Why is China going nuclear?

Yun Zhou[*1,2]

[1]Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, 79 John F. Kennedy Cambridge, MA 02138, USA

[2]Center of International Security and Studies at Maryland, School of Public Policy, University of Maryland, 4113 Van Munching Hall, MD, 20742, USA

*Corresponding author. Tel.: +1-917-293-2114; fax: +1-617.495.8963;

e-mail: yun_zhou@hks.harvard.edu

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Abstract

In November 2007, China's State Council approved its "Medium- and Long-Term Nuclear Power Development Plan," which set as a goal to increase the nation's nuclear capacity from about 7 GWe to 40 GWe by 2020. In March 2008, the National Development and Reform Commission suggested installed nuclear power capacity might even exceed 60 GWe by 2020 due to faster than expected construction. Even with this growth, nuclear power's share of China's installed total capacity would be only about 5 percent. Yet China's rapid nuclear expansion poses serious financial, political, security, and environmental challenges. This study investigates China's claim that nuclear energy is necessary to meet its growing energy demands by analyzing China's energy alternatives and assessing their likelihood of contributing to total Chinese capacity. By looking at China's transformative energy policy from several perspectives, this study finds that nuclear energy is indeed a necessity for China.

Keywords: China, Nuclear Power, Coal

1. Introduction

In the past several years China has made an extraordinary commitment to nuclear energy development. It currently has 11 nuclear power units in commercial operation, a small stake compared to the 104 operational reactors in the United States and the 59 operational reactors in France, but its nuclear energy output is expected to grow substantially in the coming decades.

As of 2004, China's nuclear power plants had a capacity of 7 GWe and produced 50.4 TWh, accounting for 2.3 percent of nation's electricity generation (National Bureau of Statistics of China, 2004)**.** A slate of subsequent policy initiatives proposed building on this total. In 2006, China's State Council approved the National Development and Reform Commission (NDRC)'s "Medium- and Long-Term Nuclear Power Development Plan (2005-2020)," which outlined plans to increase the nation's nuclear capacity to about 40 GWe by 2020, raising to 4 percent nuclear's share of the national electricity generation capacity. A 2007 State Council Information Office White Paper, "China's Energy Conditions and Policies," further enshrined nuclear energy as an indispensable energy option**.** Recent reports suggest that the country's installed nuclear power capacity might even exceed 60 GWe by 2020 due to faster than expected construction (China Daily, 2008).

While a 4-6 percent share of national generation capacity would be relatively small, the absolute quantity is remarkably large. To implement the plan, China will have to construct at least three 1-GWe nuclear power units each year for the next 16 years. This is a tremendous growth rate, particularly in contrast to growth in Western countries, many of which have pledged to phase out nuclear power or are waiting for the "nuclear renaissance" to begin.

Such rapid nuclear expansion will affect China financially, environmentally, politically, and even socially. Yet the circumstances under which China has developed these nuclear energy policies are not well understood. Why did China transform its nuclear energy policy so quickly? Is nuclear energy necessary to meet China's huge and growing energy demands? How will the Chinese nuclear expansion unfold? To address these questions requires a review of China's energy profile and challenges, especially coal uses in China, which has dominated China's energy mix for decades and will continue to dominate through 2030. A comparative study between coal and other energy sources cannot be neglected in any China's energy policy studies.

2. Can coal suffice to meet China's growing energy needs?

An increasing demand for coal. Since its economic reforms in 1978, China's gross domestic product (GDP) has grown by about 10 percent per year (Bergsten et al., 2006). This growth has quadrupled China's total energy consumption (National Bureau of Statistics of China, 1978-2006). **Figure 1** shows the total electricity generation and contributions from major generation sources from 1990 to 2009. In 2009, China had a total installed electricity generation capacity of 874 GW and generated 3,650 TWh of electricity (National Bureau of Statistics of China, 2009). The rapid growth in electricity demand spurred significant investment in new power stations. Since 2004, the total installed capacity has increased at an average rate of 90 GWe per year.

Although China's rapid growth in electricity capacity makes it the second largest country for installed capacity and electricity generation in the world, China still suffers from severe power shortages. This is most apparent in the summer, when China's coastal regions have to rotate daily power blackouts in industrial and residential areas to ease electricity load. China is aiming to quadruple its 2000 GDP by 2020, which would be equivalent to a 7.2 percent annual GDP growth rate. Projections for China's 2020 electricity demand range from 2,254 TWh to 5,200 TWh depending on differing assumptions about the relationship between electricity demand growth and GDP growth, and about the electricity elasticity of GDP **(**Li et al., 2004; Hu et al., 2005; EIA, 2006)**.**

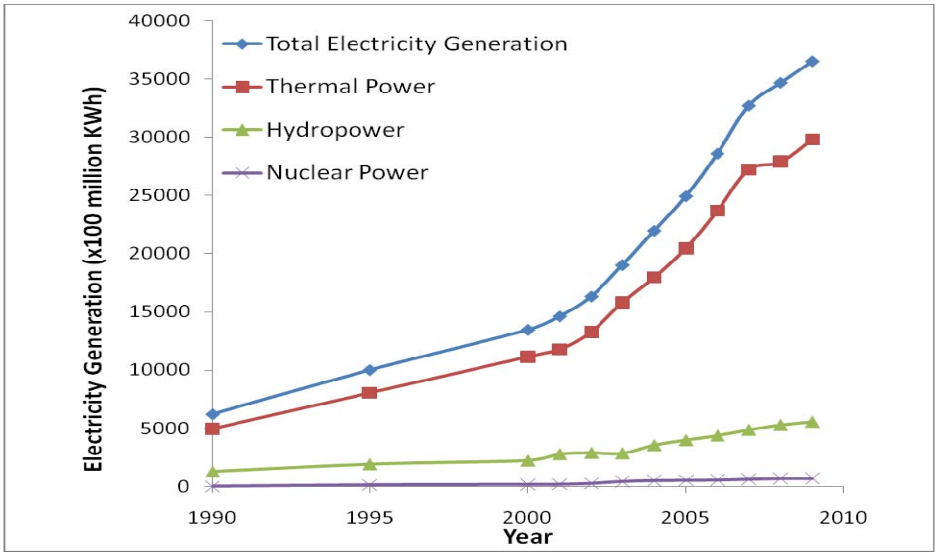

Figure 1. The total electricity generation and components in China from 1990 to 2009

While electricity demand projections are relatively uncertain, coal-fired generation will definitely play a fundamental role in China's energy mix and electricity generation. Coal, as China's primary energy resource, has supported most of it energy growth to date. Coal-fired generation accounted for 80 percent of China's electricity generation in 2007 (National Bureau of Statistics of China, 2007). Another way of characterizing China's dependence on coal is to note that electricity generation is responsible for 68 percent of the increase in coal consumption during the past 15 years; coal-fired generation has met on average 80 percent of increases in electricity demand during the same period **(**National Bureau of Statistics of China, 1990-2007**).** China's reliance on coal is only expected to increase as a consequence of rapid economic growth. Although China aims to reduce the percentage of coal use in its total primary energy consumption from 69.5 percent to 40 percent by 2050, coal-fired power generation will remain dominant.

On one hand ramping up coal generation is a sensible way to address energy demands. Compared with other energy generation options, coal-fired power generation in China has lower investment costs, shorter construction periods, and lower electricity production costs. The pollution penalties for utilities are low, and coal-fired plants often choose to pay the fee rather than invest in cleaner generation technologies. Yet, China's reliance on coal has slowed the diversification of China's energy sector and has caused a range of problems, from heavy air pollution to clogged transportation routes to unsafe coal mines.

China pursues comprehensive energy conservation and efficient energy use to lower its energy demands. China's 11th Five-Year energy development plan aims to limit China's total primary energy consumption to 2.7 billion tons of standard coal by 2010. However, in 2008, China's coal production had already reached 2.72 billion tons of coal, and total energy consumption reached 2.91 billion tons of standard coal in 2008 (see **Figure 2,** National Bureau of Statistics of China, 2003-2009). China's Medium and Long-Term Energy Conversation Plan (2004) warned that when national coal consumption approaches 3 billion tons of standard coal, society and the environment would be pushed to a critical point, posing tremendous costs and pressures on energy infrastructure construction, water resources, transportation capability. Existing environmental problems also would be aggravated to an intolerable level. If China's energy consumption continues to grow at the current pace, continued heavy reliance on coal would result in energy security challenges.

It is not clear that China would expand its domestic coal production to meet demand, even if all the attendant problems associated with coal could be solved. As part of its long-term energy policy, China has said it would like to meet 90-percent of its energy demand with domestic resources and generating capacity. Simply importing coal from abroad to meet its growing energy demand is thus not an option.

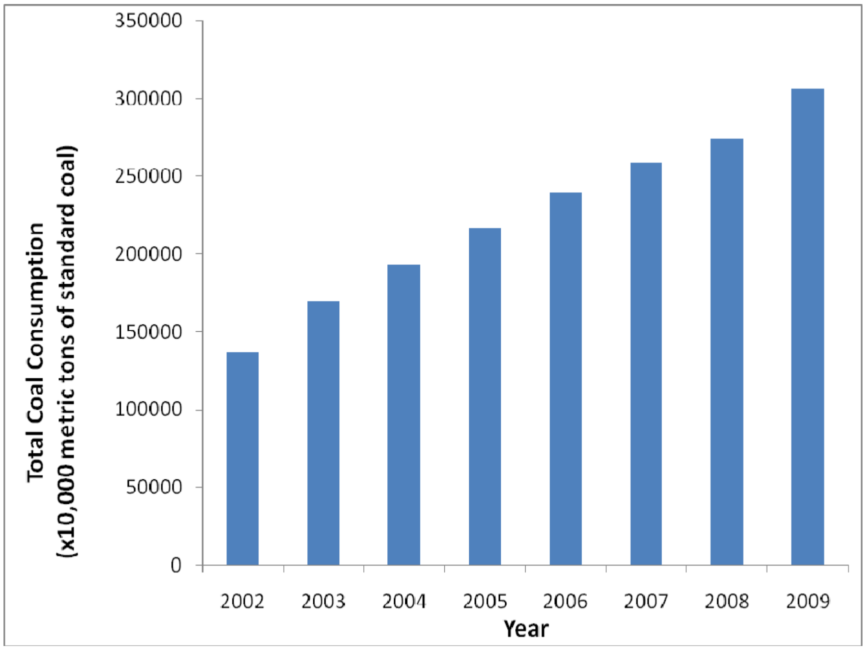

Figure 2. Total coal consumption from 2003 to 2009

Coal Transportation and Price. In January 2008, the worst winter snowstorm in five decades hit central, eastern and southern China. China's coal-dominated energy infrastructure exacerbated the disastrous consequences of the extreme weather. Snow caused bad road conditions that prevented coal from being transported from the inland regions to the major population centers on the coast. The cold weather dramatically increased electricity demand throughout the country. Coal-fired plants in several provinces, such as Zhejjiang Province, suffered a sharp decline in coal reserves. At the shortage's most severe point, coal stockpiles were sufficient to generate only three days of electricity. Some regions had to cut the power supply to their industrial areas to ensure local residents would survive.

Even in good weather, coal transportation is a very serious challenge to China's power industries. Approximately 80 percent of China's coal resources are located in mountainous regions far away from industrial centers and highly populated coastal regions as shown in **Figure 3** (Barlow Jonkers, 2001)**.** Shaanxi, Shanxi and Inner Mongolia, the three largest coal-producing provinces, contribute more than 50 percent of China's total coal output, while coastal regions such as Shanghai, Zhejiang, Guangdong, and Fujian account for a majority of coal consumption. As of 2007, the rail network had the capacity to transport more than 1.17 billion metric tons of coal per year, which amounts to more than 47 percent of the total railway transportation capacity (Xinhua News, 2008)**.** Yet this capacity has proved insufficient to deal with rising coal output (see **Table 1)** and is one of the major factors leading to rising coal prices in recent years (National Bureau of Statistics of China, 2003-2008). From 2000 to 2008, the rate of coal freight carried by national rail grew only 8.8 percent annually, much lower than the 13.7 percent coal production growth rate over the same period (National Bureau of Statistics of China, 2000-2008). The shortage of railway networks, their inferior foundations, and slow renovation schedules suggest that railway transport capacity will remain nearly saturated along all the main coal transport routes for the foreseeable future, except along the Daqin Railway, the largest coal haul railway in China and the railway with the largest annual freight volume in the world (Liu, 2007). The Daqin line uses an electrified double track system with advanced heavy-haul transportation technologies that allowed it to increase its annual load to 300 million tons of freight in 2007. The line is capable of maximally supporting the transport of 400 million tons of freight annually (Xinhua news, 2009)**.** According to the Ministry of Railways, demand for the rail transport of coal is expected to be 1,700-1,800 Mtpa by 2010 and 2,000-2,200 Mtpa by 2020, which is larger than rail capacity is expected to grow in the next decade. Therefore, bottlenecks are expected to persist, particularly in Shaanxi and the central southern part of Shanxi as coal production becomes further concentrated in these provinces and Inner Mongolia (IEA, 2009a).

Figure 3. The map of China's mainland coal resources

Table 1. Total amount of coal transported, coal output and total length of railway routes from 2003 to 2008

Total amount of coal transported by railways (10000 Metric Tons)						
Year	2003	2004	2005	2006	2007	2008
	88132	99210	107082	112034	122081	134418
Change rate		7.7% ↑	7.9% ↑	4.6% ↑	9.0% ↑	10.1% ↑
Total amount of coal output (10000 Metric tons)						
Year	2003	2004	2005	2006	2007	2008
	172200	199232	220472	237300	252597	279300
Change rate		15.7% ↑	10.7% ↑	7.6% ↑	6.6% ↑	10.6% ↑
Total length of railway transportation routes (10000 Kilometers)						
Year	2003	2004	2005	2006	2007	2008
	7.3	7.44	7.54	7.71	7.80	7.97
Change rate		1.9% ↑	1.3% ↑	2.3% ↑	1.2% ↑	2.2% ↑

Until recently, the Chinese government controlled domestic coal prices as a way to guarantee enough cheap resources to support energy use and economic development. The Chinese government shifted course in 1993 and adopted a "dual track" system. At the end of every year, the government announces its "guided" utility coal price, which reflects some increase based on market dynamics but is still below the commercial coal price. Table 2 gives the average coal prices from key state-owned mines under the Dual Track system (Pan et al., 2002-2009). In December 2005, the NDRC went a step further and abolished its use of a guiding price for utility coal. However, electricity prices remained fixed while coal prices soared hurting utility companies. The government **[?]** was forced to temporarily intervene, for example, by capping price increases at 8 percent in 2005 and capping them again in 2008. As demonstrated in **Table 2**, the gap between coal prices for electricity generation and coal prices for other users increased reached 32.4 percent in 2008, which showed the government's continued ability to mediate potential conflicts between coal producers and coal-fired plants. Nevertheless, the government has emphasized that it still plans on liberalizing coal pricing, ending government intervention, and encouraging long-term contracts between utility companies and mines. As part of coal industry reforms, the Chinese government also raised the tax rate for coal resources from 1 percent to 3 percent, and the state council proposed requiring resource-based enterprises, such as the coal industry, to set up a reserve fund system for sustainable development. In addition, the government collects an environmental recovery deposit and contributions to a production safety fund.

Table 2. Average commercial prices of coal vs. prices of utility coal during 2002 ~ 2008.

Average commercial price of coal (Yuan/Ton)							
Year	2002	2003	2004	2005	2006	2007	2008
	168	174	207	270	302	331	463
Increase rate		6.0% ↑	15.7% ↑	30.4% ↑	11.9%↑	9.6 ↑	39.9↑
Average price of coal for electricity (Yuan/Ton)							
Year	2002	2003	2004	2005	2006	2007	2008
	137	139	162	212	216	246	313
Increase rate		1.5% ↑	11.7% ↑	30.9%↑	2%↑	13.9%↑	27.2%↑
Difference between two prices (Yuan/Ton)							
Year	2002	2003	2004	2005	2006	2007	2008
	31	33	45	58	86	100	150
Increase rate		6.5% ↑	36.4% ↑	28.9%↑	48.3%↑	16.3%↑	50%↑

Coal Safety and Environmental Impacts. The central government is simultaneously attempting to reform safety regulations for coal mining. Due to insufficient safety measures and management, nearly 6,000 Chinese coal miners died on the job in 2005. Such accidents are so commonplace that only larger accidents that kill hundreds hit the news (Oster, 2006)**.** Small coal mines are especially dangerous. Because they currently account for about one-third of China's coal production but two-thirds of the deaths in the coal industry, the State Council proposed shutting down more than half of them and bringing their total number below 10,000 before 2010 (NDRC, 2008)**.** Though the campaign might increase safety, it is also likely to reduce total coal output capability by 250 million metric tons and it may take time for large state-owned mines to lift their output to compensate the shortfalls (NDRC, 2008).

While coal output, transportation capacity, and mine safety can be improved gradually, the environmental impact of massive coal use is irreversible and devastating. Coal use is responsible for as much as 90 percent of China's sulfur dioxide emissions and 50 percent of its particulate emissions (Economy, 2007)**.** Coal-generated air pollution has contributed to a recent, sharp rise in the number of people suffering from respiratory illness caused by particulates. Sulfur dioxide discharged from plants has increased acid rain that has reportedly damaged soil quality across one-third of China's landmass; and in 2005, acid rain fell in more than half of the 696 cities and counties under air-quality monitoring (Reuters News, 2006).

The environmental effects of China's heavy coal use are not China's problem alone. Acid rain is already a regional problem in China, South Korea, and southwest Japan **(**Streets et al., 1997). The government estimates that the costs of environmental damage from coal mining, including wasted resources, environmental pollution, ecological destruction, and surface subsidence, total about RMB 30 billion per year (IEA 2009a). In addition, carbon dioxide emissions are impacting global climate. Studies show that China overtook the United States as the largest emitter of carbon dioxide in 2009. According to the Intergovernmental Panel on Climate Change (IPCC), to avoid severe and irreversible consequences to the climate, nations need to stabilize the atmospheric concentrations of carbon dioxide at 550 ppmv (double the pre-industrial level) or even 450 ppmv by 2050. To reach that goal, reductions in annual carbon dioxide (CO_2) emissions need to begin by 2020. China has ratified the Kyoto Protocol so it should be trying to reduce carbon emissions even if the treaty does not mandate reductions for developing countries. In addition, China set as a goal to cut CO_2 emissions intensity by 40–45 percent below 2005 levels by 2020 as part of the agreement to emerge from the 2009 United Nations Climate Change Conference. So far, though, China has failed to lower the environmental costs of its economic growth (SEPA, 2006)**.** Without stronger and more effective measures, China will also fail to achieve the environmental goals of its 11th Five-Year Plan, which is to reduce by 10 percent the emission of major pollutants by 2010.

The sum of these challenges—the rapidly increasing demand for coal, transportation constraints, coal cost increases, and environmental costs—are driving China to diversify its energy resources and to pursue comprehensive energy conservation and efficient energy use.

3. China’s Energy Alternatives

To implement its energy self-sufficiency principle, relieve environmental and social pressures, and promote sustainable development, China needs to develop a range of domestic power generation alternatives. These alternatives have to be economically feasible, environmental friendly, publicly acceptable, and capable of being implemented on a large scale. Of the possible development directions, this analysis examines natural gas, hydropower (and other renewable energy options such as solar and wind), clean coal technologies, and nuclear power.

Natural gas. Natural gas accounted for about 3 percent of total Chinese energy consumption in 2005. The U.S. Energy Information Administration predicts that use of natural gas in China will double by 2010 (EIA, 2005). As part of this growth, China has built several large-scale liquefied natural gas (LNG) power plants in its southern and eastern regions. Compared with coal-fired power plants, LNG plants have a number of advantages. They emit only 42 percent of the carbon dioxide, 21 percent of the nitrogen oxides, and relatively little of the sulfur dioxide that a coal-fired power plant of comparable size does. LNG plants require less human, land, and water resources to construct and operate, which reduces construction investment. Capital costs of LNG plants are one-third lower than those required by similarly sized coal-fired plants. Additionally, the energy efficiency of advanced LNG plants can surpass 55-58 percent, a much higher rate than a coal-fired power plant, and these plants can be deployed on a large scale (Wu et al., 2002).

LNG plants also have several financial limitations. Fuel costs account for 60 percent of the total generating costs of LNG plants. As such, the cost and profitability of LNG power generation is highly sensitive to gas prices. In recent years, natural gas prices have only increased, while the price of coal for electricity generation remained cheap. An example of this imbalance can be found in Zhejiang Province, where the price of natural gas has been more than three times the price of coal, and where the price of electricity from natural gas generation has been twice as expensive as from coal generation. Without strong subsidy support from the Chinese government, LNG plants will have a difficult time competing with coal-fired plants (Wu et al, 2002; Yang et al., 2007; Zhu, 2007).

Insufficient domestic sources of natural gas are another major constraint to its economic viability. Chinese deposits of natural gas are distributed mainly within western provinces. China built a 4,200 kilometer-long pipeline called “west gas transport east” to bring natural gas to eastern regions, such as Shanghai and Zhejiang, yet this infrastructure would not be able to supply the large-scale LNG plants located along the pipeline were natural gas’s contribution to electricity generation to grow.

The lack of domestic supply has forced LNG plants to purchase natural gas from the international market at much higher prices. Without supply stability, many LNG plants have had to shut down after several months of operations. Additionally, natural gas suppliers and consumers typically sign long-term contracts with a fixed price. Under this kind of agreement, suppliers are unable to guarantee the provision of enough gas to meet periods of peak demand, weakening the source’s competitiveness (NDRC, 2006). All of these characteristics suggest that natural gas will not play a key role in reducing China’s reliance on coal and helping it mitigate emissions during the coming decades.

Renewable Energy. Renewable energy accounts for only a small fraction of China’s total primary energy supply. The Chinese government plans to increase the share of domestic renewable energy consumption to 10 percent of total energy consumption by 2010, according to the 11th Five-Year Plan, and it aims for a 30-percent share by 2050 (China Daily, 2007)**.** Due to grid constraints and an insufficient long-distance transmission infrastructure, large-scale implementation of renewable energy will be a challenge, and its role in industrial and highly populated regions will remain limited for the foreseeable future.

One bright spot for China has been wind power. Total installed wind capacity reached 12.2 GW in 2008, exceeding the planned capacity outlined in the 11th Five-Year Plan (NDRC, 2008). Although this rapid growth makes China the fourth largest wind market in the world, only 60 percent of this capacity is connected to grids (Forbes, 2009). Most wind resources are located in the north and the west of China, in areas such as Xinjiang, Inner Mongolia, and Gansu. This poses a huge challenge as the government will need to construct a grid and transmit the electricity generated by wind to the coastal areas where demand is high. In addition, although the recent Renewable Energy Law sets up a preferential price for electricity generated by wind power and priority access for wind power to connect to grids, it doesn't guarantee all electricity generated by renewable resources the priority access to connect to electricity grids. Grid companies don't have financial motivation to accommodate wind power as a non-baseload power source. Extensive policy support and law enforcement are needed to help wind power compete with other energy options. Thus, despite China's excellent wind resources, wind power's total percent contribution to electricity generation will probably remain low, particularly in the eastern coastal provinces.

Although China's solar power potential is enormous, the Chinese solar power industry is in its infancy. Grid-connected solar photovoltaic capacity in China is still marginal, just a few megawatts in 2006 (Martinot and Li, 2007). A large plant tied to the Chinese grid, such as the 1,000-MW plant installed in Germany in 2006, is still at least a decade away, as the cost of solar photovoltaic technology declines further and as conventional power costs rise (Martinot and Li, 2007).

Of the renewable sources available, only hydropower presently makes a significant contribution, accounting for about 16.4 percent of China's total electricity generation in 2008. China has employed hydropower for thousands of years and is currently the world's third largest consumer and producer, after Canada and Brazil. But concerns about the environmental and social impact of implementing further hydroelectric projects might ultimately limit their growth.

China has built small- and medium-sized dams without great environmental and social impact, but its large-scale dam projects, such as the Three Gorges Dam, have been controversial. The Three Gorges project was completed as planned in 2008 and is expected to produce 84.7 billion kilowatt hours of electricity, about one-tenth of China's projected electricity consumption. Critics of the dam allege that it could damage the local environment, culture, and historical resources by, for example, changing the course of the Chang Jiang River, affecting water quality and local climate, and inducing biodiversity loss. Between 1.2 million and 1.9 million people have already been forced to leave their homes and resettle elsewhere as a consequence of the dam's construction (Schreurs, 2007)**.**

Strong public opposition has slowed down several other large-scale hydroelectric projects, including the Nu River project, and has made future development uncertain. Another potential challenge for hydropower is that most plants are located in western regions. As discussed previously, transmitting energy and electricity from western regions to the east has the potential to aggravate pressures on the environment and transportation infrastructure.

Advanced-Coal and Decarbonization Technologies. In recent years, the Chinese government has improved its advanced coal technological capabilities, including clean coal power technology, pollution-control technology, coal gasification technology, coal liquefaction technology and coal gasification-based co-production technology and deployed certain technologies, such as pollution-control technologies. For example, the total installed capacity of flue gas desulfurization technologies increased from 53 GW in 2005 to 270 GW in 2007, accounting for more than 50 percent of total installed thermal power capacity (Wang et al., 2008).

However, the development and deployment of coal gasification, coal liquefaction and coal gasification-based co-production technologies are still very limited due to weak technological innovation capabilities. In addition, due to insufficient regulation enforcement and lax emission standards in China, the deployment of pollution-control technologies did not necessarily control the increase of pollutant emissions. For example, even though a lot of flue gas desulfurization units have been installed in coal-fired plants, it is not clear that the equipment is always in operation (Zhao and Gallagher, 2007). Enforcing regulations and standards, raising regulatory standards, and improving monitoring measures remain huge challenges. Since coal will continue to dominate China's energy mix for decades, decarbonization technologies cannot be ignored as a part of the solution. Innovative decarbonization technologies are well understood but have yet to be demonstrated together at commercial scale. The cost of capturing, transporting, and disposing of carbon dioxide is still high, and the environmental impacts are largely unknown. Decarbonization technology is still a far way from the deployment stage. Liu and Gallagher (2009) briefly described three phases for the development and deployment of carbon capture and storage (CCS) technology in China. By 2020, pilot-scale demonstration projects should start up, and early commercial deployment might be possible. By between 2020 and 2030, CCS could be a commercialized technology for an emerging low-carbon economy. Beyond 2030, the adoption of CCS could become standard practice for all large stationary fossil fuel installations.

4. The Nuclear Energy Option

The development of additional nuclear energy capacity in China promises to overcome many of the barriers that confront the energy sources discussed above. Though China's reliance on nuclear energy has been limited to date, it has built an extensive industrial base of nuclear and technical capabilities that is poised to support substantial growth.

China built its first heavy water research reactor and cyclotron in 1958 and connected its first indigenously designed, constructed, and managed pressurized water reactor to its electricity grid in 1991. Since then, nuclear power growth has been slow. In 2004, China's nuclear power plants produced only 50.4 TWh of electricity, accounting for 2.3 percent of national generation. In comparison, South Korea's and Japan's nuclear power sectors account for 40 percent and 30 percent, respectively, of total electricity generation.

In contrast to other potential energy sources, nuclear reactors are a fully developed and low-carbon emission electricity generating option that has the potential for large-scale expansion. Despite the large cost of nuclear power plants, China's booming economy has helped to ensure enough capital investment for planned projects. The ongoing global finance crisis has affected China, but it did not decrease Chinese investment in nuclear energy development. Instead, the government has increased the amount of financial aid and guaranteed loans for the nuclear industry. China has not participated any international nuclear liability regime, but China set up its nuclear insurance pool in 1999, which is a community comprising 15 major non-life insurance companies and four reinsurers.

Nuclear power could be cost competitive with other forms of electricity generation, except where utilities have direct access to low-cost fossil fuels, such as coal and natural gas. Yes, the cost of building nuclear power reactors is relatively high, but the operating costs are relatively low. Additionally, nuclear fuel costs are a minor portion of total generating costs, while they make up 40 and 60 percent of costs for coal-fired and LNG plants, respectively. This insulates the price of electricity generated from nuclear reactors to fuel price escalation. Standardized designs, shorter construction times, and high capacity factors have also lowered reactor construction costs to the point that even without environmental subsidies, nuclear reactors can be competitive with other power options over the their operating lifetimes (WNA, 2008). For example, when the price of coal for power generation reaches 400 Yuan/Ton, domestically designed nuclear power plants with construction costs of $1,300 per kilowatt could compete economically with coal-fired power generation in China's coastal regions, regions that don't have direct access to coal resources (Wen, 2005). The Westinghouse AP1000 design follows the simplification principle by decreasing the number of components, including pipes, wires, and valves, which helps to reduce the time and cost of construction. This simplification is one of the major reasons that Westinghouse won its bid in 2005 to construct two nuclear power plants in Sanmen and Haiyang, China.[1] Of course, no vendor can guarantee that new and more standardized designs can be built at a lower cost than previous designs. If China's AP1000 project succeeds, it would be a good demonstration of the economic advantages of standardization and serial construction. Environmental subsidies and related policies, such as a carbon dioxide tax, could be introduced in China, which would make nuclear power even more economically competitive.

Nuclear energy has several other practical advantages for China. Nuclear fuel, predominantly comprised of uranium, has the advantage of being a highly concentrated source of energy that requires less transport capacity. For example, a 1-GWe pressurized water reactor refills only one third of its fuel assemblies per year, and the total quantity of fuel is much less than the amount of coal or oil needed to generate an equivalent amount of energy. Additionally, extreme weather or seasons affect nuclear power plant operations very little.

Adequate and affordable uranium resources form the foundation of China's proposed nuclear expansion. China's estimated uranium resources, about 100,000 tons (CAEA, 2007), should enable it to satisfy uranium demands for the next decade.[2] To meet its longer-term needs,

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[1] Personal communication with personnel from the Institute of New and Nuclear Technologies at Tsinghua University and the China National Nuclear Group (names withheld by request), January 2008

[2] The annual mass of fuel, in metric tons of heavy metal (MTHM), which must be loaded into one PWR reactor is obtained as:

it will need to strengthen its domestic uranium exploration and mining capacity**.** The China National Nuclear Group, the only state-owned nuclear corporation with uranium exploration and mining capabilities, recently announced that it had verified a large uranium ore deposit in the Inner Mongolia Autonomous Region. And it claims that the amount of newly proven uranium found each year in China outpaces the country's growing demand. Assuming it will be able to mine and process these deposits at a reasonable pace, the group expects to be able to fuel Chinese nuclear power development for the long run (Xinhua News, 2008). In addition the IAEA's *Uranium 2007: Resources, Production and Demand*, also known as the "Red Book," shows that an estimated 5.5 million tons of global uranium resources exist, 130 times the global production of uranium estimated for 2007 (IAEA, 2008). Unconventional uranium sources, such as those in phosphate rocks and in seawater, are available to explore when cheap uranium sources become scarce and uranium prices increase. In addition to using natural uranium

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$$M = \frac{P \times CF \times 365}{\eta_{th} \times B}$$

where
M: mass of fuel loaded per year (NTHM/year);
P: installed electric capacity (GWe)
CF: capacity factor
η_{th}: thermal efficiency (GWe/GWth), and B: discharge burnup (GWd/MTHM). In this paper, the installed capacity of 60 GWe is assumed in 2020; the capacity factor is 85 percent; the thermal efficiency is 33 percent; and the discharge burnup is 50 GWd/MTHM. From the calculation, China needs 7090 tons uranium fuel from 2006 to 2020 with considering initial fuel load for new installed capacities.

The mass of natural uranium required for fuel production can be obtained by considering the enrichment process. The required enrichment level for a given burnup can be calculated given the amount of feed material (natural uranium 0.711%) by**:**

$$F = p \times (\frac{x_p - x_w}{x_f - x_w})$$

Where;
x_f = weight fraction of U-235 in the natural uranium; here, x_f = 0.711%
x_p = weight fraction of U-235 in the enriched uranium fuel; here, x_p = 4.5% for the time period of 2006-2020.
x_w = weight fraction of U-235 in the waste stream; here, x_w = 0.3%
F = the amount of natural uranium
P = the amount of product enriched
From the calculation, China needs 72318 tons natural uranium from 2006 to 2020.

resources, a number of Chinese researchers are looking at the reprocessing of spent nuclear fuel and advanced nuclear technologies, such as fast breeder reactor designs, as a way to significantly extend existing uranium supplies. Uranium resources are thought to be geographically more evenly distributed than any other energy resource, though a relatively few countries—including Australia, Canada, and countries in Central Asia, hold the largest shares of the most economical, high-grade uranium ores. Given this distribution of uranium resources, the risk of supply disruption is minimal as compared to oil and natural gas reserves, which are concentrated in the Middle East (EIA, 2009). In addition, countries can maintain stockpiles of nuclear fuel with relative ease, given that uranium fuel storage requires far less space than for fossil fuels. Lastly, nuclear fuel costs are only about 5 percent of total generating costs, while fuel costs for coal-fired and natural gas-fired plants make up 40 percent and 60 percent of costs, respectively (NEA, 2008). All of these arguments suggest that the availability of nuclear fuel should not constrain future nuclear expansions.

Building enough new nuclear power plants and operating them long enough to make a significant contribution to China's growing energy needs will require greater acceptance from the Chinese public. Public opposition has been a major impediment to nuclear development in the West, but as a consequence of China's relatively centralized government and government-driven economy, the Chinese public is typically informed of nuclear decisions only after they are made. Chinese authorities are taking steps to increase public involvement in nuclear energy decisions. The State Environmental Protection Administration, China's top environmental body, recently initiated limited public involvement in the nation's environmental impact assessment process. Local governments are now required to release environmental impact assessment reports and allow public feedback during a public comment period before starting construction of large-scale projects. This system has so far been ineffective and inefficient. Gradually, public participation on nuclear projects should improve because of improved regulatory transparency.

In general, the Chinese public seems willing to accept and embrace nuclear technologies and the role they will play in the country's continued development. Further nuclear development, for instance, is likely to provide thousands of jobs in local communities, which has set off a scramble among local governments eager to have nuclear power plants built in their regions. In contrast to Japan, for example, where local officials have fought to keep nuclear facilities out of their regions, local Chinese officials believe that nuclear power can positively impact the local economy, increase the local tax base, and resolve electricity shortfalls and have aggressively initiated cooperation with nuclear investment corporations, such as the China National Nuclear Group.

Still the government knows that a single nuclear safety accident could adversely affect public opinion. China's record of nuclear power operation is relatively clean, and keeping it that way is a priority for Chinese officials. By building on its existing safety culture and the new passive safety features of Generation III reactors, China hopes to maintain its safety record. Significant human resources will be needed to support the implementation of China's aggressive nuclear energy policy. As part of its military-related nuclear program in the 1950s, China had a strong nuclear technology workforce made up of technocrats, engineers, designers, and researchers. China's modest nuclear energy industry, however, couldn't sustain interest in the field. Low student demand forced many universities that had trained the initial nuclear workforce to cancel their nuclear engineering programs. Today, only a few Chinese universities have nuclear engineering programs. The Chinese nuclear industry is well aware of these problems and is attempting to ensure the necessary workforce for future nuclear energy development.[3] Universities are pitching in by launching new nuclear engineering programs. Some of these programs matriculate junior students from other engineering majors and offer one-year professional training programs focused on nuclear science and engineering. These students are often offered work in nuclear power plants directly after they graduate. Nuclear power plants pay competitive wages and offer excellent benefits in order to keep talent, yet it remains to be seen whether personnel who undergo such a short training program will be able to maintain current quality standards. These recruitment programs do not address the need for high-level research and development personnel to work on core areas, such as nuclear reactor design. One significant potential barrier to the impact of new nuclear power plants is the time it will take for these plants to come online. Three nuclear expansion scenarios present themselves as possibilities. The first scenario is the reference case and is based on China's current long-term nuclear power plan, which anticipates that nuclear power will have a 20-percent share (the current world nuclear share) of the total national installed capacity by 2050. The second scenario is a high-growth scenario, which anticipates continuous nuclear expansion and nuclear to have a 30-percent share of installed capacity by 2050. The third scenario is the low-growth scenario, which anticipates a 10-percent nuclear share by 2050. These scenarios assume that the nuclear growth will take the form of additional 1 GWe pressurized water reactors and that Generation IV reactors will be developed to the point that they are commercially deployable by 2040.

5. Meeting Rising Demand

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[3] "The Challenges and Countermeasures for Human Resources Development on Nuclear Power in the 21st Century" Presentation delivered by SNERDI at "International Conference on Opportunities and Challenges for Water Cooled Reactors in the 21st Century" Vienna, Austria. October 2009.

For a country like China, there is no single approach to accomplish the goals of reducing environmental issues and ensuring energy demands at the same time. It’s hard for one particular technology alone to ease all issues on a timescale or size scale. Of all the energy technologies discussed, nuclear has the clearest potential to contribute to increased Chinese demand and climate change mitigation strategies. Nuclear should not be left out of China’s energy mix. But how much can nuclear contribute? The current average installed capacity in countries part of the Organization for Economic Cooperation and Development is approximately 2.1 KW per capita (IEA, 2009b). Assuming that 20 percent of China’s population will reach this level of industrialization by 2050, and the remaining part of the population will reach half this level by the same time, China will need an installed capacity of 1,800 GWe to satisfy the demands of its expected 1.5-billion strong population. This is near the middle point of projections used in other studies, which range from 1,200 GWe to 2,300 GWe (Zhao et al., 2000; Wen, 2005; Liu et al., 2006)**.** The nuclear growth laid out by Chinese planning documents and the reference scenario above could contribute substantially to Chinese efforts to meet this growing demand. But this growth will depend on China ramping up what has essentially been a modest industry that has never before been incorporated into national economic planning. And there is still the question of whether China can manage the technological, financial, and social challenges associated with nuclear expansion while simultaneously addressing proliferation, waste disposal, and safety concerns.

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