Powering Non-Nuclear Growth in China with Natural Gas and Renewable Energy Technologies

by Jeffrey S. Logan and Jiqiang Zhang

ENERGY SHORTAGES IN THE BOOMING EASTERN AND SOUTHERN COASTAL provinces of China have led Chinese planners to consider large additions of nuclear power to fuel future economic growth. This paper demonstrates that a less capital intensive and cleaner solution lies in a combination of natural gas, renewables, and advanced power generation technologies. After introducing the problem, Sections II and III of this paper provide a scenario of how China will most likely meet future power demand. Section IV describes why gas and other power technologies are superior to nuclear power. Finally, Section V presents an alternative scenario that has lower capital costs and fewer carbon and sulfur dioxide emissions.

I. Introduction

Maintaining rapid economic growth while protecting the environment will be a critical challenge for China in the coming decades. Economic reforms initiated in the late 1970s have quadrupled incomes and alleviated some of the grinding poverty across China, but the associated environmental damage has raised local, regional, and global concern. Coal has fueled much of China's remarkable growth: China consumes about 1.4 billion tons of coal each year and relies on coal more than any other country in the world (Table 1). [1]

China's energy resources are also poorly distributed. Most of the country's high-quality coal is currently mined in the north-central provinces of Shanxi, Inner Mongolia, and Shaanxi while demand is heaviest along the southeastern coast. Huge volumes of coal, most of it unwashed and consisting of up to 20 percent inert material, must be transported to these demand centers each year. There is also a general shortage of energy in the coastal provinces: local coal is scarce and of poor quality; hydroelectric power from the southwest and "coal by wire" from the northern coal fields are too distant to be competitive; and imported coal is expensive. Due to these energy imbalances, nuclear power has been proposed as a solution to the coast's future power needs, and China has initiated an ambitious program to plan the construction of forty to fifty nuclear power plants over the coming decades to meet this demand. It is believed that natural gas, renewables, and advanced power generation technologies are superior to nuclear power in China, and that the alternative scenario presented in this paper will also help China develop key high-technology export markets for the future.

II. Future Power Reqirements

Based on a recent study from China's Energy Research Institute (ERI), China's electricity demand growth is projected to quadruple between 1995 and 2020 (Table 2).[2] Much of the growth in power demand is projected to occur in Shandong, Zhejiang, Jiangsu, Shanghai, Fujian, and Guangdong along the eastern coast. This forecast assumes that China will maintain an elasticity of electricity demand of approximately 0.7, far below most developing countries. Indeed, the successful energy conservation program China established in the 1980s has prevented the combustion of additional hundreds of millions of tons of coal each year.[3]

III. Current Baseline Growth Scenario

Based on the country's Ninth Five-Year Plan and current energy policies, future power needs will most likely be met as indicated in Table 3. Power capacity will grow to 725 GW in 2020 from 217 GW in 1995, the equivalent of bringing online a 780 MW plant every two weeks for twenty-five years. Coal use will continue to grow, but its share in supplying total demand

TABLE 1

This article is the second of two which discusses the environmental implications of nuclear power development in China. Please go to the ECSP website at **www.ecsp.si.edu** *to read Yingzhong Lu's article from Issue 1 on "The Role of Nuclear Energy in the CO_2 Mitigation Strategy of the People's Republic of China."*

TABLE 2

TABLE 3

will fall slightly. Likewise, hydropower will achieve a substantial absolute rise in output by 2020, but its share of total demand will fall to 12.5 percent. Nuclear and combined cycle gas technologies will make up for most of the decline in coal and hydropower, generating about 5 percent of the total demand each. Even in this conservative baseline scenario, wind and other renewables will generate a combined 4 percent of the country's electricity in 2020.

Carbon dioxide emissions from the power sector in 2020 will reach 774 million tons of carbon (MtC) per year. Total cumulative emissions over the years 1995 to 2020 will be approximately 12,370 MtC. Cumulative capital investment costs will range from a low of $54 billion over the period 1995-2000 to a peak of $110 billion from 2010-2015. These costs are for generation only and do not include transmission and distribution costs. The total capital requirement over this period will equal $504 billion, or an average of $20 billion per year. This compares favorably with the ERI baseline estimate of $19 billion per year.[4]

One reason coal will continue to generate nearly three quarters of the country's electricity is because China is a world leader in producing 300 MW and smaller coal-fired generator sets. In 1998, capital costs for these units, without sulfur control equipment, averaged about $600/kW, approximately one-third lower than equivalent technology in industrialized nations. China is also developing domestic versions of larger, high-pressure units that are more efficient and more expensive than the 300 MW versions.

The abundance of coal and of these inexpensive small generator sets has rendered coal the lowest cost electricity generation option for much of China. However, one region where coal may not provide the lowest levelized cost power due to high transport costs is along the eastern and southern coasts.[5] As a result, China has an ambitious plan on paper for accelerating use of nuclear power in these fast-growing provinces. Nuclear power may also be able to reduce some of the environmental damage in this region from coal combustion, especially acid rain.

There are currently three nuclear power units in operation in China with a total capacity of 2.1 GW. Four other plants with a combined capacity of 6.65 GW are expected to be on line by 2004 (Table 4). In addition to the plants under construction, the government has stated that it hopes to boost nuclear capacity to 20 GW in 2010, 30 GW in 2020, and 50 GW in 2050. Given the difficulties in financing these plants, however, most independent experts find these targets overly optimistic.[6]

China currently has the capability to domestically manufacture about 70 percent of the components (by value) of advanced pressurized

TABLE 4

water reactor nuclear power systems. It imports the remaining 30 percent of large stainless steel pipes, condensers, and other specialty metals in order to meet technical requirements. The Chinese-manufactured components can be up to 40 percent cheaper than imported equipment, although the quality may also be lower.

Pressurized and boiling water reactors have average capital costs of $1,810/kW in China.[7] These capital costs could drop to $1,400/kW if China learns to manufacture all reactor components domestically, but levelized costs would still be over 40 percent higher than combined cycle systems. In the United States, where the supply of electricity may soon be open to competition, many electric utilities are maneuvering to avoid the "stranded costs" of nuclear power plants that will not be able to compete with other forms of power supply.[8] China should carefully study the reasons that no nuclear plants are, or have been, under construction in countries where competition in the supply of electricity is being considered.

IV. Alternative Energy Possibilities

Natural gas, fuel cells, wind, biomass, photovoltaics, and other renewables could play a much larger role in powering future growth in China. The Chinese government must take an active role in localizing these technologies, increasing their availability, and bringing down their costs.

Natural gas could play a much larger role in China's energy sector, even though it currently accounts for only 2 percent of primary consumption. China's economically recoverable natural gas resources amount to 38 trillion cubic meters[9] (TCM), while proven reserves range from 1.2 to 5.3 TCM. Based on the country's large reserves of coal and oil, most geologists believe there will be more significant discoveries of natural gas deposits in China because the formation processes of coal, oil, and natural gas are so similar.

China could dramatically boost production and use of gas if it had a strong champion within the government. The China National Petroleum Corporation (CNPC), responsible for on-shore gas development, has historically placed petroleum production far above that of gas. Nevertheless, gas consumption, which surpassed 20 billion cubic meters per year (BCMY) in 1997, is conservatively projected to more than triple by 2010 to 70 BCMY and exceed 90 BCMY by 2020. Coal bed methane, imported pipeline natural gas, and liquefied natural gas (LNG) can further add to China's natural gas resource base. Technological, economic, political, and environmental drivers could easily double or triple these figures.

Drivers of Greater Natural Gas Use

Natural gas and other methane-rich gases have distinct advantages over coal. First, a new variety of gas-powered technologies are, or will soon be, entering the market. These technologies are efficient and have low capital costs. China could also lower its bill for imported oil by developing proton exchange membrane (PEM) fuel cells for the booming vehicle market. Greater natural gas use would additionally help alleviate the energy imbalance and supply shortages mentioned

TABLE 5

earlier. Finally, gas is a clean energy source with a minimal number of harmful environmental externalities.

Advanced Technologies

Technological advances are improving efficiencies and lowering capital costs for natural gas-based power systems faster than coal-based ones. Combined cycle gas turbines generate power at efficiencies approaching 60 percent.[10] Efficiencies continue to rise as material properties and overall designs improve. Capital costs for combined cycle units are already competitive with coal-fired systems in the southern and eastern regions of China where coal is expensive.

Levelized costs for a number of power generation technologies are shown in Table 5. Fuel costs for Fujian are used because this province is typical of the rapidly growing, yet energy deficient, coastal provinces considering nuclear power in the future. All data and assumptions used in the levelized cost calculations are presented in Table 8. Natural gas prices for the power sector are assumed to be $3/GJ, a higher level than in most countries.

Combined cycle systems are already easier to finance in many coastal regions.[12] They can be constructed faster and with greater modularity than coal-fired plants, important points in power-hungry and finance-poor China.

A new generation of fuel cells will soon enter commercial markets in developed countries and will help revolutionize transportation and power markets. These devices create electricity through chemical reactions without combustion. They are efficient, super-clean, and can operate on hydrogen, methanol, natural gas, or even gasified coal.

China has the capability to quickly "internalize" these high-value technologies: Chinese scientists have a strong theoretical background in many advanced power generation technologies and China is at a stage of development where infrastructure costs would not be overwhelming. China could help ensure strong growth and a cleaner environment by initiating an accelerated research and development (R&D) program for gas and wind turbines. Other R&D focusing on gasification processes for biomass power; thin film technologies for photovoltaics; and membranes, catalysts, and hydrogen production for fuel cells would round out the program. Institutional barriers such as poor interagency cooperation will be more difficult to overcome than the technical difficulty of making the hardware for these technologies effective.

China could establish more stable export markets without having to devalue the yuan by developing attractive energy technologies for overseas markets. By acting now to begin developing wind turbines, fuel cells, and other advanced power generation technologies, China will ensure greater efficiencies in the domestic power and transportation sector, less environmental damage, and more secure export markets.

Expanding Oil Imports

Rapid economic development combined with stagnating petroleum production forced China to become a net oil importer in 1994. By 2000, forecasters predict the country will be importing nearly 1 million barrels of oil a day (2.1 EJ/year). This figure could rise to 3 million barrels a day by 2010.[13] China is reluctant to use foreign currency to import this much oil, but it has few alternatives. One partial solution would be for the country to begin developing the PEM fuel cell for use in the transportation sector. By initiating fuel cell research and development programs now, China could create a domestic manufacturing base for these fuel cells, leading to decreases in hard currency spending on imported oil, and opening the possibility to export modular fuel cells to other countries. China should also initiate research for clean and inexpensive methods to produce hydrogen, the ultimate source of energy for fuel cells. For example, China already has a strong hydrogen production capability in its fertilizer sector. Given a breakthrough in coal to hydrogen conversion, at least 2,000 small fertilizer plants, mostly fed by coal, could be converted to clean, inexpensive hydrogen production with little investment.

Energy Supply Imbalance

The main coal production areas in Shanxi, Inner Mongolia, and Shaanxi are at least one thousand kilometers from industrial centers such as Shanghai, meaning that China must transport one hundred million tons of coal a year over 500 kilometers. Coal accounts for 40 percent of all commodity shipments on Chinese trains. As a result, passenger and other cargo lines are overburdened. China plans to build more mine-mouth power plants to send electricity rather than coal to consumption centers, but transmission is either too expensive or too inefficient beyond 1,500 kilometers. Greater use of natural gas, coal bed methane, and LNG can reduce this supply imbalance and free up the rail system for people and other commodities. Introducing more gas can also alleviate energy shortages and, consequently, the production losses these shortages cause.

Environmental Benefits

Regardless of combustion method, natural gas emits virtually no sulfur or particulate emissions. An 800 MW power plant burning low-sulfur Chinese coal (1.0 percent sulfur) for one year produces approximately 130,000 more tons of sulfur dioxide than a natural gas plant of the same size. Nitrogen oxides and reactive organic compound emissions are also lower than in coal-fired plants. Carbon dioxide emissions are 60 percent lower per kWh in a 50 percent efficient combined cycle power plant.

Other negative environmental impacts associated with coal plants but largely avoided by natural gas powered plants include particulate and mercury emissions, land subsidence, ash disposal, and thermal pollution.

Sources of Gas

Normally conservative Chinese planners forecast rapid growth in the domestic production of natural gas. New exploration and development technologies ranging from three-dimensional seismic imaging to advanced deepwater drilling processes promise to increase domestic natural gas production. Restructuring the natural gas sector will also give developers incentives to supply more gas. As incomes continue to rise, consumers will demand cleaner sources of energy. Cooperating with multinational gas companies could also help China find, develop, and transport new supplies.[14]

Coal Bed Methane

As the world's largest producer of coal, it is natural for China to take a strong interest in coal bed methane (CBM). Currently recovered volumes of CBM amount to only about 500 million cubic meters per year (MCMY), but reserves are tallied at 35 TCM. A major multinational oil company signed a $500 million contract with the China United Coal Bed Methane Corporation in January 1998 to produce an additional 500 MCMY from coal and gas fields in Anhui province.[15] This area alone is thought to contain more than 60 BCM of methane reserves. Because China's coal mines are extremely gassy and prone to explosions, worker safety and productivity are low. China could raise productivity and reduce the number of miners killed each year by first tapping the methane in these mines.[16] Carbon dioxide injection may be an effective way to produce more CBM in the future while slashing greenhouse gas emissions.[17]

Imported LNG

China has yet to begin importing LNG despite relatively strong potential demand in Guangdong, Fujian, Jiangsu, Zhejiang, and Shanghai. Japan, on the other hand, accounts for over 60 percent of the world's trade in LNG, importing enough of the fuel to power over 25 percent of its electricity generation. Compared to coal-fired plants, LNG-fueled plants would operate at higher efficiencies, require less start-up capital, and create a fraction of the environmental damages caused by coal-fired plants. Levelized cost power would be about the same. As part of the Ninth Five-Year Plan, China began scoping studies to build three LNG terminals in southern China. These terminals could begin operation in the 2002-2005 timeframe. Current technology for producing and transporting LNG is capital-intensive and relies on economies of scale, but much less so than nuclear power.

International Pipeline Trade

Importing natural gas to China via pipeline has received heightened attention over the past few years. With proven reserves of over 56 TCM, countries of the former Soviet Union are a logical first choice of supply. The Irkutsk Basin gas fields near Lake Baikal in Siberia lie about 3,000 kilometers from Beijing. Multilateral discussions are underway over a pipeline that would transport 30 BCM of natural gas per year from Siberia to China's east coast. Talks are also proceeding regarding a pipeline from Kazakhstan that would reach over 6,000 km to China's east coast. A 1996 World Bank study on natural gas trade estimates that the fuel can be brought from Central Asia to China for about $3.00/GJ at the rate of 27.6 BCM per year.[18] Over a distance of 7,600 km, the delivered price would rise to $3.75/GJ. There are barriers to overcome before pipeline projects of the scale mentioned above can be implemented. Financing is probably the most difficult hurdle; even short pipelines (from Siberia or Irkutsk, for example) would cost nearly $7 billion to construct.

Chinese economists realize that the power sector is not the first priority for natural gas use. Since coal use in the residential and small industrial sectors damages human health and the local environment more than in the power sector, switching from coal to natural gas should have priority there. By initiating an accelerated gas development program, however, China could switch over more coal to gas

TABLE 6

than in the baseline case and still have gas available for power generation. Table 6 presents future gas availability estimates in the baseline and accelerated policy development scenarios. We estimate that one quarter of China's gas can be used to generate power without impacting the required fuel switching if supplies are boosted as shown in Table 6. In 2020, this would amount to 90 BCM, or enough to power approximately 85 GW of electric power.

TABLE 7

V. An Alternative Scenario

In the alternative policy case presented in this paper, gas supplies are assumed to reach the total amount indicated in Table 7 and gas-fired and renewable energy technologies are assumed to have been strategically developed with the aid of a strong government policy. Still, coal plays a smaller, yet dominant, role. First, it is assumed that the government will maintain its strong commitment to energy efficiency. Specifically, the elasticity of electricity demand is assumed to decline by 0.5 percent each year from its 1997 level of 0.69. By 2020, these yearly efficiency gains would lower demand by almost 13 percent, from 4,000 TWh to 3,497 TWh. Market forces now entering the Chinese industrial sector, exemplified by the new performance contracting energy management companies, or ESCOs, could help achieve this elasticity reduction at little or no cost.[19]

Coal in this scenario would be used to generate 47 percent of the total demand, significantly less than the baseline case. Hydropower and natural gas account for about 16 percent, while wind and other renewables would each be responsible for about 9 percent. No new nuclear plants would be added and nuclear power's share would decline to under 2 percent.

Cumulative greenhouse gas emissions would be 23 percent lower, amounting to 9,501 MtC. A total of $466 billion in capital investment costs from 1995 to 2020 would be required, $38 billion lower than the baseline scenario. These savings could be used to finance construction of the power sector's share of the needed natural gas infrastructure, pipelines, and LNG terminals. Even if it is assumed that the power sector provides half of this capital investment (while using only one quarter of the output), it could help finance $25 billion worth of domestic natural gas infrastructure, three international pipelines ($10 billion each), five LNG receiving terminals ($400 million each), and $20 billion in R&D for renewables and advanced power generation technologies. Costs to achieve the energy efficiency savings in this scenario, if any, would also come from the $38 billion in capital savings. This scenario would also reduce damage to health and the environment, and position China to be a leading exporter of advanced power generation technologies.

VI. Conclusions

China can meet the rapidly growing demand for power in the coastal provinces by accelerating the development of natural gas, renewables, and other advanced power technologies. Nuclear power cannot compete with these power generation technologies. A champion of natural gas must emerge from within the government to further boost its development and use. The government must also begin developing its educational, training, and R&D capacity so that China can "localize" gas turbine, fuel cell, wind, photovoltaic, biomass, and other renewable energy systems and thus bring down their costs. By acting on these issues now, China will lay the groundwork for a clean future, and secure the high technology export markets that it will need to become a true world power.

TABLE 8

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Endnotes

1 Energy Information Agency, U.S. Department of Energy (Washington, DC: http://www.eia.doe.gov).

2 The Energy Research Institute (ERI) estimated electric power demand for 7 regions in China through 2020 using the MEDDEE/ENV model. For more details, see William Chandler and Jeffrey Logan, *China's Electric Power Options: An Analysis of Economic and Environmental Costs* (Washington, D.C.: Pacific Northwest National Laboratory, 1998).

3 China has held energy growth at half the level of economic growth since initiating reform in the late 1970s. Energy elasticity, defined as the rate of growth in energy use divided by the rate of growth in the economy, is thus 0.5. Without this unique achievement, China would be consuming much more energy than it does today. Electricity elasticity, although slightly higher, is still lower than in most developing countries.

4 ERI assumed a mix of generation technologies with a higher percentage of coal-fired plants in their baseline case, accounting for the difference in the capital investment cost estimates.

5 Levelized cost analysis spreads out all costs involved in building a facility and producing electricity over its life, allow-

ing direct comparison of different generation technologies.

6 *The Economist Intelligence Unit*, "Nuclear Power in China: Slow Breeder," 19 January 1998.

7 Estimates for new plants in the short term by China's ERI and PNNL.

8 Stranded costs refer to economic assets in the electric power sector that would lose a portion of their value in a restructured, or deregulated, environment. In a competitive power supply environment, power generated from nuclear plants and other expensive sources would not be able to compete with cheaper generators using gas and coal. Owners of these assets would not be able to recover their investment costs, leading to "stranded costs."

9 Divide by 35.3 to convert cubic meters to cubic feet. To convert billion cubic meters (BCM) to exajoules, divide by 26.5 (that is, 26.5 BCM = 1 EJ). To convert BCM to Quads, divide by 27.9 (that is, 1 Quadrillion BTU = 27.9 BCM). In general, 1 BCM of natural gas will fuel an 800 MW combined cycle plant for one year at a 70 percent capacity factor and 50 percent efficiency.

10 Lower heating value (LHV) is one of two common measures of efficiency. The lower heating value of the fuel refers to the direct heat energy produced when burning the fuel. Additional energy is available in the form of the condensation heat of steam present in the combustion gases. When this is added to the LHV it yields the higher heating value (HHV) of the fuel. For gaseous fuels, LHV is about 10 percent higher than HHV.

11 Assumes sulfur emission control will be required for all new coal-fired power plants in coastal regions by 2010.

12 See Allen Blackman and Wu Xun, "Climate Impacts of Foreign Direct Investment in the Chinese Power Sector: Barriers and Opportunities," Preliminary Draft (Washington, D.C.: Resources for the Future, November 1997) for a discussion of why combined cycle systems are easier to finance.

13 See David Fridley, "China: Energy Outlook and Investment Strategy," presented at the *Oil and Money Conference*, London, United Kingdom 18-19 November 1997 (Berkeley, CA: Lawrence Berkeley National Laboratory, 1997).

14 Jeffrey Logan and William Chandler, "Incentives for Foreign Participation in Natural Gas Development in China," forthcoming in *China Business Review*, June/July 1998.

15 See "Companies Cooperate to Develop Methane Resources," *China Business Net*, 9 January 1998.

16 Approximately 10,000 coal miners die each year due to explosions and accidents in China's mines.

17 Robert Williams, "Fuel Cells, Coal and China," Paper presented at the 9th Annual U.S. Hydrogen Meeting, Washington, D.C. (Princeton, March 1998) 10-15.

18 MMBtu, or million British thermal units, is a natural gas measure equivalent to 985 cubic feet of gas, or approximately 1 gigajoule. See World Bank, "Natural Gas Trade in Asia and the Middle East," IEN Occasional Paper No. 8 (Washington, D.C.: World Bank, 1996).

19 The Global Environment Facility (GEF) and the World Bank are currently introducing private energy management companies (EMCs) in Beijing, Liaoning, and Shandong. These companies will identify, design and finance energy efficient plant upgrades at host facilities in exchange for a portion of the monthly energy savings, so called "performance contracting."

20 See Debra Lew and others, "Industrial-Scale Wind Power in China" (Princeton, NJ: Center for Energy and Environmental Studies, November 1996).

Environmental Work at the Sinological Institute of Leiden University

Researchers at the Sinological Institute of Leiden University (Holland) are engaged in a number of projects on environmental issues in China:

• Research is currently being conducted on the formulation and implementation of rangeland policy in the Ningxia Hui Autonomous Region. This project attempts to trace constraints in the implementation of rangeland conservation policies, particularly related to desertification of pasture. A quantitative survey of 200 farmers in four counties in Ningxia has been conducted, as well as various interviews with officials and farmers. This research covers ten different villages located in both the desert-steppe region, as well as the loess area of Ningxia. The research is being conducted in cooperation with the Ningxia Science and Technology Commission and the Ningxia Academy of Social Sciences.

• Extensive research has been performed on industrial pollution, water conservation, the rural paper industry, and rural environmental issues in China.

• There are preliminary plans to undertake a project on soil and water conservation policies in China in cooperation with the University of Liverpool and the Chinese Academy of Agricultural Sciences, and to expand research on rangeland conservation to the Inner Mongolian region.

For more information on these projects, please contact Peter Ho of the Sinological Institute at PPSHO@rullet.LeidenUniv.nl.