw gasification technology for villages with less than 300 families has been developed and applied in the Shandong and Hebei provinces. A 1 MW experimental fluidized bed biomass burner which burns rice paddy shells is in operation. This plant plays an important role in improving the local environmental conditions. Biomass liquefaction and urban garbage are both being developed as potential sources of fuel.

vi) Ocean energy: There are 8 tidal energy power generators in China with an overall installed capacity 6120 KW. Bulb turbine units with 500 KW and 700 KW capacities have been produced in China. The experimental shore-based, wave-activated power stations with capacities of 3 KW and 20 KW have been constructed. A swinging wave-activated power station with a capacity of 100 KW is under currently being researched.

The above actions indicate that the Chinese government has been seeking substitutes for coal in response to the problems it creates.

B. Clean Coal Technology and Generation

Clean Coal Technology

Since the 1980's China has worked on preventing and reducing the pollution emitted by burning coal. In 1994 a group was formed to implement and lead the national campaign for clean coal technology. The members include the SDPC, MOST, the Economic and Trade Commission (ETC), the Ministry of Coal and the Ministry of Electricity. In 1997 the State Council approved the "Development Compendium on China's Clean Coal Technology for the Ninth Five-Year and 2010". This plan was set forth at a technology conference held in August of last year. The plan accelerates the development of clean coal technologies and supports the rapid industrialization of clean energy production technologies.

In recent years the Nation has issued a few laws and regulations concerning clean coal technologies such as: "Coal Act of People's Republic of China", "Energy Conservation Act of People's Republic of China", and "Prevention and Cure of Air Pollution Act of People's Republic of China". These laws and regulations explicitly require that "the Nation develop and spread clean coal technologies". In such memorandums as the "Outline of China's Energy Conservation Technology Policy", the "Directory of Key Fields in High Technology Industrialization Developed Priority of China", and the "Catalogue of Industries Prospective to Foreign Investment" issued by SDPC, MOST and ETC, the development of clean coal technologies is required. The State Council approved several files issued by ETC in 1999. These files, such as; the "Catalogue of Backward and Eliminated Production Power, Processes and Products (first group)" and the "Notice on Issuing the Catalogue of Eliminated Processes and Equipment Polluting the Environment" legislate that the ten industries with the highest coal intensities must eliminate production processes which are inefficient.

Meanwhile, the Nation is investing large amounts of capital, carrying on relevant research and development, and constructing a series of full scale demonstration projects using introduced, or domestically-developed, technologies to facilitate the development and application of efficient clean coal technologies.

Twenty-two CFBC boilers of 220tons/hour, 240t/h and 410t/h capacity were purchased and are in operation. China has the ability to design and manufacture a 100MW CFBC power station. A 15MW PFBC experimental power station has entered the demonstration phase. An IGCC demonstration power station has been approved by SDPC. Flue gas can be desulfurized by a variety of means; liquid limestone spray, semi-dry rotating spray, seawater, and foreign firms have demonstrated an electron beam removal technology for sulfur. Coal-water slurry firing has been successfully demonstrated at the Baiyanghe Power Station. Three direct coal liquefaction studies by Sino-Germany, Sino-Japan and Sino-American collaborations have proven the

feasibility of the technology. Coal-bed gasification technologies are feasible as well.

Adjustment of Generation Structure

Due to the industrial structure of China industry will remain the largest consumer of energy. Therefore, energy consumption and economic growth will be tightly correlated in the foreseeable future.

Coal consumption accounts for 74% of the energy produced in China, 3 times the world average. The majority of coal is consumed by end-users in secondary processes, such as steel coking. These processes account for 80% of coal use, resulting in tremendous environmental degradation, and restricting the sustainable development of the economy. In the United States end-use consumption of coal accounts for only 10% of coal use. The implementation of the “Air Pollution Act” will force an adjustment in the structure of China’s energy consumption. That using natural gas or electricity converted from burning coal directly raise the ratio of coal using to generate. Using coal and natural gas to produce electricity will reduce the amount of direct coal use by the industrial sector. Approximately six hundred thousand medium and small boilers, burning 300 Mtce coal, will be modified to use natural gas or electricity. Using gas or electricity will result in the electricity demand increase. Although coal will be used to produce the majority of electricity, suitable pollution abatement measures will be installed to reduce emissions to “Air Pollution Act” standards. At the same time increased access to electricity in rural communities will raise the standard of living and the rate of urbanization within the rural community. Due to the changes in energy production and consumption the demand for electricity will be rapidly increasing in the near future. This will result in a shift away from the current technologies which degrade the environment and reduce the quality of life for all Chinese citizens.

Since 1999 the balance has shifted from a lack of supply to a surplus of supply, alleviating the possibility of an electricity shortage. Most regions experience more supply than demand, and generation capacity continues to grow. The average annual using hour of generation equipment of the whole nation decreases annually In 1998 the capacity factor of electricity generators was 51% and declining. However, this situation is temporary. The installed generation capacity is only 0.222kW per capita and electricity consumption 927 kWh/year/person. These figures will increase as China continues to industrialize. Electricity produced from coal is still very inefficient. In China electricity generation from coal requires 404g/kWh, 70g/kWh more than necessary in industrialized countries. Much of the generation equipment is outdated and inefficient. 200 GW of gas fired electricity plants are sub-critical and super-high-pressure units with only 3.90 GW of super-critical units. Electricity producing units are divided into three size categories, <100MW, 100-210MW and >300MW, which each contain 33% of the market. There are 30.5 GW of condensation units producing 50 MW or less, this accounts for 15.3% of the electricity generation units. The environmental problems related to these inefficient and highly polluting

plants is extreme.

Based on the information above the first step in adjusting the energy sector is to adjust electricity structure. China must adopt advanced coal firing technologies. The government and experts agree that we must control the overall amount of coal consumed and accelerate the shift to new technologies. The government and some experts advance that while control the overall amount, accelerate the power to adjust the structure. To control the amount of coal consumed China must regulate the construction of coal firing units with capacity below 300 MW, as well as regulating improvements made to existing units. China must also integrate cutting edge technologies funded with foreign investment and demonstrate super-critical units and clean coal technologies. As for the problem of closing small electricity generation plants the ETC requires that before the year 2003 condensation units with capacities below 50 MW must be closed. The State Power Corporation has formulated and implemented a plan to close small coal electricity power plants. Plants generating 2840 MW were closed in 1999 and in 2000 1800 MW should be closed by the end of the year. By 2003 a total of 12 GW of small, inefficient plants will be shut down. This plan will create space for the construction of high efficiency, low emissions plants to begin the adjustment towards a more environmentally benign electricity generation structure.

In order to realize the sustainable development strategy and accelerate structural adjustment it is necessary to adopt advanced technologies. The most practical and applicable pathway includes accelerating the construction of super-critical units, equipping them with FGD's, and constructing natural gas combined cycle units. Considering Chinese dependence on coal it is also necessary to develop coal gasification technologies and build plants that can utilize that fuel.

Increasing the efficient utilization of coal and reducing environmental pollution have always been in the interest of the Chinese government. In recent years various coal-fired generation technologies have been developed. Different technologies, such as: CFBC, PFBC-CC and IGCC have been studied and applied to coal technology. Moreover, clean coal generation technologies are one of the scientific guide projects of the State Power Corporation which obtains the attention and support of SDPC, ETC and MOST.

Strategy of 21st Century Energy

It is necessary to understand the different facets of China's rising energy demand. The population is demanding more energy as it shifts from a rural to an urban setting. Industry will also require more energy as the economy grows. China will need to make use of international energy resources and use the comparative advantages of China's resources. According to the 21st century energy strategy of China, we must reduce the energy intensity and air pollution and improve energy efficiency. This will help to

ensure China's energy security, reducing the effects of supply shortages and dampening the shock of energy price fluctuations.

The first priority is to diversify the energy supply. China also needs to practice the policy of promoting exchange on the basis of domestic resources. China must utilize the comparative advantage of the vast coal resources within the country. Coal is a labor intensive resource and exports of coal will bring foreign revenue into the country. In the future China should export large quantities of coal, making coal account for 5% of exports in the near future, 10% in the metaphase, and over 20% in the long term. China will become not only one of the largest coal export countries, but also one of the most important energy export countries.

Finally China must plan for the role that oil will play in the future. Oil is of great national importance, it will play a major role in the economic development of the country and measures should be taken to ensure that supplies are available to meet increasing demand. The oil strategy of the 21st century should be to develop and utilize two markets, the domestic market and the international market. The success of this policy relies on making use of the comparative advantages within the oil sector. Maximizing the national interest depends on the comparative advantages, disadvantages and the dynamic movement of various resources of China such as labor resources, natural resources (especially the oil resource), capital resources and technology resources.