Coal Initiative Reports

White Paper Series

▸ Coal in China: Resources, Uses, and Advanced Coal Technologies

Guodong Sun,[1] *Energy Technology Innovation Policy Group, Kennedy School of Government, Harvard University, Cambridge, MA*

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PEW CENTER ON Global CLIMATE CHANGE

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Executive Summary

China's energy-development pathway has increasingly become a topic of international attention, particularly as China has become the largest national source of annual greenhouse gas (GHG) emissions. At the forefront of this pathway is a reliance on coal that has spanned many decades. In a world faced with increasing environmental pressures, China must develop ways to utilize coal more efficiently and more cleanly. Its ability to do so will be crucial for its domestic energy security, for its local environment and the well-being of its population, and for the future of the global climate.

China became the world's largest coal user in 1986 and has been on top ever since. In 2007, China's coal consumption was about 41 percent of world's total, more than two times that of the second largest user, the United States.[2] Coal has dominated China's primary energy supply since the rapid industrialization that began there in the 1950s. A priority of China's energy policy since the 1980s has been to reduce the reliance on coal to relieve the heavy burden of coal transportation, to reduce environmental pollution associated with coal production and use, and more recently to bring down coal-mining fatalities. But the share of coal in total primary commercial energy has never fallen below 60 percent. A further drop in this share will be challenging in the foreseeable future because the potential for substituting other energies for coal is limited.

About half of China's coal is consumed for electricity generation. China's efforts in increasing electricity supply have led to record-speed expansion, with coal-fueled power plants dominating new capacity additions. China's future technology mix depends on the fate of small coal-fired units which are being phased out in conjunction with energy efficiency efforts, and on China's prospects for acquiring and employing advanced power generation technologies, especially advanced coal technologies. Ultra-supercritical pulverized-coal (USC-PC) technology will likely become more popular in the absence of severe power shortages. The prospects for integrated gasification combined cycle (IGCC) and poly-generation technologies have become much better in recent years. With current environmental policies controlling sulfur dioxide (SO_2) and nitrogen oxide (NO_x) emissions not stringently enforced and mercury not yet regulated, IGCC currently has no economic advantage over USC-PC technology. But all major power producers have initiated their own IGCC projects, with at least three of them using domestically developed coal-gasification technologies. China will gain tremendous experience in the design, manufacturing, construction, and operation in both USC-PC technologies and IGCC technologies after the first batch units are in service. China's coal industry has tremendous interest in poly-generation because it converts coal to high-value chemicals and brings in more profits.

The use of coal-based liquid fuels will further drive coal consumption to higher levels in coming years. Coal-to-liquid fuels (CTL) have a long history in China that started in 1937, but most CTL facilities were closed in the 1960s after the large Daqing oil field was discovered. In the early 1980s, China's interests in CTL technologies were reactivated because of a wave of research and development (R&D) efforts and breakthroughs in industrialized countries in the aftermath of world oil crisis. Both direct and indirect coal liquefaction technologies have been pursued in China. After China became a net oil importer in 1993 and as both foreign-oil dependence and oil prices quickly rose, the Chinese government made more investment in R&D for CTL technologies. Many companies have launched technology demonstration and commercial projects in recent years. While future climate policies will have enormous impacts on their viability, climate risks have been largely ignored to date.

A number of organizations in China have started to conduct research on carbon-capture technologies including oxy-fuel combustion, membrane separation, and chemical looping combustion. Most of these efforts are driven by needs from industries (for instance, producing carbon dioxide [CO_2] for enhanced oil recovery) or researchers' interests in advanced technologies. But experience and technological progress will help China to prepare for a carbon-constrained future. While China has large clusters of CO_2 emission sources, including high-concentration sources with geographical proximity to prospective geological storage sites, no reliable estimate of the storage capacity is available. There is an urgent need for detailed geological assessments that can quantify China's CO_2 storage capacity. Such assessments will be crucial for long-term energy planning.

Tremendous efforts have been made to pursue the development of advanced coal technologies in China through indigenous innovation and international technology transfer. A number of key issues, however, remain. First of all, the threat of global climate change is not among the major forces that have shaped China's innovation agenda for advanced coal technologies. Improvements in energy efficiency will help to reduce China's CO_2 emissions, but improving efficiency alone is not sufficient to meet the ultimate goal of preventing dangerous anthropogenic interference with the climate system. The second major issue is that while the central government has improved its understanding of the long-term challenges facing China and the need for advanced energy technologies to effectively address them, many of China's energy policy measures are not backed with sufficient financial resources. Current government support for advanced coal technologies is much higher than before, but still needs to be increased to a level that can have more meaningful impacts on firms' technology choices. Until then, they will continue to favor options that have less technological uncertainty and better market potential in the near-term.

Introduction

China has the largest population in the world, about 1.3 billion in 2005 or 20 percent of the world total. It also has the fourth largest economy in terms of gross domestic product (GDP), or the second largest in terms of GDP adjusted for purchasing power parity (PPP) after the United States.[3] China has been among the most rapidly growing economies for nearly three decades. From 1980 to 2005, China's real GDP has increased at an average rate of 9.5 percent per year. But China is still a developing country. Its per capita GDP was US $1,714 in 2005 and it has about 220 million people living on less than one dollar a day.[4] Continued strong economic growth is essential to lifting the poor out of poverty, to sustaining the rising living standards of the others, and to creating enough employment opportunities for millions of people joining the workforce each year.

China is the second largest energy user in the world following only the United States, and the third largest energy producer following the United States and Russia. In 2007, it consumed about 78.3 Exajoules (EJ) of primary energy or 16.8 percent of the world's total.[5] But China's per capita energy use (58.8 Gigajoule [GJ], or 1.4 ton of oil equivalent, in 2007) is still below the world average (71 GJ), and is only one sixth of the U.S. level (332 GJ).

Energy demand will continue to increase in the coming decades as strong economic growth continues, as living styles very likely become more energy intensive, and as more people gain access to modern energy services. The International Energy Agency (IEA) has projected that China's primary energy demand will more than double from 73 EJ in 2005 to 160 EJ in 2030. During this time period, China will account for one third of the increase in worldwide energy demand.[6]

An overarching goal of China's energy policy has been to quadruple the GDP in twenty years from the level in 2000 while only doubling its energy use, thereby limiting energy demand under 80 EJ by 2020. To achieve this goal requires an average annual energy-demand growth rate of less than 3.5 percent between 2000 and 2020. But energy use surged during 2000 and 2007 at an average annual rate of 9.8 percent, and almost doubled in seven years. This implies that either energy demand has to stop growing over the next 13 years or China needs to set a more realistic goal.

Coal Utilization in China

CHINA'S ENERGY MIX

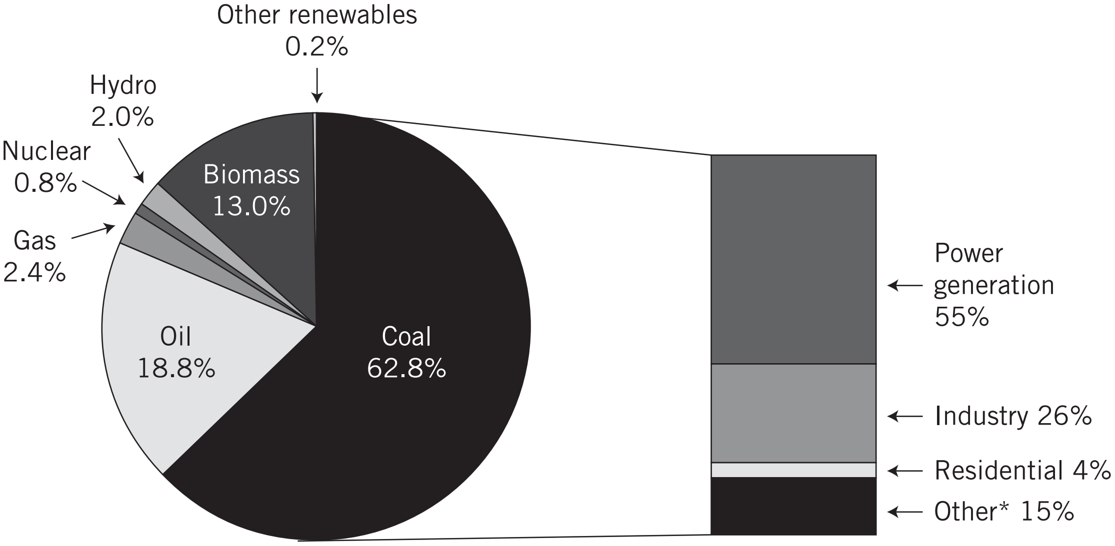
China became the world's largest coal user in 1986 and has remained on top ever since. In 2007, China's coal consumption was about 41 percent of world's total, or more than two times that of the second largest user, the United States.[7]

Coal has dominated China's primary energy supply since industrialization began in the 1950s. In the 1950s, over 90 percent of the primary commercial energy was from coal. Its share dropped to about three quarters in the late 1980s as the contributions of oil, hydro-power, and natural gas increased. This trend has accelerated since then because of the rapid increases in oil consumption and primary-electricity generation (mainly hydropower and nuclear power). From 1990 to 2005, primary commercial energy use increased by 127 percent while total petroleum increased by 190 percent, and primary electricity by 258 percent.[8]

A priority of China's energy policy since the 1980s is to reduce reliance on coal to relieve the heavy burden of coal transportation, to reduce environmental pollution associated with coal production and use, and more recently to bring down coal-mining fatalities. But the share of coal in total primary commercial energy has never fallen below 60 percent, and any further drop will be difficult. Diversification away from coal is challenging since China lacks oil and natural gas resources. With only 1.4 percent of world's proven oil reserves and 1.2 percent of natural gas reserves (and a likely peaking of domestic conventional-oil production in the next one to two decades), new increases in oil and natural gas demand will be largely met with foreign resources and will further elevate China's oil dependency, which exceeded 52 percent in 2007.

China has 378 Gigawatts (GW) of exploitable hydropower resources and may be able to develop a significant amount of this, assuming that sufficient financial resources and technological capacity are available, and that relocating millions of farmers and concerns over ecological consequences do not lead to major political barriers. Nuclear power has great potential in displacing a large fraction of coal, but this potential is unlikely to materialize in the near future. A research team at Tsinghua University evaluated the energy options to meet the goal of capping China's CO_2 emissions at 7.7 Gigatons (Gt) by 2050. It found that about 653 GW of nuclear power is needed to generate 4,569 Terawatt-Hours (TWh) of electricity in 2050.[9] This cannot be adopted as a practical goal unless major breakthroughs in fast breeder reactor technology, which is still at the early stage of development, can be achieved. To build 653 GW of nuclear power capacity over 45 years is also a great challenge to China's finance, engineering, equipment manufacturing, and construction capabilities, which are barely able to support 2 GW per year at present.

Figure 1. Coal in China's Primary Energy Demand (2005)[10]



* Other includes other energy sector, transport, services, agriculture, non-energy use and non-specified.
Note: Total Primary Energy Demand in 2005 = 1742 Million Tons Oil Equivalent (MTOE)

COAL RESERVES AND DISTRIBUTION

The volume, quality, and geographical distribution of coal reserves throughout the country have important implications for China's energy policy, and for technology strategies in the coal industry and in major coal-consuming industries such as power generation, and coal-chemical production (including converting coal to liquid fuels).

China's coal resources are concentrated in a small number of regions (Figure 2). The northern regions (i.e., north of Kunlun Mountain-Qinling-Dabieshan line) account for over 90 percent of China's accumulated proven coal resource (APCR).[11] Around 58.5 percent of these are located in the region between Taihang Mountain and Helan Mountain in northern China, which include the Provinces of Shanxi, Shaanxi, Ningxia, Henan, and the southern part of Inner Mongolia. Outside this region, Xinjiang, situated in the far west, accounts for 11 percent of the total. Three southern provinces (Sichuan, Guizhou, and Yunan) have 8.7 percent of China's APCR.

About 89 percent of China's APCR is located in regions to the west of Great Xingan Ridge—Taihang Mountain—Xuefeng Mountain line. The concentration of coal resources in a small region is further complicated by the fact that the major economic hubs and population centers, and as a result the large energy-consuming centers, are situated far from these resources, primarily in the coastal areas of eastern and southeastern China. While about half of China's population lives in the eastern coastal provinces, over 95 percent of China's coal resources are found outside of this coastal region.

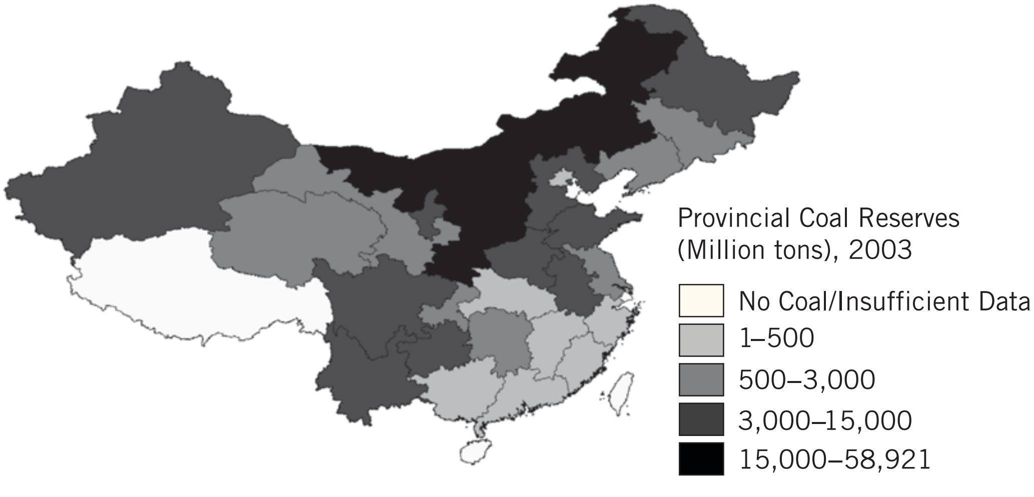
One consequence of such uneven regional distribution of supply and demand is that coal must be transported long distances before it can reach the end user, an average of 400 kilometers. While coal-transportation normally utilizes about half the capacity of the railway system and is given higher priority over other businesses at times of high coal demand, the railway system has been a constant bottleneck in the supply chain. China finished an exclusive coal-transportation line (Datong-Qinhuangdao) that links the largest coal-producing region, Shanxi, to a seaport in Hebei province in 1992. Its original capacity was 50 Million tons (Mt)/year, but by 2005 this had quadrupled to meet the soaring demand for coal. Continued growth in the demand and the increasing need for reliable transportation have resulted in dedicated railway lines for each of the ten major coal-production areas, which form a key component of China's railway expansion plans.

Coal is also transported by heavy-duty trucks, which have grown into a huge burden on the highway system. This problem has led local authorities to limit, or even ban, coal trucks. The transportation of coal over long hauls also consumes a large amount of liquid fuels and has been criticized for consuming high-quality fuels (liquid fuels like diesel and gasoline) to transport low-quality fuels (i.e., coal).

Uneven distribution of water resources is another constraint. Coal-fired power plants consume large amounts of fresh water. In 2005, the average water use rate of thermal power plants was about 3.1 kilograms/kilowatt-hour (KWh).[12] A typical 1,000-Megawatt (MW) power plant consumes about 20 Mt of fresh water a year. The geological distribution of China's water resources—rich in the east and the south, but poor in the north and the west—is contrary to that of coal resources. The northern region has over 90 percent of China's coal resources, but only 20 percent of the water resources. Northwestern China, where the five coal-richest provinces (Shanxi, Shaanxi, Ningxia, Inner Mongolia, Xinjiang) are located, has China's most arid climate and the least water resources. The China National Administration of Coal Geology surveyed the water resources in the 13 major coal-mining areas, and found that local resources can only meet half of their water demand.[13]

This contrasting distribution pattern has important implications for regional planning (for example, conservation of constrained water resources and the fragile ecological system in China's major coal-producing areas) and for technology choice for new power plants. From the sole perspective of water use, USC-PC with air-cooling technology and IGCC have significant advantages over other coal-fired power generation technologies.

Figure 2. China's Coal Reserves by Province[14]



DEMAND FOR COAL

Nearly 97 percent of China's coal is consumed in five sectors: power generation, industrial sectors, coking, residential use, and heating supply.[15] Power generation has been the largest coal-consuming sector since 1995 when it overtook the industrial sectors. Since 1990, at least 40 percent of the incremental increase in coal consumption is attributed to the power generation sector. When China's total coal use dropped from 1998 to 2000, it was the only sector whose coal use significantly increased. The power sector's increasing share of coal use will likely continue in the coming decades.

Within the industrial sector, cement, steel, and chemical fertilizer production are the major coal users. China also has about a half million industrial boilers. Their average capacity is about 2.5 ton-steam/hour; and average efficiency is about 65 percent while their design efficiency is 72 to 80 percent. These industrial boilers are major sources of local air pollution including SO_2 and particulate matters. Environmental regulations have been poorly enforced in these industrial sectors.

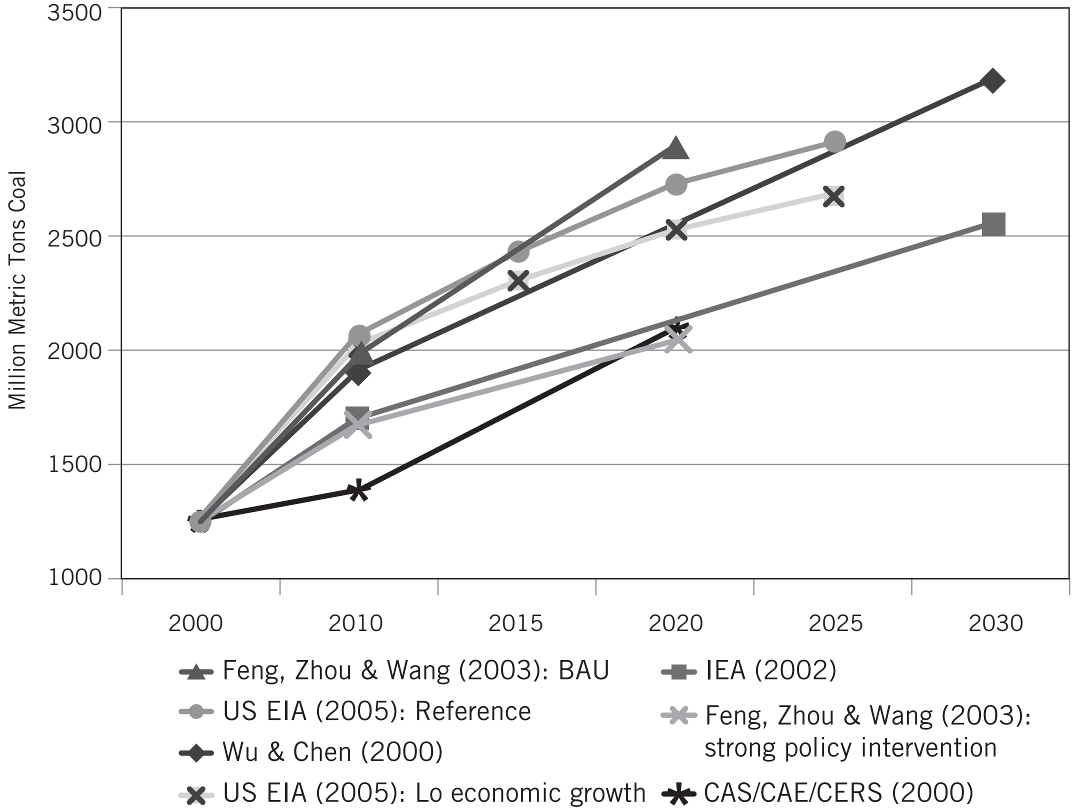
Residential consumption is the only sector where coal has a shrinking market. Coal consumption in this sector peaked at 175 Million tons in 1988 and has experienced constant decline since then. In 2003, residential energy consumption accounted for about 5 percent of total coal use. But it is still a major source of indoor air pollution. Because of its proximity to humans, residential coal use contributes disproportionately to people's exposure to pollutants associated with coal use including particulate matter, sulfur dioxide, and arsenic.

FUTURE DEMAND FOR COAL

It is difficult to predict future coal consumption in China with great accuracy. The future market is subject to a number of uncertainties, including those related to economic growth, energy, and environmental policies. Inaccuracy in coal statistics, due to a variety of political and technical factors, imposes additional challenges to establishing a reliable starting point for projection. For instance, from 1999 to 2001, China's actual coal consumption may have been underestimated by as much as 20 percent because local governments under-reported, or did not include, outputs from small coal mines in their statistics in response to a central government policy to limit their production.[16] The IEA estimates that in 2000 China consumed 899 Million tons of Coal Equivalent (Mtce), and 1563 Mtce in 2005.[17]

Figure 3 summarizes the key findings from several major studies conducted within the last ten years. They were designed and conducted by organizations both inside and outside China, and for purposes including long-term energy and environment planning, and near-term coal market forecasting. These projections have a large variation because of different underlying assumptions. Despite this variance, the studies all lead to the conclusion that China's coal consumption will increase significantly in the coming decades, and that a large fraction of the increase in the world's coal demand over this period will come from China.

Figure 3. Scenarios of China's Future Coal Consumption[18]



Note: Wu & Chen data and 2000 base year data converted from tons of coal equivalent to metric tons of coal at 5000 kcal/kg-coal.

COAL AND CARBON EMISSIONS

China's reliance on coal has contributed to its large share of global CO_2 emissions. According to the Carbon Dioxide Information Analysis Center (CDIAC), coal consumption contributed to 72 percent of China's CO_2 emissions associated with energy use in 2004.[19] Coal-related CO_2 emissions may rise to 5,887 Mt in 2025, at which time they will account for 15 percent of the world's total energy-related CO_2 emissions, or will be 1.5 times the combined emissions of western European countries.[20]

Advanced Coal Technologies for Power Generation

Since the advent of economic reforms in late 1970s, great efforts have been made to develop China's electricity industry. Total installed power generation capacity increased from 66 GW in 1980 to 319 GW in 2000. From 2001 to 2005 alone, 176.55 GW of new power generation capacity was added.[21] Over 100 GW were added in China in 2006, the largest year-on-year increase ever recorded in China, or in any nation in the world.[22] According to a report from the China Electricity Council (CEC), total installed capacity reached 713 GW at the end of 2007: 554 GW of thermal power (coal, oil, and natural gas), 145 GW of hydro-power including pumped-storage, 8.85 GW of nuclear power, and 4.03 GW of wind-power.[23]

TECHNOLOGICAL STATUS OF COAL-FIRED POWER PLANTS

A variety of advanced power generation technologies have been developed, imported, and adopted in China. The first 200-MW coal-fired power generation unit was put into operation in China in 1972, and the first 300-MW unit in 1974. Both units used technologies developed indigenously. In the early 1980s, China acquired licenses and know-how for 300 MW and 600 MW sub-critical technologies from several foreign companies. Using both indigenous and imported technologies, about 170 300-MW units and seven 600-MW units were manufactured and installed by the end of 2000. During the process, Chinese companies accumulated significant experience in the design, manufacturing, and operation of large-scale sub-critical units.

Super-critical technology was first introduced into China in the late 1980s. Two 600-MW units from ABB[24] were put into operation in 1992. Several companies based in Shanghai participated in their design and were provided with most of the design software. With support from the central government during the 9th Five Year Plan (1996–2000), China's first domestically-manufactured super-critical unit was put into operation in 2004. China's experience in 600 MW sub-critical technology facilitated the move to super-critical technology. Since the mid-1990s, each of the three major manufacturers of steam turbine and boilers, Shanghai, Dongfang, and Harbin, organized joint-venture companies with foreign technology providers to work on super-critical technologies. China added an additional 18 GW of super-critical power capacity plants in 2006, bringing total super-critical capacity to about 30 GW. There are about 100 GW of super-critical capacity on order, implying that the share of super-critical technology in new capacity will increase significantly over the next few years. As a result, the IEA expects the average efficiency of coal-fired power plants will improve from 32 percent in 2005 to 39 percent in 2030.[26]

China's first power plant using ultra-supercritical pulverized-coal (USC-PC) technology, Yuhuan Power Plant of the Huaneng Group, began commercial operation in December 2006. All of the five largest power generation companies have their own USC-PC units. Rapid deployment of USC-PC technologies is partially due to limited availability of good sites for large-scale coal-fired power plants, which require easy access to coal, water, and sufficient environmental capacity. A typical ultra-supercritical unit has a capacity of 1,000 MW, which is much larger than a sub-critical unit, and allows power generation companies, who are vigorously competing with each other to expand their total capacity, to use the sites more efficiently.

Table 1. China's Thermal Power Generation Units with 6 MW/unit or larger

	2002		2005	
	Number of units	Capacity (GW)	Number of units	Capacity (GW)
600+ MW	26	15.6	84	55.5
300–600 MW	278	86.0	450	144.1
200–300 MW	248	51.3	255	53.0
100–200 MW	456	54.4	573	70.9
6–100 MW	5,026	87.5	5,619	100.6
Total	*6,034*	*294.8*	*6,981*	*424.1*

Source: CEC 2005 Yearbook, and State Power Information

Table 1 provides China's total number of power generation units, and their combined capacity, by unit size. By the end of 2005, China had 104 thermal power plants at GW-scale and their total capacity was 145 GW. Of the 129.3 GW of capacity increase between 2002 and 2005, large units (300+ MW) account for 98 GW, or 76 percent.

The increasing use of larger and more efficient units has contributed to a significant improvement in the efficiency of China's power generation. The average heat rate of thermal power plants has dropped from 427 grams of coal equivalent (gce)/kWh in 1990 to 357 gce/kWh[26] in 2007.[27] CEC's survey in 2005 found that the average heat rate of power plants was 329 gce/kWh for those using 600 MW units or larger, and 340 gce/kWh for those with units between 300 and 600 MW. Small units have a very high heat rate, 428 gce/kWh for power plants with 50- to 100-MW units, and 443 gce/kWh for units smaller than 50 MW.

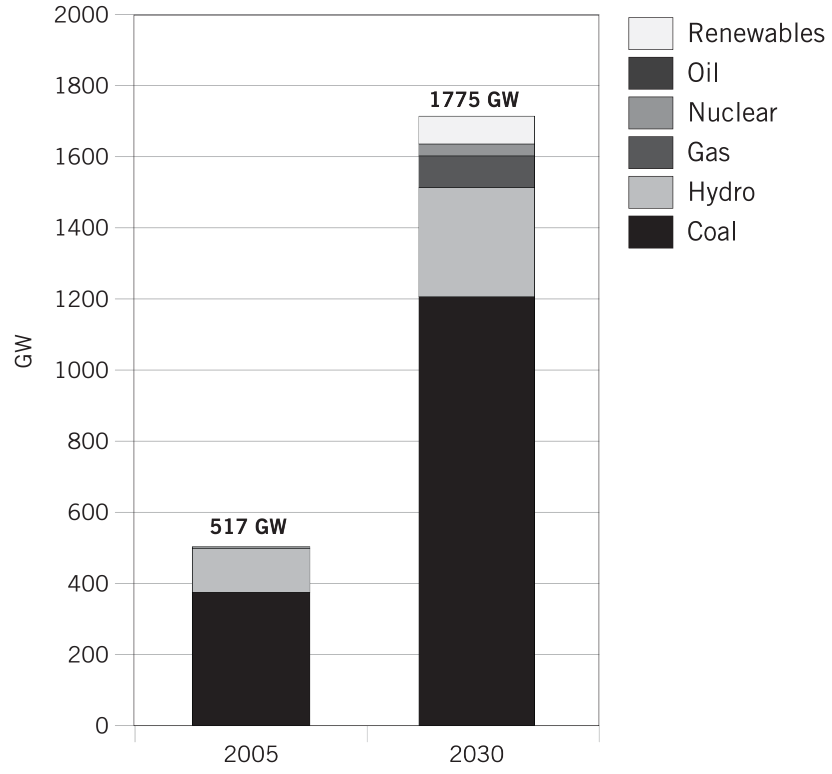
Substituting larger units with advanced steam conditions for these small units has been a major component of China's recent energy efficiency efforts, though cycles of power shortages have resulted in limited implementation. Severe power shortages in the late 1980s and early 1990s caused the government to put energy efficiency concerns aside, and gave small units an opportunity to grow. When the power supply situation improved significantly in the late 1990s, with large surpluses experienced in some regions, the central government took advantage of this opportunity to launch its first serious attempt to close the less efficient plants. In 1999, the State Economic and Trade Commission implemented a policy with the primary goal of retiring coal- and oil-fired units with capacities of less than 50 MW by 2003.

This policy was again pushed aside when another round of power shortages started in 2002. Great energy-saving potential still exists with large power generation units. There were 191 300-MW steam-turbine units in service at the end of 2002. Of them, 177 units were domestically manufactured with either licensed technologies or indigenous technologies, and normally have heat rates that are about 20 gce/kWh higher than those of imported units. Technologies developed by Chinese companies are available to lower their heat rate by 10 gce/kWh or more.

FUTURE SCENARIOS FOR CHINA'S POWER SECTOR

The 2003 China Energy Development Report had projected that electricity demand would increase to 2,830–2,970 TWh in 2010, and projected China's total installed power generation capacity would reach 600 GW in 2010 and 950 GW in 2020.[28] But actual generation and capacity far exceeded these projections. China's electricity generation reached 3,256 TWh in 2007, and total installed capacity reached 713.29 GW.[29] The IEA's 2007 World Energy Outlook projects that China will have 1,775 GW of installed capacity by 2030, as illustrated in Figure 4.

Figure 4. China's projected Power generation Capacity (2005 and 2030)[30]



Note: Coal capacity for 2005 includes some other thermal power sources.

The future technology mix of China's coal power fleet depends on a number of factors, including the fate of its small and inefficient units, and its success in acquiring and employing advanced power generation technologies.

A recent measure adopted by the central government to facilitate energy efficiency targets by reducing the operation hours and in some cases shortening the life of these less-efficient units. In April 2006, eight ministries, including the National Development and Reform Commission (NDRC), requested that local governments speed up their progress in shutting down small condensing steam-turbine units and oil-fired units. An NDRC document articulated a specific goal of forcing 15 GW of coal-fired units (50 MW/unit or smaller) and 7 GW of small oil-fired units to retire by 2010.[31] To improve the implementation of these policies, the central government has attempted to link the political future of local government officials and business managers with their performance on energy efficiency. In July 2006, at the request of the central government, thirty provinces and fourteen enterprises that are directly managed by the central government (including the five largest power companies) submitted a written commitment to meet the energy-efficiency goals set by the central government for 2010.[32]

ADVANCED POWER GENERATION TECHNOLOGY

An assumption in Wu and Chen's study is that power generation efficiency will increase to 42 percent by 2050 because of the use of advanced power generation technologies, including coal-fired units with advanced steam conditions (super-critical and ultra-supercritical), integrated gasification combined cycle, and natural gas combined cycle.[33] These technologies are high on China's technology innovation agenda. Both the High-Tech Research and Development Program (the "863" Plan) and the National Basic Research Program (the "973" Plan) have identified advanced coal technologies as a high-priority area for government support.

During the 10th Five Year Plan period (2001-2005), the 863 Plan invested about 320 million Yuan in clean-coal technologies, which included ultra-supercritical technology, pollution control technologies for coal-fired power plants, integrated gasification combined cycle technology, and coal poly-generation technology. These highly competitive 863-Plan grants, which are regarded not only as financial support but also as a recognition of the awardees' technical leadership, leveraged about one billion Yuan of investment from industry and local governments.

Significant progress has been achieved in a number of areas. A poly-generation system that employs a coal-slurry, entrained-flow gasification technology developed by Shanghai Science and Technology University was put into operation in Shandong Province in 2005. A two-stage dry feed gasification technology is in field-test stage and has been adopted in a demonstration project named GreenGen, China's counterpart of US Department of Energy's FutureGen. A grant from the 863 Plan also played an important role in building China's first coal-fired power plant using ultra-supercritical technology (26.25 MPa/600°C/600°C), and in the development of several SO_2 and NO_x control technologies.

It will take several years for some of these technologies to have a significant impact on the technology mix of China's coal-fueled power generation fleet. Increasing pressure from the central government to mitigate SO_2 emissions will facilitate the adoption of SO_2 control technologies. Ultra-supercritical technologies will become more popular in the absence of severe power shortages, which are thought unlikely in the near future due to rapid capacity expansions over the past five years. An absence of power shortages opens the door for the central government to have more political willingness, in the face of less opposition, to implement the forced early retirement of small power generation units, and to seriously enforce other energy-conservation policies and environmental regulations.

One of IGCC's primary advantages is that it emits fewer conventional air pollutants than traditional coal plants. With current environmental regulations for SO_2 and NO_x not sufficiently enforced in China, and CO_2 and mercury not yet regulated, IGCC has less of an economic advantage over ultra-supercritical technology. But IGCC has made significant progress since 2006. With financial support from the Ministry of Science and Technology under the 863 Plan, three IGCC projects were launched to demonstrate coal-gasification technologies developed in China. Huaneng will use the two-stage dry feed gasification technology developed by Thermal Power Research Institute in a 250 MW unit in Tianjin. Huaneng also signed an agreement with Tianjin Municipal Government to build two more IGCC units (400 MW each) in Phase II. Huadian, another major power producer, will use the coal-slurry, entrained-flow gasification technology developed by Shanghai Science and Technology University in a 200 MW project in Hangzhou. The most recent one is a project in Guangdong Province that will use a fluidized-bed gasification technology developed by Institute of Engineering Thermophysics. Other major power producers also have IGCC projects at various stages of development.

China's IGCC plants will benefit from recent success in poly-generation projects. The coal industry has tremendous interest in this technology because it can bring more profits to coal-mining companies that can convert their coal to high-value chemicals. But it is unlikely that poly-generation technology will be used to generate a significant amount of electricity. In the near future, poly-generation plants face major institutional barriers to entering the electricity market. In the longer term, it is not clear whether users of poly-generation technologies will be willing to deal simultaneously with both regulated markets (electricity) and deregulated markets (chemicals).

Advanced Coal Technologies for Transportation Fuels

China has a long history of producing liquid fuels from coal. China's first coal-to-liquid (CTL) facility started operations in 1937 in a chemical plant in Jinzhou. China also tested a Fischer-Tropsch (F-T) process in the early 1950s. But most of China's CTL facilities were closed in the 1960s after the discovery of the large Daqing oil field.

RESEARCH AND DEVELOPMENT IN CTL TECHNOLOGIES

In the early 1980s, China's interests in coal-to-liquid (CTL) technologies were reactivated by a wave of research and development (R&D) efforts and breakthroughs in CTL technologies in a number of industrialized countries in the aftermath of world oil crisis. Since this time, both direct and indirect coal liquefaction technologies have been pursued in China.

A direct coal liquefaction (DCL) laboratory was established within the China Coal Research Institute during the 6th Five Year Plan (FYP) period (1981–1985) with support from the State Planning Commission, the Science and Technology Commission, and the Ministry of Coal Industry. In the two following FYP periods (1986–1995), this laboratory conducted a series of R&D work including coal screening to identify suitable DCL feedstock, process development, and catalyst development. Collaborating with foreign technology providers, this laboratory also conducted, in the late 1990s, market studies of three DCL technologies in China.

Until the early 2000s, China's R&D in indirect coal liquefaction (ICL) technologies was concentrated in the Shanxi Institute of Coal Chemistry (SICC) of the Chinese Academy of Sciences. SICC first developed a fixed bed Fischer-Tropsch process and conducted the field test on a 2,000 ton-coal/year unit in 1993. With low oil prices in the following years, neither government nor business had interest in supporting its scaling-up and demonstration. In 1997, SICC started work on slurry bed F-T process and made a series of breakthroughs in catalysts and reactors. It also built a 1,000 tons-coal/year unit in 2002 to test these new technologies.

However, these two organizations lacked both the financial and engineering capabilities to move their technologies into the market (or even to the demonstration stage). China's efforts in CTL were limited at the R&D stage until Shenhua Group, China's largest coal mining company, took a strategic move into the CTL business in 2000. Shenhua's DCL plant in Inner Mongolia will be China's first CTL project.

Shenhua's choice of DCL technology instead of ICL has been questioned outside the company. A major concern is that DCL's high CO_2 emissions and lack of flexibility to be retrofitted to capture CO_2 will put the CTL plant into a very difficult situation if China decides to mitigate its CO_2 emissions. DCL was chosen because of the production-cost advantage: about 2000 Yuan/ton for ICL and 1300–1500 Yuan/ton for DCL. The potential future cost of the CO_2 emissions was not factored into the assessment.

CTL DEMONSTRATION AND COMMERCIAL APPLICATION

Following Shenhua's DCL project, a number of CTL projects were initiated. Sasol of South Africa is negotiating with NDRC to develop two CTL plants with a combined capacity of 6 Mt/year. Yanzhou Coal, China's second largest coal mining company, is planning to build an ICL plant with an annual production capacity of about 880,000 tons F-T diesel. Shenhua's goal is to increase its CTL capacity to 30 Mt/year (including one of the Sasol projects) by 2020.

These efforts to develop CTL are mainly driven by market forces and governmental policies. First, large coal-mining companies have become more interested in liquid fuels, other coal chemicals, and electricity businesses, which are more profitable than coal-mining alone. There are also a growing number of such companies that have gained the capability to enter the coal-chemical business because of a government policy that encourages the merger of traditionally small coal mines. Another factor is that their efforts are encouraged and supported by the local governments, which can expand their tax base and retain more profits from large coal-mining companies after the central government transferred their ownership to them in the 2000s. High oil prices worldwide in recent years also played a significant role.

These new projects, however, face major barriers to entering the transportation fuel markets, which are predominantly controlled by a few large and vertically-integrated oil companies. These companies have refused to open their retail system to methanol from CTL plants. Eliminating this entry barrier will likely require the involvement of the central government. At very high oil prices, coal-based methanol has become competitive with conventional gasoline even in regions like Shanghai, where coal prices have also been very high. In 2005, it was well known that some independent gas stations secretly blended methanol into gasoline. While it is likely that the central government will remove this barrier when CTL plants start to produce alternative fuels, it has failed to signal such a move and reduce the uncertainties in the planning and development stages.

Carbon Capture and Storage

Coal use is responsible for the majority of China's CO_2 emissions. Coal for electricity generation contributes around 40 percent of China's CO_2 emissions annually. Carbon capture and storage (CCS) is the only option that can reconcile a scenario in which China will continue to rely on coal to meet its energy needs and China may have to mitigate its CO_2 emissions in the future.

The three major approaches to CO_2 separation and capture that can be applied to a coal system are (1) post-combustion separation where CO_2 is separated from flue gases produced in the combustion of coal in air; (2) oxy-fuel combustion, which burns coal in oxygen instead of air, producing a mixture consisting predominantly of CO_2 and water vapor that can be separated; and (3) pre-combustion separation where CO_2 is separated from reformed syngas from the coal gasification processes. A variety of capture technologies are commercially available and have been used at large industrial facilities to separate CO_2 streams. Amongst them, the monoethanolamine (MEA) process, a chemical absorption process, can be used to retrofit pulverized-coal power plants; and the Selexol or Rectisol processes, both physical absorption processes, can be applied to gasification-based systems. In addition to sorbents and solvents, membrane separation is also a preferred method to separate a high-pressure stream. The capture efficiency of a current commercial CO_2 capture system is in the range of 85 to 96 percent. It can reduce the CO_2 emission per kWh by 63 to 94 percent for existing PC power plants, 81 to 88 percent for new PC plants, and 81 to 91 percent for new IGCC power plants.[34]

A carbon-capture system reduces the energy efficiency and increases the cost-of-electricity (COE). The types of carbon capture technology and power generation technology used are the two major factors that determine the magnitude of COE increase. The cost of adding a capture system to a pulverized-coal power plant ranges from 18 to 34 US $/MWh, and for IGCC power plants, 9 to 22 US $/MWh.[35]

A number of organizations in China have started to conduct research on carbon-capture technologies including oxy-fuel combustion, membrane separation, and chemical looping combustion. Most of these efforts are driven by needs from industries (for instance, producing CO_2 for enhanced oil recovery) or researchers' interests in advanced technologies. But experience and technological progress in these fields will help China to prepare for a carbon-constrained future. For example, the Nanjing Chemical Industry Corporation developed an improved MEA to recover CO_2 from flue gas, in which MEA and steam consumption are reduced by 77 percent and 37 percent, respectively. This technology has been applied in an industrial facility.[36]

China's interests in enhanced oil recovery (EOR), enhanced coal-bed methane (CBM) production, and products requiring CO_2 as feedstock have led to modest research, development and demonstration efforts in CO_2 utilization. Notable among these efforts were the following:[37]

- In 1994, a CO_2-flooding experiment for EOR was finished in Daqing, China's largest oil field since the 1960s.
- Another CO_2-flooding experiment was conducted in Shuangjing, Jilin, in 1994. Each ton of CO_2 injected yielded 3.3 tons of oil.
- A CO_2-flooding experiment started in 1996 in the Fumin Oil Field of Jiangsu indicated that it can increase oil production by 2.09 percent.
- CO_2-capture systems were installed in the oil refinery and fertilizer plant of the Zhongyuan Oil Field. Their combined capacity was 50 ton-CO_2/day and the capture cost was 210 Yuan/ton-CO_2.
- In 2003 China also tested the use of CO_2 to enhance CBM production in the Qinshui Basin.

While these efforts were not motivated by a concern for or policy on climate change, they produce knowledge that will be useful to future large-scale CO_2 storage. At the very least, they generate information that can be used to inform China's policy debate on carbon capture and storage.

China's coastal region has one of the four largest clusters of large stationary CO_2 emission sources (>0.1 $MtCO_2$/year) in the world. China also has good prospects for geologic CO_2 storage. There is also a cluster of high-concentration (>95 percent) CO_2 sources reported to be in close geographical proximity to prospective geological storage sites.[38] If these reports are proven accurate, this poses an excellent opportunity for carbon capture and storage.

Despite the potential proximity of storages sites to CO_2 emissions sources, no reliable estimate of the geological storage capacity in China is available. Furthermore, capacity estimates without detailed geological assessments (including examining seismic and well data) are of limited value. Detailed geological assessments are needed to quantify China's storage capacity.

Summary and Conclusions

China's goal of increasing the use of advanced coal technologies is clear. Tremendous efforts have been made to pursue these technologies through indigenous innovation and international technology transfer.

A number of key issues, however, remain. First of all, the threat of global climate change is not among the major forces that have shaped China's innovation agenda for advanced coal technologies. The three major forces have been oil security, energy efficiency, and local environmental pollution. Improvements in energy efficiency will help to reduce China's CO_2 emissions. But improving efficiency alone is not sufficient to meet the ultimate goal of preventing dangerous anthropogenic interference with the climate system.

The second major issue is that while the central government has improved its understanding of the long-term challenges facing China and the need for advanced energy technologies to effectively address them, many of China's energy policy measures are not backed with sufficient financial resources. Current government support for advanced coal technologies is much higher than before, but still needs to be increased to a level that can have more meaningful impacts on firms' technology choices. Until then, they will continue to favor options that have less technological uncertainty and better market potential in the near-term.

Appendix I—Characteristics of Chinese Coal

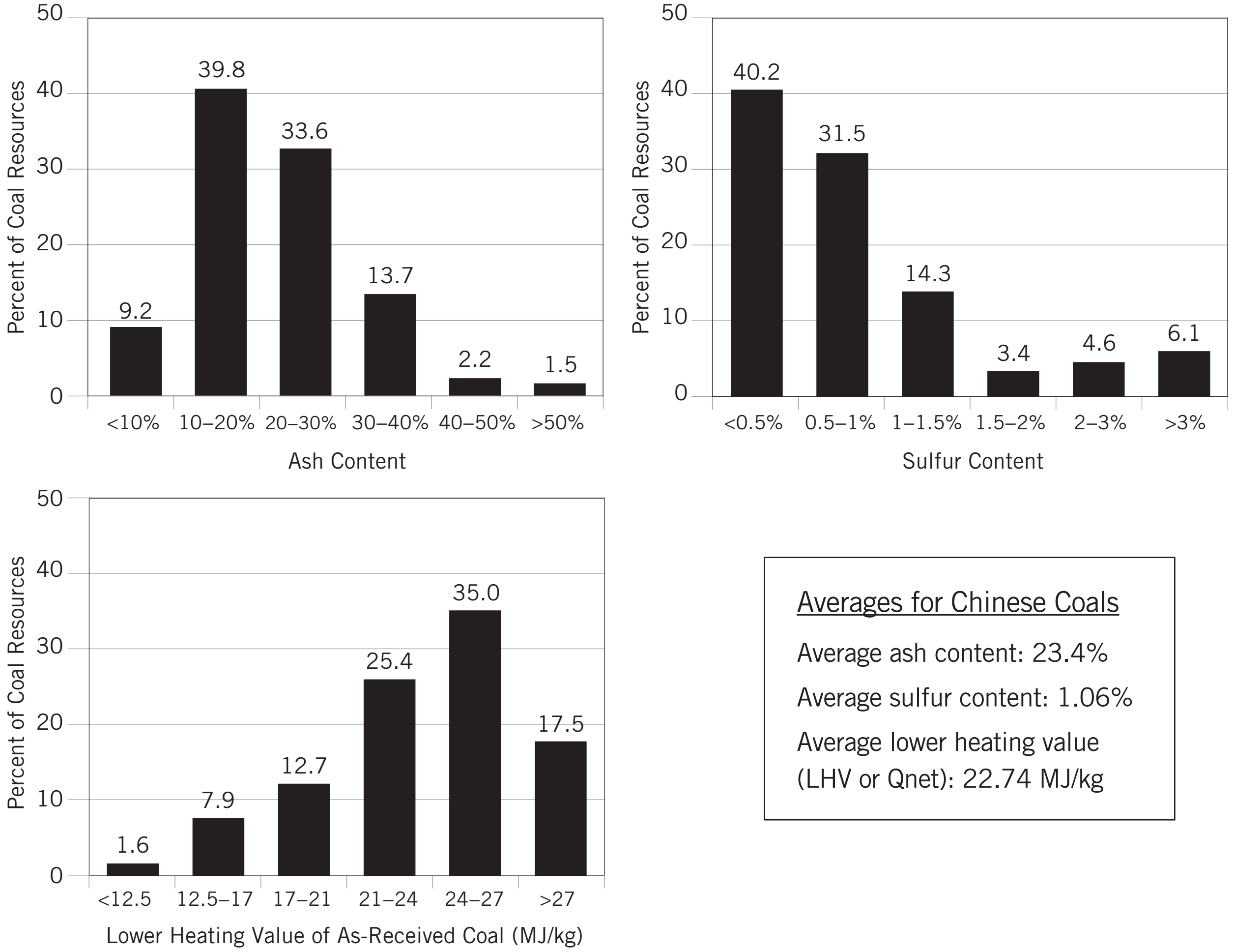
China's coal resources cover the entire spectrum of coal formation (or coal rank), from lignite to sub-bituminous to bituminous to anthracite. Lignite accounts for about 12.7 percent of accumulated proven coal resources (APCR). Sub-bituminous has the largest share, about 42.6 percent of APCR. Only 27.6 percent of APCR is suitable for coking, or can be classified as metallurgical coal. The remaining resources include meager coal and anthracite coal.

A characteristic of Chinese coals, which is critical to technology choice, is that they, on average, have high ash content, high ash fusion temperature (AFT), high inertinite content, and low sulfur content.[39] Average ash and sulfur contents of Chinese coals are 23.4 percent and 1.06 percent, respectively. More details about their distributions are in Figure 5. The average lower heating value (LHV or Qnet) of Chinese coal is about 22.74 MJ/kg on an as-received basis.[40]

As ash content increases, the efficiency of the combustion, gasification, and direct liquefaction processes drops. Ash fusion temperature (AFT), which is largely determined by ash composition, is a characteristic more important to gasification than to combustion. But different gasification technologies have different requirements. Coal with an AFT higher than 1500°C is difficult for use in entrained flow gasifier with a slugging process. A fluidized bed gasifier needs the AFT to be above 1100°C.

Two major constituents of dry and ash-free coal (i.e., pure coal) are vitrinite and inertinite. Inertinite macerals are denser, poorer in volatile matters, and less reactive than vitrinite maceals. Coal with high inertinite macerals needs more time, and hence larger reactors, to achieve a specific conversion rate. For Chinese steam coal, about 29.5 percent of its pure coal is inertinite by volume. This share is much higher than that of North American coals that are dominated by vitrinite macerals ranging from 50 to 90 percent.[41]

Figure 5. Characteristics of Chinese Coals



Averages for Chinese Coals

Average ash content: 23.4%

Average sulfur content: 1.06%

Average lower heating value (LHV or Qnet): 22.74 MJ/kg

Appendix II—Coal Resource Statistics

A review of the available statistical data on coal resources in China requires a close examination of the definitions of the various data categories published in Chinese resource assessments. In many cases these categories differ from international convention, and as with many Chinese energy statistics, inferences about uncertainty can be drawn from statistical collection methods.

COAL RESERVE ESTIMATES AND ACCOUNTING

In 1992, the State Planning Commission and the Ministry of Coal Industry organized the Third Prediction of Coal Fields. It was finished in 1997 and is still the latest assessment of China's coal resources (*The 1997 Assessment*).[42] This comprehensive assessment generated a number of estimates of China's coal resources and reserves. They include the following categories, listed below in order from most to least uncertainty associated with the estimates:

- total coal resources (*meitan ziyuan zongliang*),
- accumulated proven coal resources (*leiji tanming meitan chuliang, or yi faxian ziyuan*)
- remaining coal resources (*baoyou chuliang*),
- coal resources (*meitan pucha ziyuan liang*)
- coal reserve base (*meitan chuliang*).

Another category, "identified coal resources" (*yi chazheng ziyuan*) is a sum of the last 2 categories ("coal resources" and "coal reserve base").

"Total coal resources" refers to the total amount of underground coal resources, estimated with methods that include simulation, and comparison with known fields on the basis of geological theories. Generally, no exploration or field appraisal is involved in formulating these estimates. Consequently, many of these resources many never be mined because they are too difficult to access. The 1997 Assessment found that China's total coal resources within 1,000 meters of the earth's surface totaled 2,862 billion tons, and that an additional 2,708 billion tons of coal reserves are between 1,000 meters and 2,000 meters (or between 1,000 and 1,500 meters in southern and northeastern China). Coal seams located beyond 1,000 meters are very difficult to mine because of technical challenges, including high temperature and high water pressure.

The Assessment reported that by the end of 1992, the "accumulated proven coal resources (APCR)" were 1,044 Gt and the "remaining coal resources" were 1,018 Gt.[43] Of the 26 Gt difference between them, about 20 Gt was mined out between 1949 and 1992.[44,45] It is important to note that these coal-resource estimates have very high uncertainties and, thus, limited value except in providing rough estimates of coal reserves.

"Identified coal resources" (*yi chazheng ziyuan*) is a more useful estimate. It is composed of "coal resources" (meitan pucha ziyuan liang), and "coal reserve base" (meitan chuliang). "Coal resources" is estimated based on information obtained from resource prospecting, which employs either exploratory entrench or shallow shaft methods or both to verify coal resources in area with high prospects. The design and construction of coal mines require more detailed engineering data than any of these resource estimates provide, and therefore typically requires further—usually commercial—exploration efforts, which provide data to estimate the "coal reserve base."[46] According to the 1997 Assessment, China's "identified coal resources" totaled 677 Gt by the end of 1992 (including 233.6 Gt of "coal resources" and 443.4 Gt of "coal reserve base"). The degree of uncertainty in these estimates has been reduced to a level such that they can be used in the development of long-term economic plans and in making national energy policy decisions.

Another category of reserves, "recoverable reserves" (*Kekaicai chuliang*), is also used to refer to the fraction of "coal reserve base" that is economically feasible to mine under existing economic and operating conditions, according to available geological and engineering information. It is similar to what is known outside China as the term "proven reserves." By the end of 2005, China had about 114.5 Gt of recoverable coal reserves.[47]

Notes and References

1. The author is now in the Department of Technology and Society of SUNY Stony Brook University. His current email is guodong.sun@stonybrook.edu, and phone number is (631) 632–3241. The author is thankful to Joanna Lewis for her help on the draft.

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24. 24.2 MPa, 538 °C/566 °C.

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26. Or 10.45 MJ/kWh.

27. Heat rate (*gongdian meihao*) is defined as the amount of energy input that is required to generate one unit of electricity (for example, 1 kilowatt-hour). A lower efficiency unit has a higher heat rate. Data are from the China Electricity Council Website (http://tj.cec.org.cn/)

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This paper examines advanced coal technologies available to help China address its energy and environmental challenges. It is part of a Pew Center on Global Climate Change Coal Initiative, a series of reports examining and identifying policy options for reducing coal-related GHG emissions. The Pew Center brings a cooperative approach and critical scientific, economic, technological, business and policy expertise to the global climate change debate at the state, federal and international levels.

Pew Center on Global Climate Change
2101 Wilson Boulevard, Suite 550
Arlington, VA 22201

Phone (703) 516-4146

www.pewclimate.org