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China's Coal: Demand, Constraints, and Externalities

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China’s Coal Industry: Resources, Constraints, and Externalities

Contents

Executive Summary

- China has been, is, and will continue to be a coal-powered economy. In 2007 Chinese coal production contained more energy than total Middle Eastern oil production. The rapid growth of coal demand after 2001 created supply strains and bottlenecks that raise questions about sustainability.

- Urbanization, heavy industrial growth, and increasing per-capita income are the primary interrelated drivers of rising coal usage.

    - In 2007, the power sector, iron and steel, and cement production accounted for 66% of coal consumption.
    - Power generation is becoming more efficient, but even extensive roll-out of the highest efficiency units would save only 14% of projected 2025 coal demand for the power sector.
    - A new wedge of future coal consumption is likely to come from the burgeoning coal-liquefaction and chemicals industries. If coal to chemicals capacity reaches 70 million tonnes and coal-to-liquids capacity reaches 60 million tonnes, coal feedstock requirements would add an additional 450 million tonnes by 2025.
    - Even with more efficient growth among these drivers, China's annual coal demand is expected to reach 3.9 to 4.3 billion tonnes by 2025.

- Central government support for nuclear and renewable energy has not reversed China's growing dependence on coal for primary energy. Substitution is a matter of scale: offsetting one year of recent coal demand growth of 200 million tonnes would require 107 billion cubic meters of natural gas (compared to 2007 growth of 13 BCM), 48 GW of nuclear (compared to 2007 growth of 2 GW), or 86 GW of hydropower capacity (compared to 2007 growth of 16 GW).

- Ongoing dependence on coal reduces China's ability to mitigate carbon dioxide emissions growth. If coal demand remains on a high growth path, carbon dioxide emissions from coal combustion alone would exceed total US energy-related carbon emissions by 2010.

- Within China's coal-dominated energy system, domestic transportation has emerged as the largest bottleneck for coal industry growth and is likely to remain a constraint to further expansion. China has a low proportion of high-quality reserves, but is producing its best coal first. Declining quality will further strain production and transport capacity. Furthermore, transporting coal to users has overloaded the train system and dramatically increased truck use, raising transportation oil demand.

- Growing international imports have helped to offset domestic transport bottlenecks. In the long term, import demand is likely to exceed 200 million tonnes by 2025, significantly impacting regional markets.

I. Overview

This study analyzes China's coal industry by focusing on four related areas. First, data are reviewed to identify the major drivers of historical and future coal demand. Second, resource constraints and transport bottlenecks are analyzed to evaluate demand and growth scenarios. The third area assesses the physical requirements of substituting coal demand growth with other primary energy forms. Finally, the study examines the carbon- and environmental implications of China's past and future coal consumption.

The following three sections address these areas by identifying particular characteristics of China's coal industry, quantifying factors driving demand, and analyzing supply scenarios. Section two reviews the range of Chinese and international estimates of remaining coal reserves and resources as well as key characteristics of China's coal industry including historical production, resource requirements, and prices. Section three quantifies the largest drivers of coal usage to produce a bottom-up reference projection of 2025 coal demand. Section four analyzes coal supply constraints, substitution options, and environmental externalities. Finally, the last section presents conclusions on the role of coal in China's ongoing energy and economic development.

II. China Coal Resources and Production

It is widely agreed that China possesses the third largest coal resources in the world, behind the United States and Russia.[1] However, there is no such consensus on the precise extent or availability of China's coal resources. Estimates vary among Chinese and international sources, in reference to differing types of coal, and due to confusion of reserve and resource categories.

2.1. Reserve estimates

China's reserve estimates have declined significantly from early 20th-century estimates of as high as 1 trillion tonnes in the 1920s. Reserves estimates fell from 700 billion tonnes in the 1950s to 300 billion tonnes in the 1970s. After a series of extensive national resource surveys, China reported their reserves to the World Energy Council (WEC) as 114.5 billion tonnes in 1992. The WEC has continued to use this number in spite of more than 25 billion tonnes of Chinese domestic coal consumption in subsequent years. The implication of the WEC's frozen reserve estimate is that resources have been converted into reserves at a rate equal to annual consumption—or that the central government has not formally reported revised numbers. The WEC reserve estimate is commonly cited in other references, including the annual BP Statistical Review of World Energy. In 2003, based on a new national survey of resources, China's Ministry of Land and Resources released an updated estimate of 189 billion tonnes total coal reserves.[2] Figure 1 displays China's coal resource and reserve estimates, from 189 billion tonnes of indicated economically-viable coal, 326 billion tonnes of reserve base, on to a 1,021 billion-tonne estimate of total resources.[3] The reserve base encompasses all identified resources that meet the physical and economic criteria for extraction as well as those that have potential for

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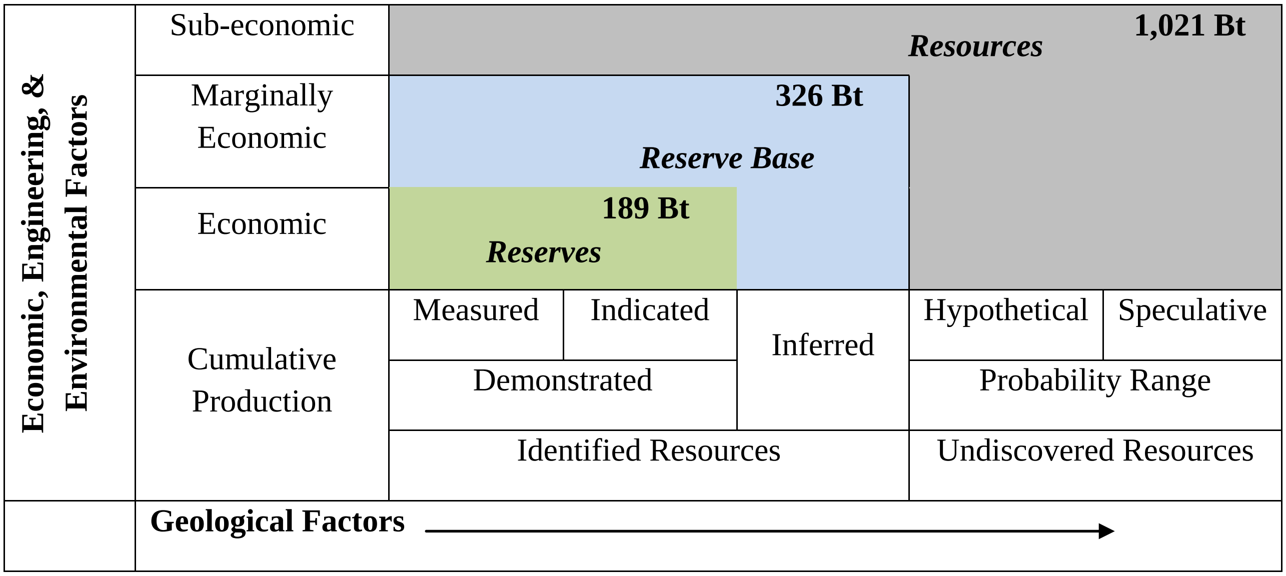
[1] World Energy Council. 2007 Survey of Energy Resources. London: WEC Press.

[2] MLR. 2003. *National Coal Resources and Reserves Circular*. Beijing: MLR, cited in IEA. 2009. *Cleaner Coal in China*. Paris: IEA.

[3] Ghee Peh, Wei Ouyang. (2007) *UBS Investment Research: China Coal Sector*. (17 January 2007; www.ubs.com/investmentresearch) ; NBS. 2007. *China Statistical Yearbook 2007*. Beijing: NBS Press.

becoming extractable in a time horizon beyond proven technology and current economic conditions.

Figure 1: China Coal Resources and Reserves, 2008[4]



According to the National Bureau of Statistics (NBS), coal completely dominates China's fossil fuel reserve base. Figure 2 illustrates the energy content of the reserve base (基础储量; translated in Chinese sources as "ensured reserves") of coal, oil and natural gas published in the 2008 China Statistical Yearbook. Here NBS reports a reserve base of 2.8 billion tonnes of petroleum and 3 trillion cubic meters of natural gas, along with the coal reserve base of 326 billion tonnes raw coal. For China, coal constitutes 97% of the fossil fuel reserve base by energy content; in contrast, in 2007, the WEC estimated that 62% of world conventional fossil fuel reserves were coal by energy content; 19% were oil, and 19% natural gas.

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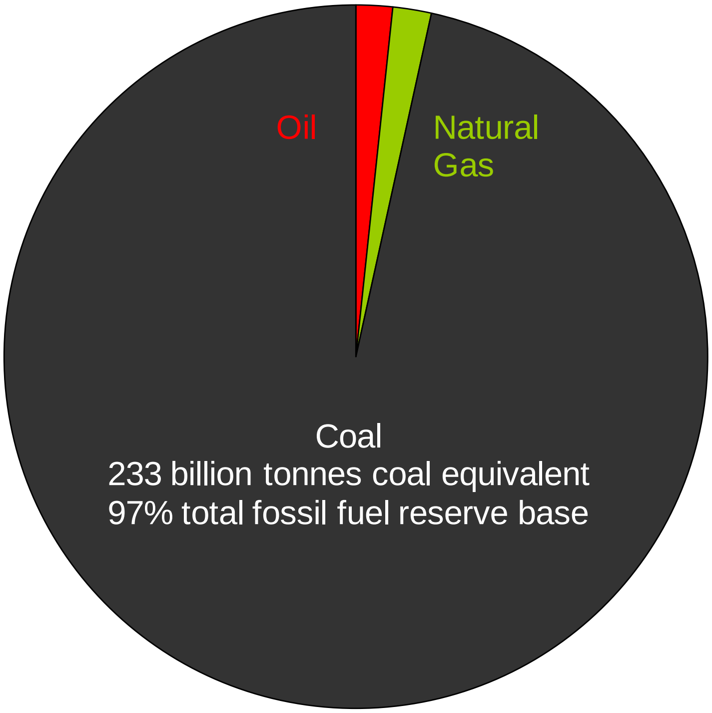
[4] Data are sourced from the Ministry of Land and Natural Resources and NBS. Display sourced from http://fti.neep.wisc.edu/neep533/SPRING2004/lecture2.pdf.

Figure 2: Energy Content of China's Fossil Fuel Reserve Base, 2007

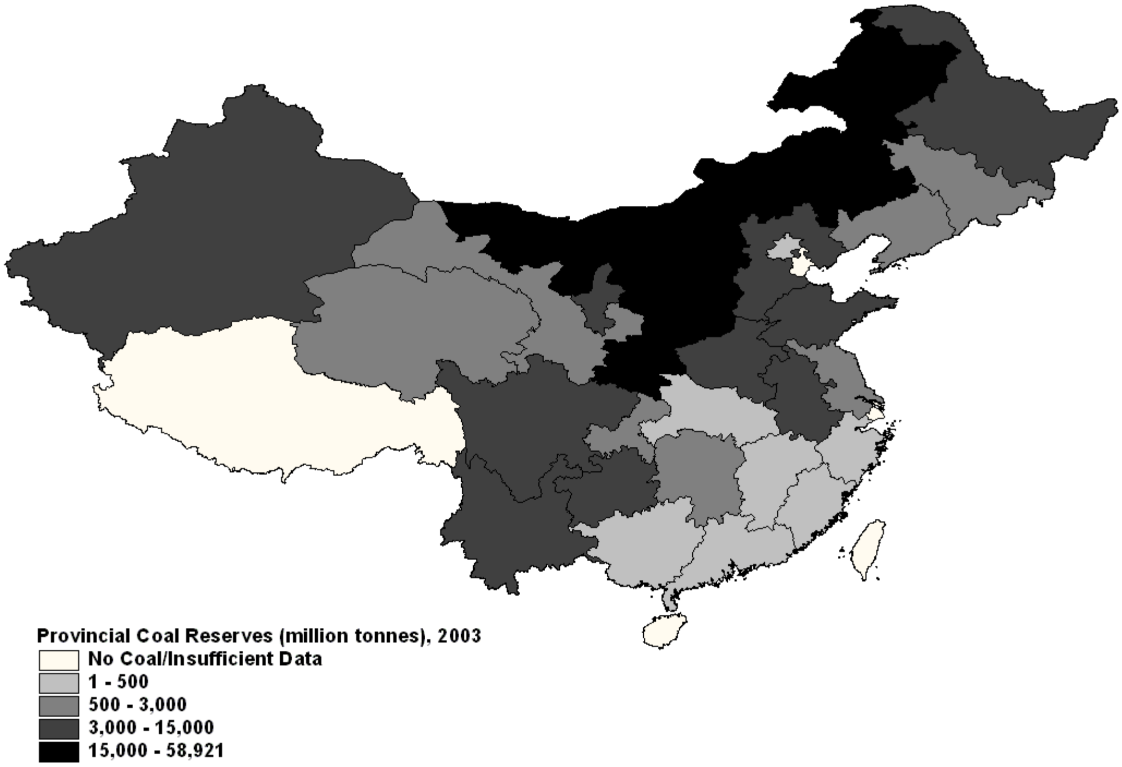


2.2. Reserves by location, quality, and depth

Most of China's coal reserves are concentrated in the northern provinces of Shanxi and Inner Mongolia. Southern coastal areas with the highest GDP growth, such as Guangdong and Fujian, are among China's least coal-abundant provinces. Map 1 illustrates the provincial distribution of indicated economic reserves according to the Ministry of Land and Resources 2003 Survey.

Three provinces were estimated to have indicated economic coal reserves of at least 15 billion tonnes. Shanxi province has the richest coal endowment in China—almost 59 billion tonnes. Inner Mongolia trails Shanxi with an estimated 47 billion tonnes. Shanxi's western neighbor province, Shaanxi comes in a distant third place with an estimated 16 billion tonnes of indicated economic coal reserves.

Map 1: China Provincial Coal Reserves (Mt), 2003



The quality of China’s coal production ranges from 3,446 kcal/kg in Guangxi to 6,245 kcal/kg for Ningxia coal.[5] China’s highest quality coal reserves are concentrated in the four provinces of Gansu, Ningxia, Shaanxi, and Shanxi. On a national level, 54% of China’s coal reserves are classified as bituminous coal by volume, versus 29% sub-bituminous and 16% lignite.[6] Shanxi province in Northern China accounts for 31% of China’s indicated economic reserves. In addition to being the most plentiful, Shanxi coal is among the country’s highest quality—average provincial calorific values are 6,242 kcal/kg, versus the national average of 5,350 kcal/kg. The average heating value for American coal is 5,600 kcal/kg.[7]

The average depth of China’s coal mines is 456 meters. Whereas northern China has the most abundant and highest quality coal, Xinjiang province (in far western China) has more than half of coal reserves located less than 1,000 meters below the surface. Only 27% of northern Chinese coal is located less than 1,000 meters below the surface, compared to 40% of total Chinese coal.[8] Mines in eastern China are particularly deep, with an average depth of 600 meters. Although the

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[5] Ghee Peh, Wei Ouyang. (2007) *UBS Investment Research: China Coal Sector*. (17 January 2007; www.ubs.com/investmentresearch)

[6] World Energy Council. 2007 Survey of Energy Resources. London: WEC Press.

[7] IEA. (2007) *World Energy Outlook 2007*.

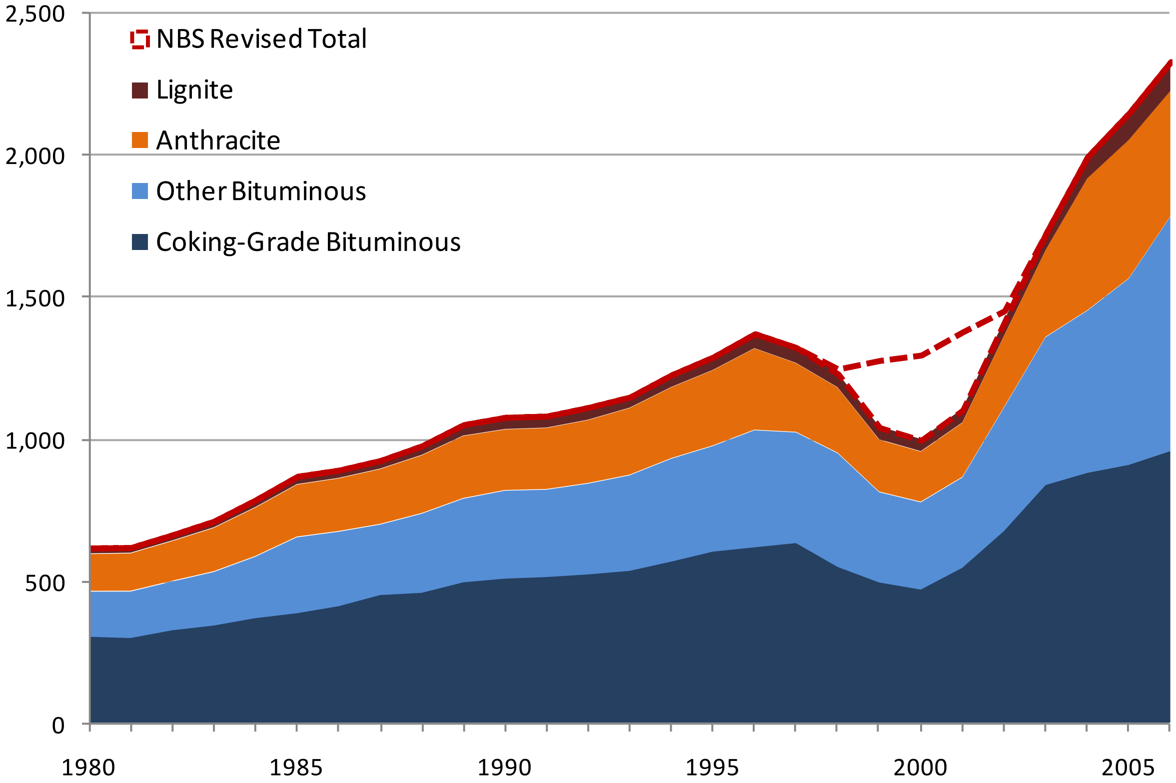
[8] Pan Kexi. (2005) “The Depth Distribution of Chinese Coal Resource,” Fudan University, School of Social Development and Public Policy. August 22, 2005.

average sulfur content of Chinese coal ranges up to 5%, it increases with depth in north China, suggesting that sulfur content will rise over time.[9] Due to deep coal resources, more than 90% of Chinese mines are pithead mines, compared with less than 40% in the United States, Australia, and India. The dominance of pithead mines in China lowers the coal recovery rate and increases extraction costs relative to open-pit mining.

2.3. Production by coal type

Since 1980, China maximized its high-quality coal production by primarily focusing on extraction of bituminous coal, with lower production growth of anthracite, lignite and brown coal. While bituminous coal is estimated to comprise 54% of China's coal reserves, the bituminous share of total production varied from 73% to 78% between 1980 and 2006.[10] Figure 3 illustrates the growth of bituminous, anthracite, and lignite production.

Figure 3: Raw Coal Production by Type of Coal, 1980-2006



Note: production data are reported by coal quality rather than end use; 1998-2002 production data from China Coal Industry Yearbook have not been revised to accord with revised aggregate production numbers (as shown by the dotted line, for which coal quality is unknown).

As illustrated in the figure above, China's production of bituminous coal has risen steadily, with comparable increases in both coking-grade bituminous coking and lesser-quality bituminous coal. As the largest share of total coal production, bituminous coal consisted of 76% of China's total

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[9] IEA. (2007) *World Energy Outlook 2007*.

[10] World Energy Council. 2007 Survey of Energy Resources. London: WEC Press.

coal production in 2006. With the exception of the late 1990s contraction, bituminous coal production has increased each year, rising from 467 million tonnes in 1980 to 1,785 million tonnes in 2006. During this period, an average of 47% of China's total coal production was composed of coking-quality coal while 30% composed of other general bituminous coal. There were no major fluctuations in the relative proportions of coking and other general bituminous coal until 2004 when the coking-quality share of total production began to diminish.

Anthracite coal production follows bituminous coal production with an approximately 20% share of total production throughout the same time period. Its production volume increased nearly four-fold from 129 million tonnes in 1980 to 442 million tonnes in 2006. This was followed by the production of lignite and brown coal, which also increased four-fold in production volume from 24 to 105 million tonnes. Whereas lignite and brown coal accounted for 4% of total coal production in 2006, China's coal reserves are estimated to be 16% lignite by volume.[11]

2.4. Production by mine ownership

Unlike the relatively steady trends in the production shares of coal types, the shares of different types of coal production ownership in China has changed drastically since 1980. Overall, the production share of centrally administered state-owned mines has decreased, from a share of 56% in 1980 to 47% in 2005, while the shares of collective and private mines have both increased. In parallel with centrally-administered mines, shares of local state-owned mines have decreased, falling from its highest share of 26% in 1980 to its lowest share of 14% in 2005. Among different types of local state-owned mines, provincial mine ownership has decreased the most, followed by prefectural and county ownership. Government policy influences the collective and private mines' share of production through regulation of mine safety, production volume, and coal quality. The ongoing lack of coordination among smaller private mines accounts for China's relatively low resource extraction rates.

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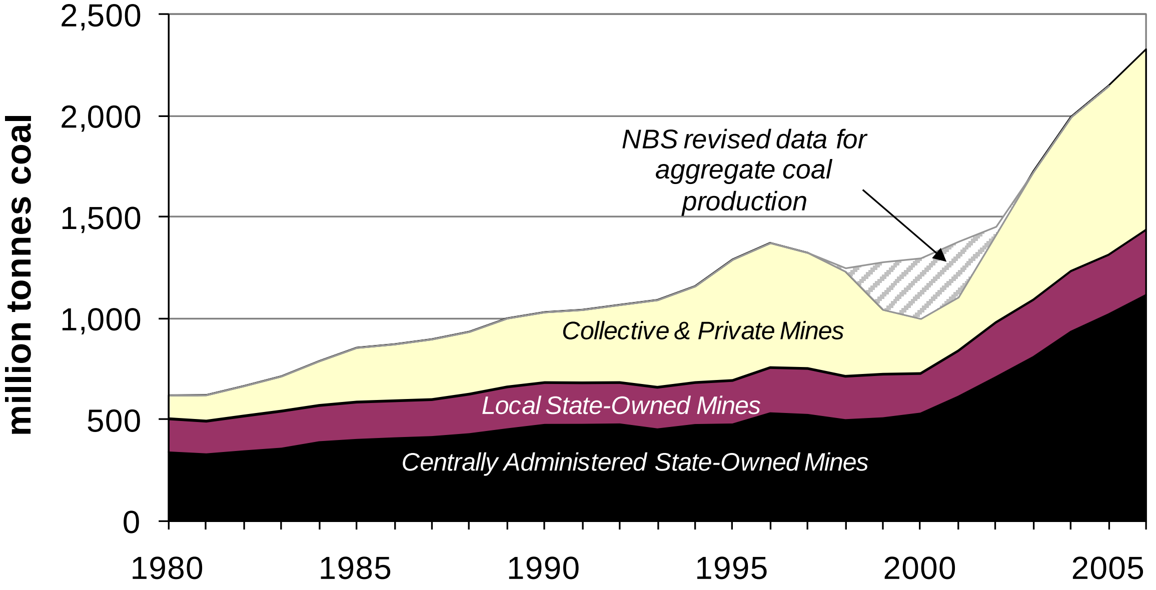
[11] World Energy Council. 2007 Survey of Energy Resources. London: WEC Press.

Figure 4: Coal Production by Mine Ownership, 1980-2006



Source: Coal Industry Yearbook, various years; China Statistical Yearbook, various years.
Note: mine ownership data are from the Coal Industry Yearbook, which has not published any revisions; additional production is likely to have come from collective and private mines.

In terms of output production growth, the average annual growth between 1980 and 1995 was low for centrally administered state-owned mines and even lower for local state-owned mines. Local state-owned mines' coal production, in particular, often underwent negative annual growth. In contrast, average production growth for collective and private mines was very high before 1996 and almost all of the gains in national coal production can be attributed to these mines. The growth in production output from collective and private mines during this period resulted largely from many households responding to the government's encouragement for small mines.

China's 11th Five-Year Plan presented targets for coal industry restructuring and reform by 2010. Most of these targets are oriented towards industry consolidation and increased efficiency. Lack of technology among small Township and Village Coal Mines (TVCM) partially explains their very low average extraction rate of approximately 15%.[12] NDRC-mandated mine closures were expected to reduce production by 200 million tonnes—perhaps a reason that mines were re-opened in 2008 as national supply tightened. Industry consolidation and mechanization are central efforts in the NDRC's target of raising average recovery rates from the 2005 official national average of 46% to 50% by 2010.[13] Closure of smaller mines is a key component of the Eleventh Five Year Plan. In 2006, the National Development Reform Commission (NDRC) announced that only mines producing at least 300,000 tonnes per year would be considered for

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[12] International Energy Agency (IEA). 2007. *World Energy Outlook 2007*. Paris: IEA.

[13] National Development Reform Commission (NDRC). 2007. *11th Five Year Plan on Energy Development*, NDRC, Beijing. Separate media reports indicate that the actual recovery rate may be lower. One report, for example, says that China's average coal recovery rate is 30% nationally and 40% in Shanxi province (http://www.cnmn.com.cn/Show_26346.aspx).

approval; the NDRC has also announced that it intends to reduce the number of small mines to 10,000 by 2010.[14] However, local officials are more severely punished for mining accidents and safety violations than low recovery rates.[15] This dynamic has limited the government's control of small mines and highlighted tradeoffs between improved aggregate coal recovery rates and local-scale investment and regulatory costs.

2.5. Water resources and requirements

China's average per-capita water availability is 2,300 m^3, which is approximately one-third world average. While coal reserves and production are concentrated in the north, limited water resources have posed problems for increased production and coal washing. North China contains the vast majority of domestic coal reserves and more than half the population; however, the region has access to only 20% of national water resources. Average per-capita water availability in North China is 271 m^3—one eighth the national average and 1/25th the world average.[16] As a result of imbalanced rainfall distribution, North China has an arid climate where its naturally dry conditions were worsened by repeated droughts in the 1990s. The water shortage problem has been exacerbated with increased coal mining as well as increased demand from a growing population in the north. In contrast, southern China has ample water resources and often faces the threat of annual flooding.

As for China's mining industry, it has been estimated that the extraction of 1 tonne of coal requires 53 – 120 liters of water, depending on the location and depth of the coal.[17] An additional 4 tonnes of water is needed for coal washing, which can reduce sulfur and particulate content while increasing energy content of raw coal. As a result of high water requirements, the portion of washed coal production has remained low. Finally, water is also needed for cooling, beneficiation, and other plant operations within thermal electric power plants. The unit water requirement of coal-fired electricity generation is estimated at 0.164 m^2/GJ, compared to 0.109 m^2/GJ for natural gas fired electricity generation.[18]

2.6. International coal prices and trade

In parallel with the surge of energy consumption after 2001, domestic Chinese coal prices moved from stable levels under $40 per tonne to more than $70 per tonne for coking coal in 2006. From 1998 to 2002, domestic prices for steam and coking coal varied between $26 and $38 per tonne. As illustrated in Figure 5, domestic steam and coking prices have risen unsteadily since 2002, with steam prices converging with coke prices three times before resuming lower levels.

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[14] National Development Reform Commission (NDRC). 2007. *11th Five Year Plan on Energy Development*, NDRC, Beijing.

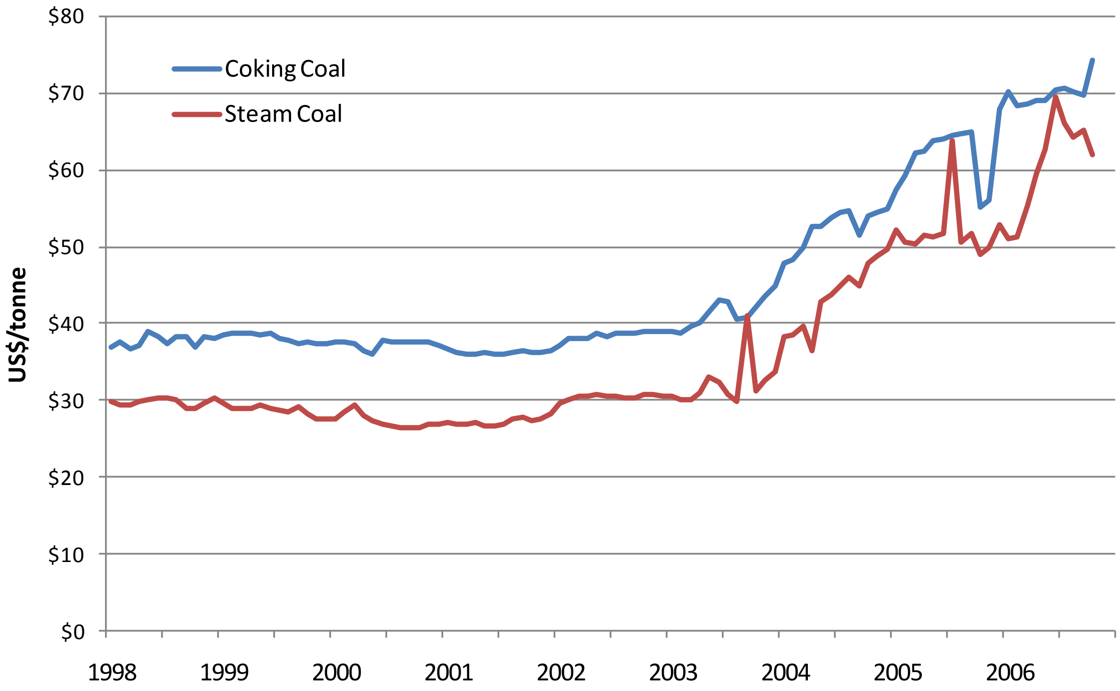
[15] See for example http://www.guardian.co.uk/business/feedarticle/7644650.

[16] Guan Dabo, Klaus Hubacek. (2007) "Assessment of regional trade and virtual water flows in China," *Ecological Economics* 61:159-170.

[17] Elspeth Thomson. (2003). *The Chinese Coal Industry*. New York: RoutledgeCurzon, 192.

[18] Gerbens-Leenes, Winnie and Hoekstra, Arjen and Meer van der, Theo (2007) *The Water Footprint of Energy Consumption : an Assessment of Water Requirements of Primary Energy Carriers.* ISESCO Science and Technology Vision, 4 (5). pp. 38-42.

Figure 5: Nominal Domestic Prices for Steam and Coking Coal, 1998 - 2006



Data Source: Beijing Energy Efficiency Center, available at: http://www.beconchina.org/energy_price.htm

Overall, domestic coal prices increased when electricity demand and power plant construction soared. Prices reached historical highs in 2008. At Qinhuangdao, China's main coal pricing terminal, coking coal prices have risen to $137/tonne in 2008, and steam coal prices have strengthened as well.[19] Datong premium blend (6,000 kcal/kg) traded in May 2008 at 655-670 RMB per tonne FOB ($94-96/tonne).[20] By early 2009, prices dropped back in the face of economic slowdown, bringing Datong premium blend back to 590 RMB per tonne ($86/tonne)—still more than double prices earlier in the decade.[21]

From an international perspective, China's domestic coal prices after 2000 have been increasing more consistently than other countries, such as Australia. In contrast to Chinese domestic prices, Australia's FOB export value for coking coal was relatively stable before 2004, as was the value for its steam coal before 2003. After 2004, however, Australia's FOB export value for coking coal significantly increased by $40 per tonne while its steam coal export value also increased by $20 per tonne. The two price trends have become increasingly interrelated: as China's coal exports have declined and imports increased because of a tighter domestic market, import demand from China's former customers has shifted to other Asia-Pacific countries as has China's import demand, pushing up benchmark prices in Australia.

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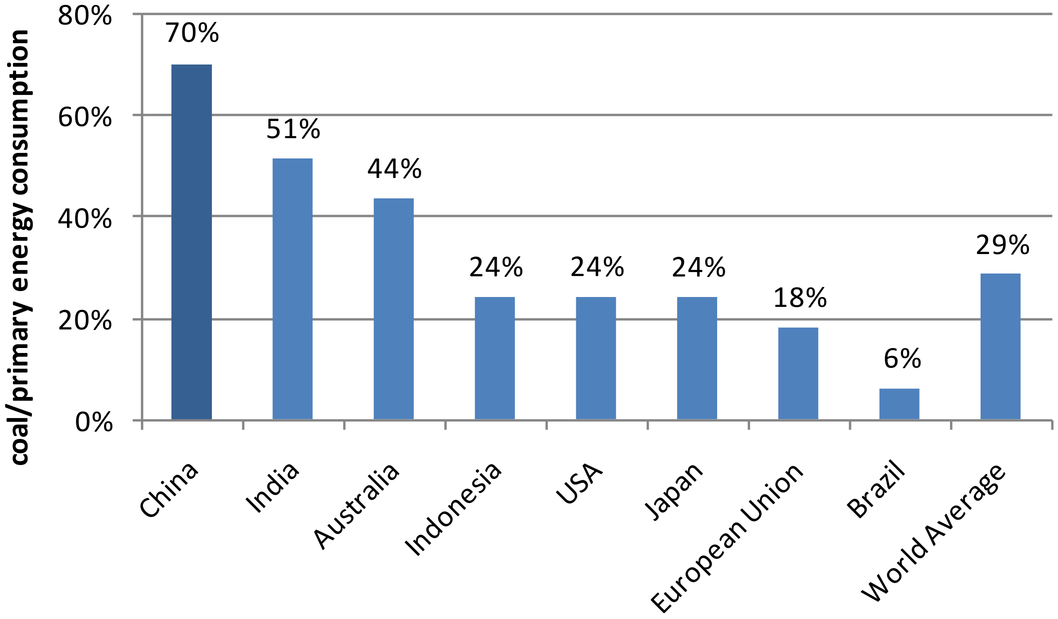
[19] See for example http://news2.eastmoney.com/080527,1025,848560.html.
[20] Interfax. 2008. *China Energy Report Weekly*. Vol. 8 (18):23.
[21] Interfax. 2009. *China Energy Report Weekly*. Vol. 8 (6):18.

III. Chinese Coal Demand

Although China has a smaller coal resource endowment than the United States and Russia, it is more dependent on coal as a primary source of energy.[22] Coal's dominant share of primary energy ultimately derives from its 97% share of total fossil fuel endowments (Figure 2). Figure 6 shows that coal comprised 70 percent of China's 2006 total primary energy consumption, compared to 24 percent in the United States and 16 percent in Russia.

Figure 6: Comparative Coal Dependence of Primary Energy Consumption, 2007



Source: BP Statistical Review of World Energy 2008.

The high level of domestic coal dependency in China is partly a result of the high degree of resource self-sufficiency (Figure 7). Given China's unbalanced fossil resource distribution, self sufficiency and energy security lead to high levels of coal usage. Although countries such as Indonesia and the US are completely self-sufficient in coal supply and are net exporters, coal is a much smaller percentage of their total primary energy consumption because of the availability of other fossil fuel resources in large volumes.

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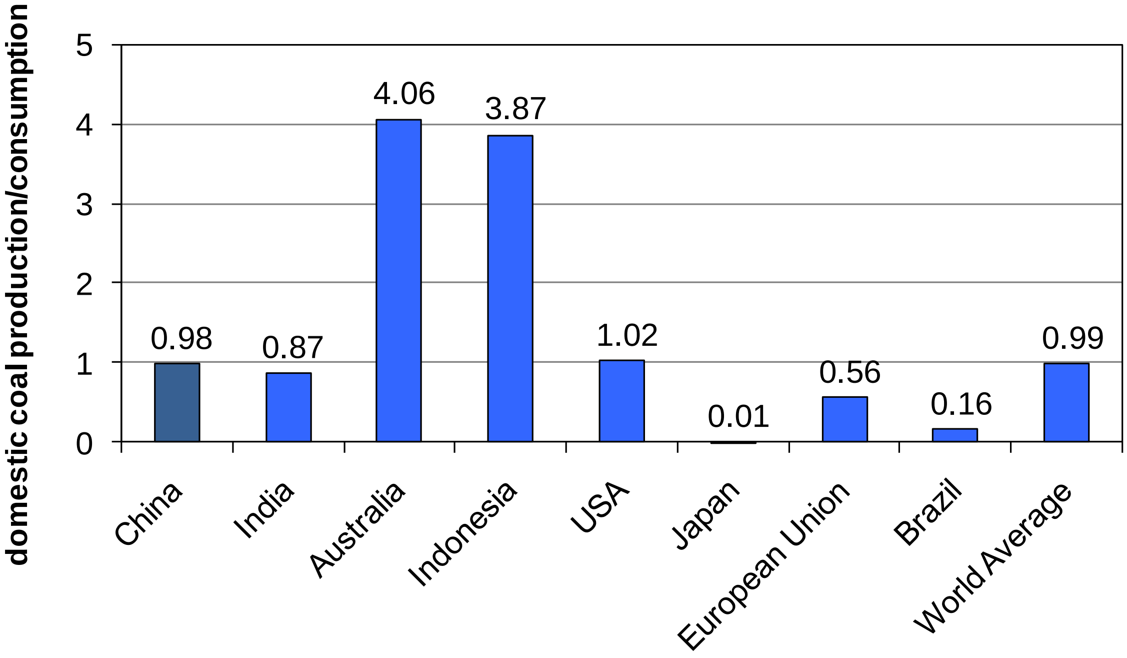
[22] World Energy Council. 2007 Survey of Energy Resources. London: WEC Press.

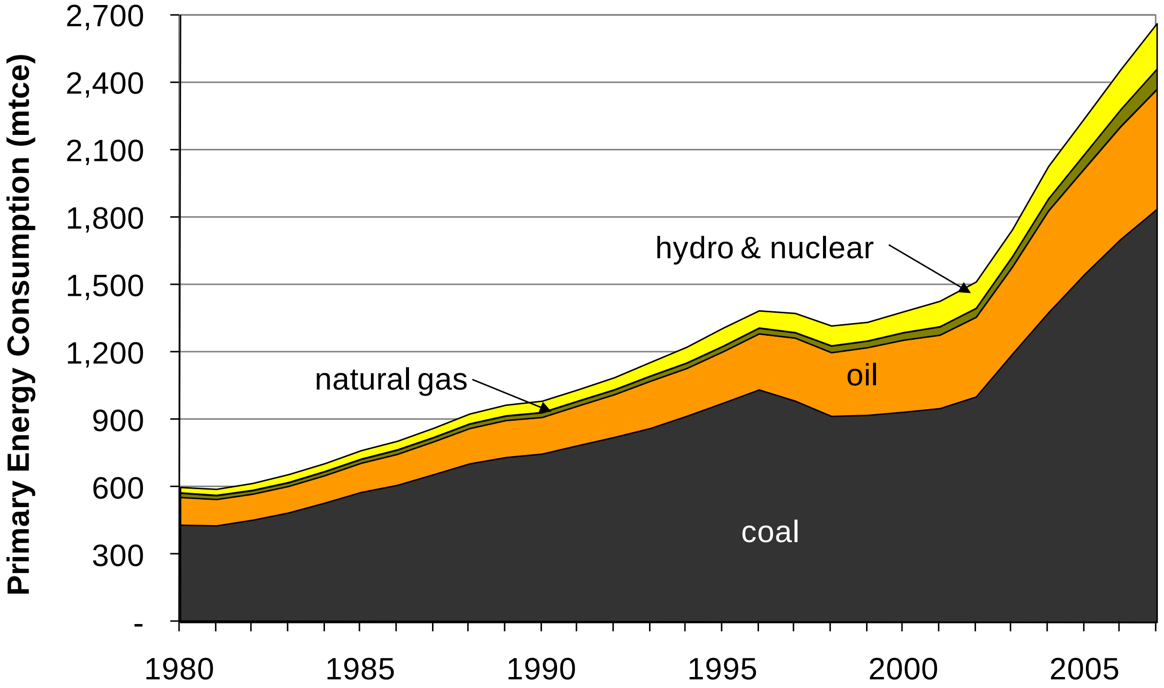
Figure 7: Ratio of Domestic Coal Production to Consumption, 2007



Source: BP Statistical Review of World Energy 2008.

While China's dependence on coal as a primary energy source declined between 1980 and 2000, coal's share rebounded from 68% in 2000 to 70% in 2006. In the face of oil and natural gas price rises, coal's share may be further enhanced as coal-based fuel and feedstock substitution programs are implemented. In this sense, China's coal crunch is not merely demand-derived, but is part of a larger energy crisis rooted in supply concerns in the oil and natural gas industries.

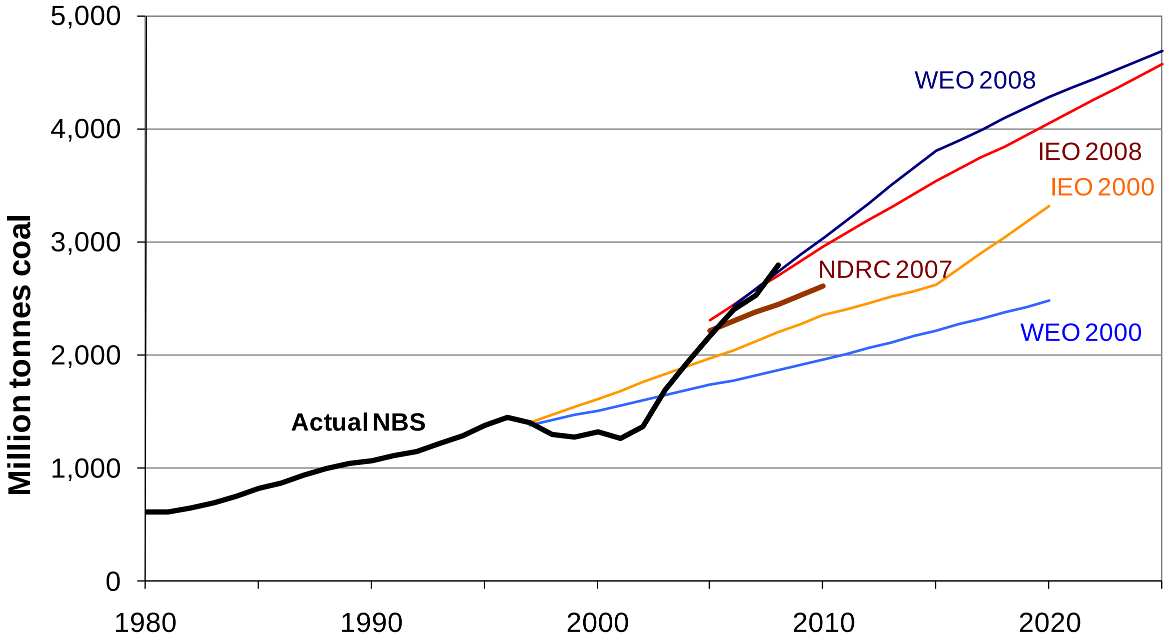
Figure 8: China Primary Energy Consumption, 1980-2007



3.1. Actual and forecasted coal use

Since 2003 actual Chinese coal consumption has exceeded forecasts from the IEA and the EIA, as well as from China's own National Development and Reform Commission (NDRC). As shown in Figure 8, the average annual growth rate of coal consumption has exceeded 10% since 2001. China's reported 2007 coal consumption of 2,580 million tonnes exceeded the IEA's WEO 2000 forecast for 2020 coal consumption of 2,473 million tonnes. In its 11th Five-Year Plan for Coal Industry Development, the NDRC forecast that China's coal production would reach 2.6 billion tonnes in 2010—a level that was exceeded in 2008. In their 2008 forecasts, the IEA and US EIA estimate China 2025 coal consumption at 4.7 and 4.6 billion tonnes, respectively (Figure 9).

Figure 9: Historical and Forecast Chinese Coal Consumption, 1980-2025



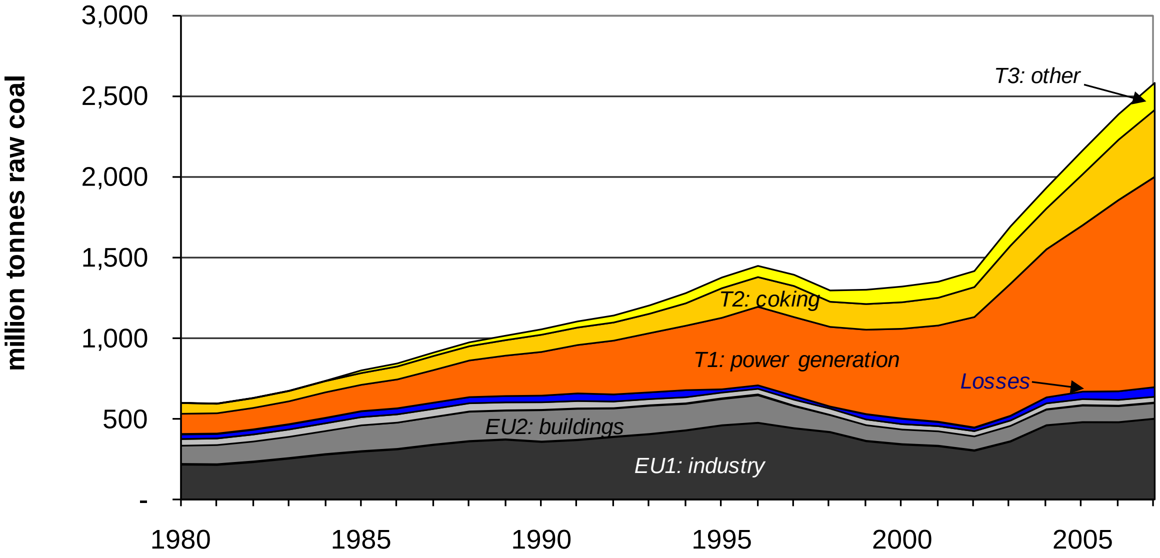
Note: Actual NBS data are displayed for consumption from 1980 to 2008.

3.2. Drivers of demand: urbanization, heavy industry, and rising income

The long-term trend in China's coal usage is a monotonic shift from direct end use to transformation, primarily through thermal electricity generation. Between 2000 and 2006, total direct end use of coal dropped from 35% to 26% of annual coal consumption. Over the same period, power generation increased from 42% to 50% of the total. Industry end use of coal increased on an absolute basis, but declined from 26% to 20% of total consumption. The shift from end use to transformation of coal is driven by inter-related processes of urbanization, heavy industry growth, and rising per-capita consumption.

Between 1990 and 2007 the urban share of China's population surged from 26% to 45% of total. The addition of 290 million urban residents had three direct effects on China's energy system: cement and steel had to be produced for building and infrastructure construction, electricity demand rose with home appliance ownership, and overall demand was stimulated by the replacement of rural non-commercial (largely biomass) energy with urban commercial energy services—principally electricity. This study examines the coal demand implications of 66% urbanization in 2025.

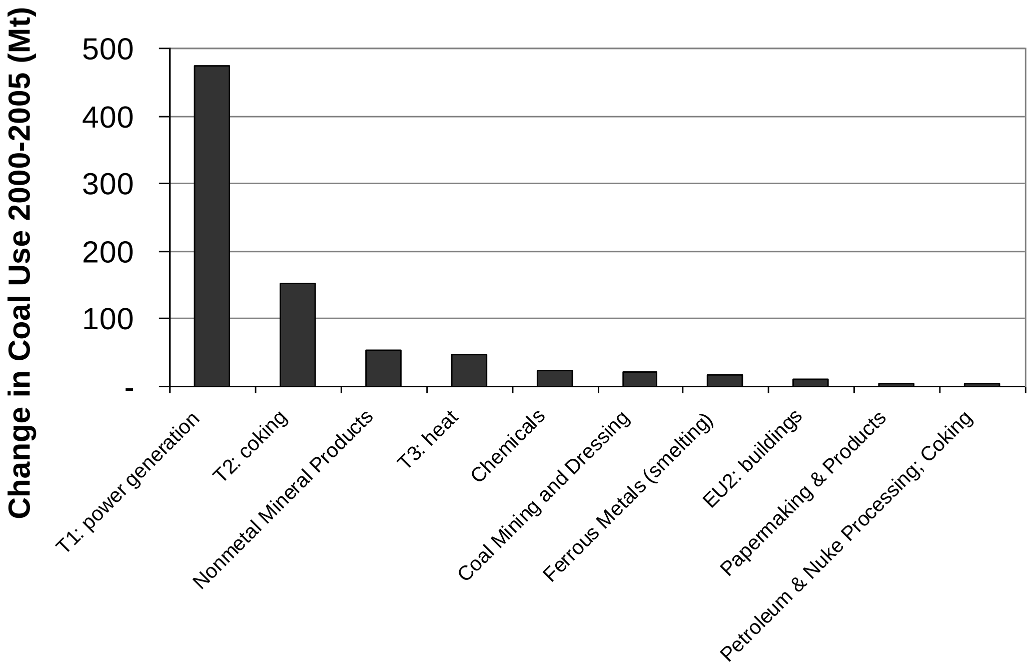
Figure 10: Chinese Coal Consumption by End Use and Transformation, 1980-2007



Source: NBS, 2007. EU2 = commerce + other (government) + residential; T3 = heating + gas production.

As shown in Figure 10, the surge of coal consumption between 2000 and 2007 was largely driven by the rapid rise in electricity demand. Coal-fired power generation accounted for 56% of the marginal increase in coal use between 2000 and 2005 (Figure 11). Over the same period, growth in coal use for power generation was followed by the growth in coal use for coke production (18%), the end-use of coal for production of building materials (6%), delivered heating (district heating) (6%), and chemicals production (3%) as the largest growth drivers.

Figure 11: Drivers of Growing Chinese Coal Use, 2000-2005



Under the assumption that China will maintain its planned growth trajectory, both Chinese and international assessments indicate that urbanization will continue to be a primary driver of energy consumption. In its 11th Five-Year Plan, the NDRC forecast China's population will expand from 1.31 billion in 2006 to 1.36 billion in 2010, of which 47% are expected to be urban residents. By 2025, the UN expects 57% urbanization and the McKinsey Global Institute forecast 66%, out of a total population of 1.403 billion.[23] China's urbanization is characterized by a combination of economically-motivated rural-urban migration and establishment of new urban centers in formerly rural areas. The requirements of urbanization—infrastructure, housing, services, transportation, and a shift to commercial energy use by residents—drive growth in the heavy industries that supply the materials, products and energy for urban construction and residential services.

3.3. Power generation

Coal increasingly dominates China's electricity generation system. Since 1980 coal's share of electricity generation capacity has grown steadily, from 69% to 78% in 2007. As shown in Figure 12, the absolute amount of coal-fired capacity grew at an average annual growth rate of more than 12% between 2000 and 2007, from 238 to 554 GW. In spite of this rapid growth, China's per-capita electricity generation capacity is comparatively low (0.5 kilowatts per person in 2007). Japan's per capita generation capacity, for example, was 1.9 kw per person in 2007.

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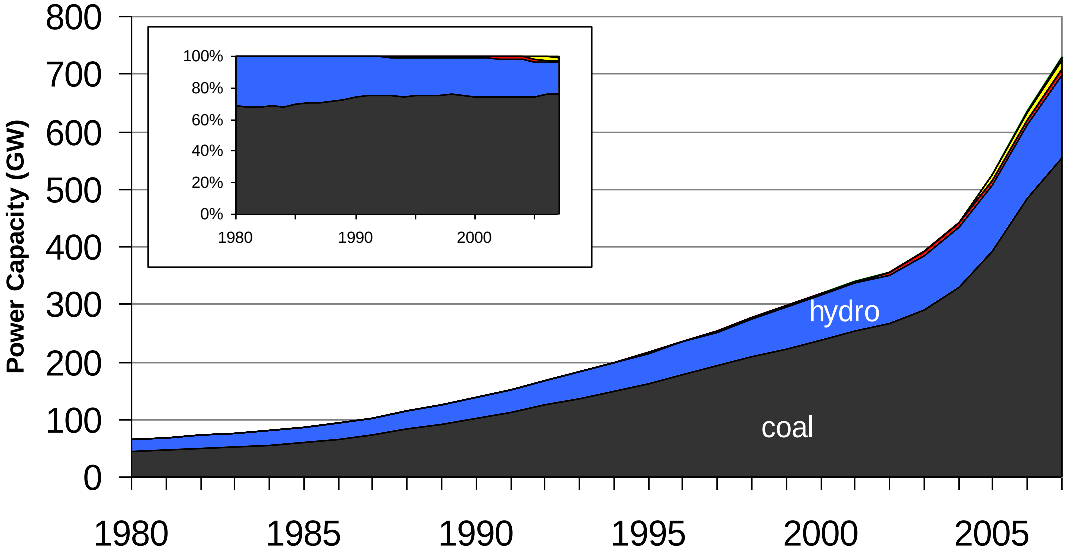
[23] United Nations. 2007. World Urbanization Prospects: The 2007 Revision Population Database (http://esa.un.org/unup/index.asp?panel=3; accessed May 5, 2008)
McKinsey Global Institute. 2008. "Preparing for China's Urban Billion: Summary of Findings," Shanghai: McKinsey Global Institute, March 2008.

Figure 12: Electricity Generation Capacity by Fuel, 1980-2007



Note: nuclear, natural gas, and renewable-based electricity capacity displayed above hydropower in this figure.

3.3.1. Electricity pricing

In the beginning of 2008, 42% of China's statistically-sampled thermal power plants lost money due to the convergence of government caps on retail electricity prices, increased repair and maintenance costs related to severe snowstorms, and rapidly rising coal prices.[24] While electricity pricing reform policies were initiated in the last decade, prices are still set and controlled at the central, provincial and even municipal and county levels. Specifically, power producers' prices for selling electricity to the provincial power companies and to the State Power Corporation must be reviewed and approved by provincial bureaus and the State Development and Planning Commission and the State Pricing Bureau, respectively.[25] In 2004, the National Electricity Regulatory Commission established a policy stipulating the adjustment of electricity prices if average coal prices fluctuate more than 5% within 6 months.[26] In practice, however, electricity prices were not allowed to rise in spite of rapidly increasing coal prices in 2007. To avoid exacerbating inflation and its social and economic impacts, a cap on electricity prices was implemented to control the consumer price index.

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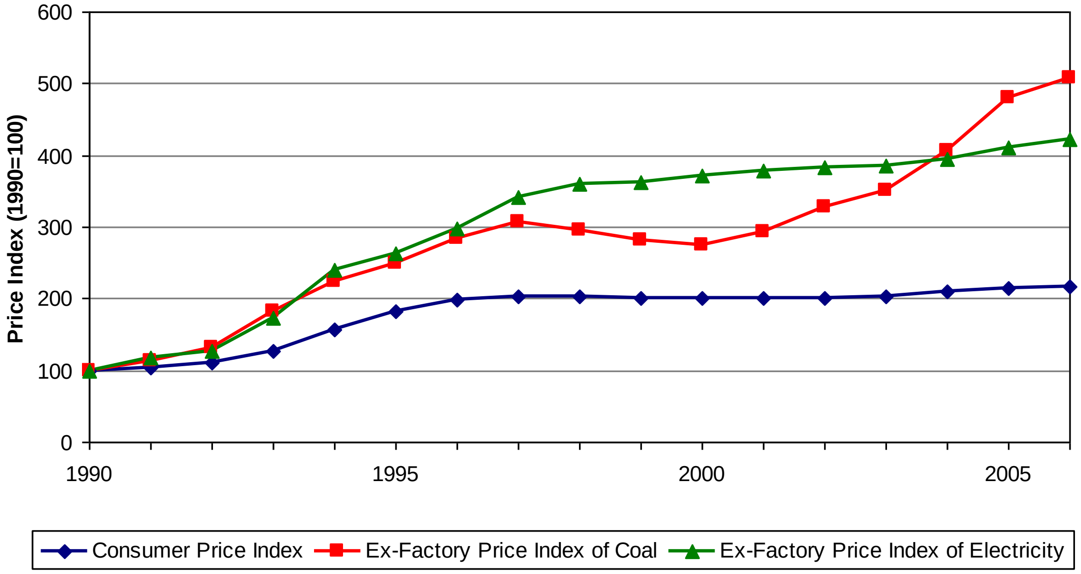
[24] *Interfax China Energy Report Weekly*, April 3, 2008, Vol. 7:14, p. 5.

[25] Lam, P., 2004, "Pricing of electricity in China," *Energy* 29 (2): 287-300.

[26] Wang, B., 2007, "An imbalanced development of coal and electricity industries in China," *Energy Policy* 35 (10): 4959-4968.

Figure 13: Price Indices of Coal and Electricity, 1990-2006



Source: NBS, 2007.

In conjunction with national government price caps, provincial governments adjust electricity tariffs among end-use sectors. Retail electricity prices are set in provincial catalogues for eight categories of users, including the introduction of a "commercial" category in the 1990s for profitable enterprises in the commercial sector. While relative tariff levels vary by region, a prevailing trend is relatively low catalogue tariffs for residential, industrial, chemical, agricultural and irrigation users and higher tariffs for non-residential lighting and commercial users.[27] Additionally, time-of-day tariffs also vary between different user classes. For example, residential and irrigation users are exempt from the time-of-day tariffs while heavy industry, chemical plants and agriculture users face significantly lower tariffs.

The disparity between controlled electricity prices and more market-oriented coal prices has created cost incentives for generators to maintain low coal inventories, thereby rendering them vulnerable to supply disruptions, as illustrated in extensive power outages during the spring festival holiday in 2008. Controlled electricity prices have also provided a profit incentive for coal producers to export rather than taking a lower power plant price on the domestic market. In June 2008, the government acknowledged that the disparity between coal and electricity prices was unsustainable and increased tariffs modestly by ¥0.025 per kWh. This increase may not have covered the increased coal costs to generators, but traditionally such price changes have been undertaken in "stairstep" fashion over time in an attempt to minimize the inflationary impact of the adjustments—i.e., further adjustments are likely. Sustained high prices both domestically and internationally may stimulate a return to Chinese domestic coal price controls in order to stem electricity generators' financial losses if inflation is considered too serious to allow large increases in electricity pricing.

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[27] Andrews-Speed, et. al, 1999, "Do the Power Sector Reforms in China Reflect the Interests of Consumers?" *The China Quarterly* 158: 430 – 446.

3.3.2. Thermal technology: efficiencies and costs

The average efficiency of thermal electricity generation is comparatively low in China due to the prevalence of small, outdated coal-fired power plants. According to the China Electricity Council, average capacity of coal-fired power plants was 58 MW in 2006, and only 45% of plants had a capacity of at least 300 MW. Larger-scale plants are more capital intensive but require less coal per unit of output—600 MW plants, for example, are on average 17% more energy efficient than 100 MW plants.[28] Thermal coal electricity generation efficiency also varies by plant technology type. This study examines four coal-thermal generation technology types currently or planned to be deployed in China; Table 1 shows the average heat rate and efficiency for each type.

Table 1: Average Heat Rates & Efficiencies for New Coal Thermal Power[29]

Technology	Sub-critical	Supercritical	Ultra-supercritical	IGCC
Heat rate (gce/kWh)	324	300	256	223
Efficiency	38%	41%	48%	55%

Note: IGCC refers to integrated gasification combined cycle technology.

The vast majority of China's thermal power generators use sub-critical combustion technology. Supercritical and ultra-supercritical technology attains higher fuel efficiency by operating at high temperatures and pressures where the boundary between water's liquid and vapor states disappears. According to the World Coal Institute, there were more than 240 supercritical units worldwide in 2006, of which 22 were operated in China.[30] China added 18 GW of supercritical capacity in 2006, bringing the supercritical share of total coal capacity to 6%, up from the China Electricity Council's previous estimate of 4.3% in 2006.[31] The China Huaneng Group began commercial operation of China's first commercial ultra-supercritical plant in November 2006. In 2007, domestic Chinese manufacturers were reported to have orders for 30 new units of ultra-supercritical power generation equipment.[32]

Four scenarios were developed to quantify the effect of new technology adoption on average power plant fleet efficiency. In all of the scenarios total electricity generation capacity grows to 1,576 GW in 2025, of which 1,060 GW are coal-thermal. The scenarios also include 10 GW per year of retired coal-fired capacity between 2009 and 2015, and 5 GW per year thereafter. The

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[28] Mi Jianhua. 2006. "Analysis of Energy Efficiency Status of Power Generation Industry in China," *Electrical Equipment*, 7(5): 9-12. (*in Chinese*)

[29] Li Zhenzhong, et al. 2004. "Ultra-Supercritical Coal Combustion for Electricity Generation: Technology Choice and Industrial Development," China Association for Science and Technology, 2004. (*in Chinese*: "超超临界燃煤发电机组的技术选择与产业化发展"); IEA, WEO 2007; IEA Greenhouse Gas Program. Lower efficiency levels have also been estimated for some of these technologies, depending on the specific circumstances of deployment.

[30] China Daily (July 2, 2007) "Being Supercritical," (http://www.zoomchina.com.cn/new/content/view/26601/266, accessed May 2008).

[31] Sun Guodong. (2008) *Coal in China: Resources, Use, and Advanced-Coal Technologies*. Pew Center on Global Climate Change. Mi (2006).

[32] China Daily (July 2, 2007) "Being Supercritical," (http://www.zoomchina.com.cn/new/content/view/26601/266, accessed May 2008).

efficiency of the retired capacity is estimated at the average fleet heat rate from fifteen years prior to retirement.

The baseline scenario simulates current trends in thermal electricity generation efficiency improvements. Between 2008 and 2015, the baseline scenario assumes 40% of new capacity will use supercritical technology, one gigawatt of ultra-supercritical capacity will be added per year, and the remaining new build will use sub-critical technology. From 2016 to 2025, the baseline scenario assumes 60% of new capacity will use supercritical technology with five gigawatts per year of ultra-supercritical capacity, with the remaining build using sub-critical technology. Average fleet efficiency in the baseline scenario improves from 357 kilograms coal equivalent per kilowatt-hour (kgce/kWh) in 2007 to 323 kgce/kWh (38% efficiency) in 2025.[33] The second scenario assumes that half of all new capacity will use supercritical technology between 2008 and 2025 and the other half will use ultra-supercritical technology. The third scenario assumes that all new build between 2008 and 2025 will use ultra-supercritical technology. The fourth scenario, IGCC, is a hypothetical, most technologically-aggressive scenario—it assumes all build between 2008 and 2010 will use ultra-supercritical technology and all plants thereafter will use IGCC technology.

Figure 14: Historical and Hypothetical Efficiency of China's Coal-Fired Electricity Generation, 1990-2025

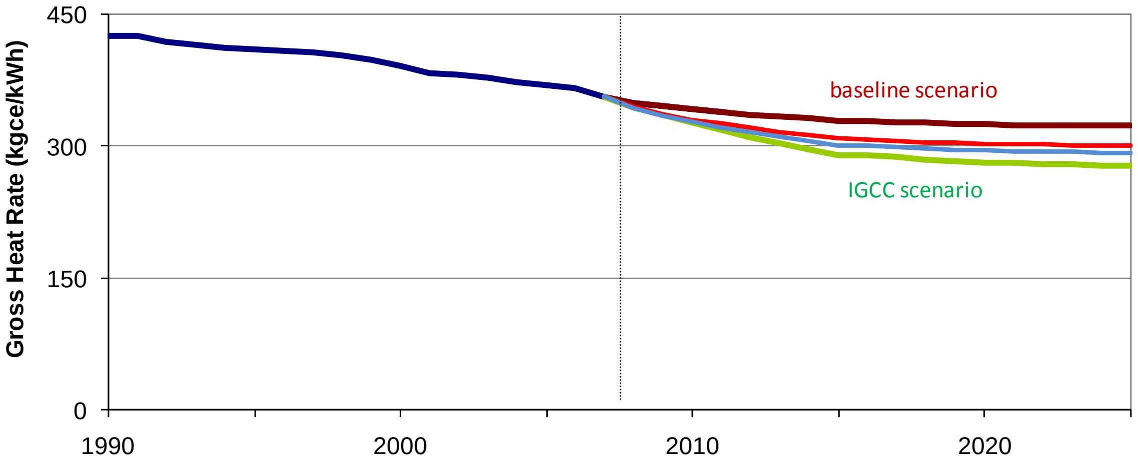

Figure 14 shows that the most aggressive adoption of the highest-efficiency coal combustion technology will only improve total fleet efficiency by 14%, from 323 kgce/kWh to 278 kgce/kWh in 2025. Aside from their different levels of thermal efficiency, each of the scenario technologies has varying costs and requirements. In comparison with regular pulverized coal combustion, Chinese researchers found that IGCC plants offer higher input and output flexibility, lower cost CCS possibilities, and require less water—all at higher capital cost and lower reliability.[34] At a coal price of 300 RMB/tonne, Chinese researchers estimate the cost of electricity for an ultra-supercritical plant at 280 RMB/MWh (4 cents per kWh), versus 350

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[33] Average efficiency data for 2007 quoted in 全国电力工业统计快报 (2007) CEC.

[34] Liu Hengwei; Ni Weidou; Li Zheng; Ma Linwei. (2008) “Strategic thinking on IGCC development in China,” *Energy Policy* 36 (2008)1-11.

RMB/MWh (5 cents per kWh) for IGCC technology.[35] Without government regulation or financial support, IGCC may have difficulty competing with ultra-supercritical or—if it develops beyond lab-scale—oxy-fuel technology.

3.3.3 Carbon capture and storage: efficiency penalties and emissions mitigation

Carbon capture and storage (CCS) refers to a range of technologies being developed to enable carbon dioxide from fossil fuel combustion to be sequestered in geological sites rather than being emitted to the atmosphere. Carbon dioxide is an innate product of fossil fuel combustion; however, there is a growing consensus that carbon emissions need to be mitigated. The power requirement to operate CCS results in an effective reduction of power plant efficiency. Model-based estimates for the efficiency penalty of CCS technology vary from 14% to 28%.[36] This study uses a 25% efficiency penalty to examine the implications of CCS technology implementation. In addition to its efficiency penalty, published research estimates that IGCC deployment would diminish a 500 MW plant's net capacity by 8% and increase the cost of electricity by 45%, while decreasing the related carbon emissions (kg CO2/kWh) by 89%.[37] The lack of commercial-scale CCS deployment limits the reliability of these data; however, current research makes it clear that CCS technology will not provide a simple or cheap solution to China's coal-carbon quandary.

3.3.4. Coal-bed and coal-mine methane

Effective capture of coal-bed and coal-mine methane presents an opportunity for increased energy productivity and safety in China's coal industry. However, methane capture has not been extensively developed in China due to lack of transparency regarding resource property rights and lack of available technology. These constraints are directly related to the consolidation of mine ownership and available capital in China.

On March 28, 2008, Shanxi Electric Power Corp. officially commenced operation of the world's largest CBM (coal-bed methane) power plant. In order to fire the plant's 120-MW capacity, the plant will consume 178.7 million cubic meters of methane and produce 840 GWh of electricity per year. In 2007, the Shanxi Jincheng Anthracite Coal Mining Group, the project's developer and one of the provinces largest CBM companies, produced 208.38 million cubic meters of CBM aboveground and 330.42 million cubic meters underground.[38]

CBM development was historically under the China United Coal-bed Methane Corporation (CUCBM) established in 1996. Because of the slow pace of development and consistent undershooting of production targets, CUCBM lost its monopoly rights in late 2007 as the government moved to open up the sector to further foreign investment. Indeed, CBM

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[35] Sun Guodong. (2008) *Coal in China: Resources, Use, and Advanced-Coal Technologies*. Pew Center on Global Climate Change. Mi (2006).

[36] Gibbins, Jon; Chalmers, Hannah. 2008. "Carbon Capture and Storage," *Energy Policy* 36: 4317-4322.
Chen, Chao; Rubin, Edward S. 2009. "CO2 control technology effects on IGCC plant performance and cost," *Energy Policy* 37: 915-924.

[37] *Ibid*.

[38] *Interfax China Energy Report Weekly*, March 27, 2008, Vol. 7:13, p. 13.

development is now the main focus of China's Clean Development Mechanism (CDM) projects, attracting 63% of the total UN-certified carbon credits in 2006.[39]

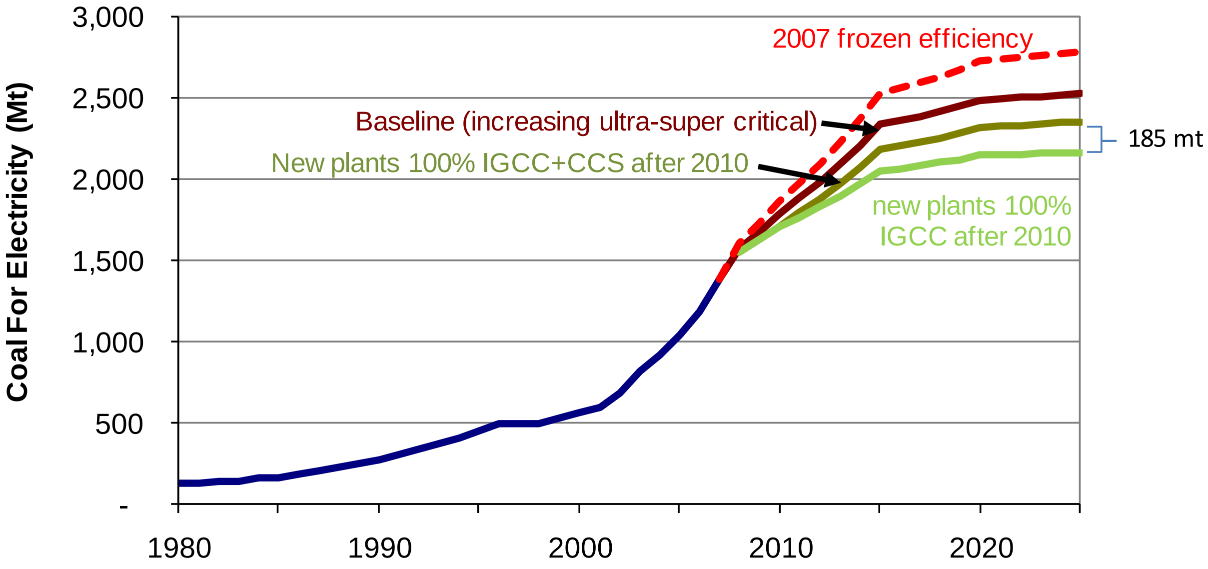
3.3.5. Mandatory closure of small-scale power plants

In 2007, China shut down 553 small-scale generators with a total capacity of 14,380 MW—exceeding the central government's target by 43 percent. Companies that closed small generators in 2007 were promised government compensation equal to three years worth of revenue. Closures have also been facilitated by an expanded power generation quota trading program whereby small power plants are allowed to sell their production quotas to larger power plants and raise cash to manage shutdowns. Quota trading amounted to 53.6 billion kWh in 2007, which is estimated to have saved 6.16 mtce and 143,000 tonnes of sulfur dioxide emissions.[40]

3.3.6. Demand scenarios

In order to quantify the potential savings of high-efficiency thermal power generation, this section examines coal requirements for the technology scenarios discussed in Section 3.3.2 above. At 2007 heat rates, China would require 2.8 billion tonnes of coal for electricity generation in 2025 (as illustrated by the dotted line in Figure 15). If China were able to improve its fleet efficiency from the baseline path to the hypothetical IGCC path, 14% less coal (349 million tonnes) would be required for electricity generation in 2025. Figure 15 shows that the baseline development path includes efficiency improvements that would require 269 million tonnes less coal in 2025 than generation requirements at the frozen 2007 average efficiency level.

Figure 15: Coal Demand for Electricity Generation in Four Technology Scenarios, 1980-2025



The improvement between the baseline and IGCC scenarios demonstrates that currently available thermal power generation technology does not offer a silver bullet for mitigating, much

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[39] Fridley, David, "Natural Gas in China", in Jonathan Stern, ed, *Natural Gas in Asia*, Oxford: Oxford University Press, 2008

[40] *Interfax China Energy Report Weekly*, March 27, 2008, Vol. 7:13, p. 8.

less reversing, rapidly growing thermal coal demand. The rapid build of power generation capacity between 2000 and 2007 will influence China's coal consumption path for many years.

3.4. Coking coal for iron & steel production

China has emerged as the largest producer and consumer of steel in the world. However, per-capita consumption remains below other industrialized countries. Table 2 shows the range of aggregate and per-capita steel consumption among a range of developing and developed countries. In 2008, China's per-capita steel consumption is expected to have reached 390 kg, thereby surpassing the US level in 2005.

Table 2: Aggregate and Per-Capita Steel Consumption (2005) [41]

Country	*Million tonnes*	*Kg per capita*
China	350 mt	270 kg
United States	113 mt	382 kg
United Arab Emirates	-	1,314 kg
Taiwan	-	1,044 kg
Japan	83 mt	649 kg
India	41 mt	38 kg
World	1,013 mt	189 kg

Projections of future structural steel production are scaled off of building construction growth; historically, half of Chinese steel use was structural and the other half was finished products.[42] Product steel projections are based on the growth of other industrial sub-sectors. The coal requirement for steel production is based on assumptions regarding the share of primary (basic oxygen furnace) steel to secondary (electric arc furnace) steel and a constant share of steel exports. Based on urban population growth, building construction, and demand for finished products, Chinese crude steel production would grow from 489 million tonnes in 2007 to 588 million tonnes in 2025.[43] Increased recycling and more efficient primary production would reduce coking coal requirement from 416 million tonnes in 2007 to 291 million tonnes in 2025.

3.5. Cement and building materials

In this analysis, future cement production levels are derived based on the amount of cement consumed to construct China's urban and rural buildings and infrastructure (roads, highways, bridges, airports, etc.). This methodology takes into account changes in the share of urban construction in total construction over time as well as changes in the average amount of cement used per square meter of construction. Cement production is driven by urbanization and the level of exports. The energy intensity of cement production varies by the assumed share of inefficient vertical shaft kilns as well as the timing of China reaching world best practice efficiency.

Annual urban construction and cement use data are combined with cement intensity to calculate total cement demand (total cement = (annual urban construction * cement intensity) / urban share

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[41] Source: World Coal Institute. Coal & Steel Facts 2007; International Iron & Steel Institute.

[42] Urandaline Investments. 2009. "China's Infrastructure Boost and Its Impact on 2009 Metal Demand" Beijing: Access China Conference.

[43] NBS 2008 reported 2007 crude steel production of 489 million tonnes; personal communication with Chinese steel specialists suggests that China's 2007 crude steel production was actually 449 million tonnes.

of total cement). With reference to the growing average height of Chinese urban buildings, cement intensity of construction is assumed to grow from 220 kilograms of cement per square meter of new construction in 2007 to 260 kg/m^2 in 2025. Based on the assumptions and methodology described above, cement production is expected to decline from 1.36 billion tonnes in 2007 to 1.15 billion tonnes in 2015 and 1.04 billion tonnes in 2025; the coal requirement for non-metal mineral product manufacturing is also expected to drop from 170 million tonnes in 2007 to 120 million tonnes in 2025.

3.6. Coal-to-liquids and coal-to-chemicals

Coal liquefaction and chemicals production present a potential fourth wedge of new coal demand between 2008 and 2025. To examine the potential impact of this burgeoning industry, this study calculates the coal feedstock requirements for 60 million tonnes of CTL capacity and 70 million tonnes per annum of coal-to-chemicals capacity in 2025.

In 2008, Shenhua coal company commissioned a 1 million-tonne direct coal liquefaction plant in Inner Mongolia.[44] China has reviewed plans for total coal-to-liquids capacity development of up to sixty million tonnes by 2020. At present, coal liquefaction requires 4.5 to 5 tonnes of coal and 10 tonnes of water per tonne of product.[45]

Regarding coal-to-chemicals, methanol production has displaced a growing share of ethanol production from grains and other feedstocks. Coal is increasingly viewed as a chemical feedstock. In 2007 China consumed 9 mt of methanol, of which 2.7 mt was blended with gasoline. Methanol is a feedstock for the production of dimethyl ether (DME) which is being piloted as a diesel fuel substitute in buses in Shanghai. By 2010 production capacity is expected to reach 39 mt of methanol. According to current technology, coal-to-chemicals production requires 1.5 to 1.7 tonnes of coal per tonne of methanol and 2 to 2.5 tonnes coal per tonne DME.

Based on current process efficiencies, growth to 60 million tonnes of CTL capacity and 70 million tonnes per annum of coal-to-chemicals capacity would require up to an additional 450 million tonnes of coal in 2025.

3.7. Demand Outlook Scenario

According to the development outlook of the basic drivers described above, China's total coal demand would grow to 4.26 billion tonnes in 2025 including coal-to-chemicals and coal liquefaction development, or 3.81 billion tonnes without CTL and CTC. In either case, electricity generation remains the largest driver of new coal demand. The growth of coal-to-chemicals and coal liquefaction to 450 million tonnes of annual coal use in 2025 does not offset the growth of electricity generation from 50% of total use in 2006 to 59% in 2025. Figure 16 illustrates the dominant role of electricity generation (baseline scenario) in driving Chinese coal demand.

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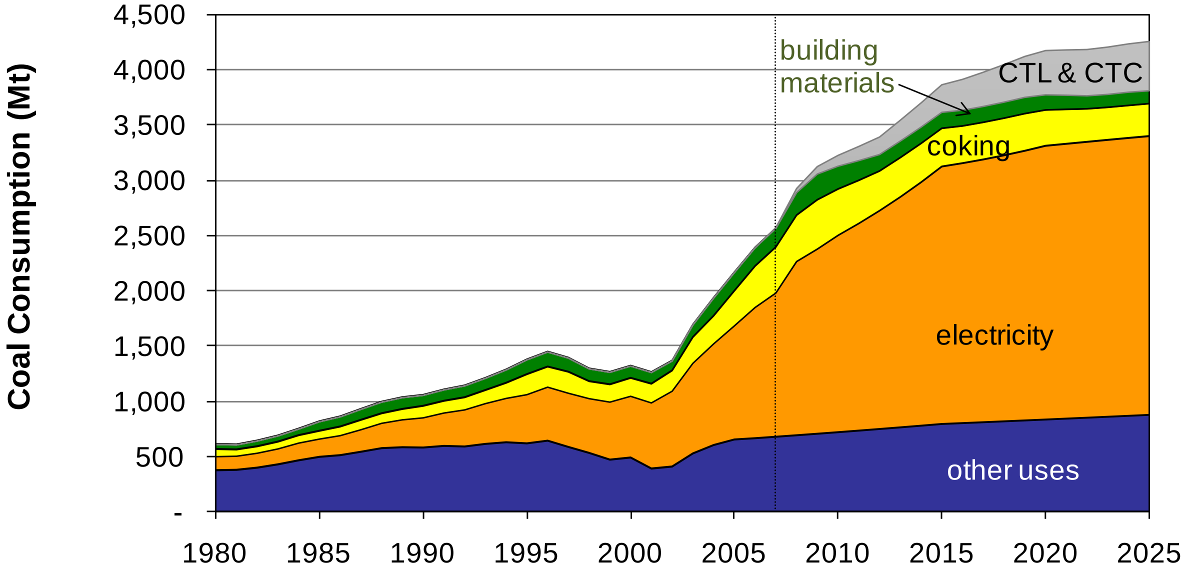
[44] Media reports conflict as to whether the plant is located in Shanxi or Inner Mongolia. See http://www.platts.com/weblog/oilblog/2009/01/china_joins_south_africa_as_a.html and http://www.bloomberg.com/apps/news?pid=20601072&sid=a3SIXbVZ8JiE&refer=energy#.

[45] Nolan, P., Shipman, A., Rui, H. (2004) 'Coal Liquefaction, Shenhua Group, and China's Energy Security,' *European Management Journal* 22(2): 150-164.

Figure 16: Historical and Forecast Coal Demand, 1980-2025



Growth in the "other uses" category of Figure 16 is primarily driven by four energy trends in China. Residential final coal consumption declined from 1996 to 2006, but rebounded in 2006; unless residential natural gas prices rise dramatically, expanded residential gas use is expected to limit further coal growth. As district heating expands with urbanization in the northern heating zone, coal use for district heating will depend on the availability of natural gas as a preferential fuel. Fertilizer production will also drive coal demand growth as coal remains the primary Chinese feedstock and self-sufficiency in domestic food production remains a key state policy goal. Likewise other industry is expected to drive coal demand growth as few options exist for substitution; efficiency improvements are expected to moderate, but not reverse, demand growth.

IV. Coal Supply Constraints, Substitution Options, and Externalities

The number of published forecasts for Chinese coal production is limited. On the near-term end of the spectrum, coal production targets of the Tenth and Eleventh Five-Year Plans were exceeded shortly after their publication. In the long term, the China Academy of Sciences has targeted zero growth of energy consumption after 2040.[46] Between China's official short and long-term projections, this study uses modified logistics curve analysis to quantify extraction scenarios in accord with published reserve data; these scenarios provide a foundation for analyzing coal gap potential between 2008 and 2025.

4.1. Constraints to expanded supply

In order to minimize the negative impacts of its potential coal gap, China is seeking to maximize domestic coal production. However, the rapid depletion of China's accessible, high-quality coal

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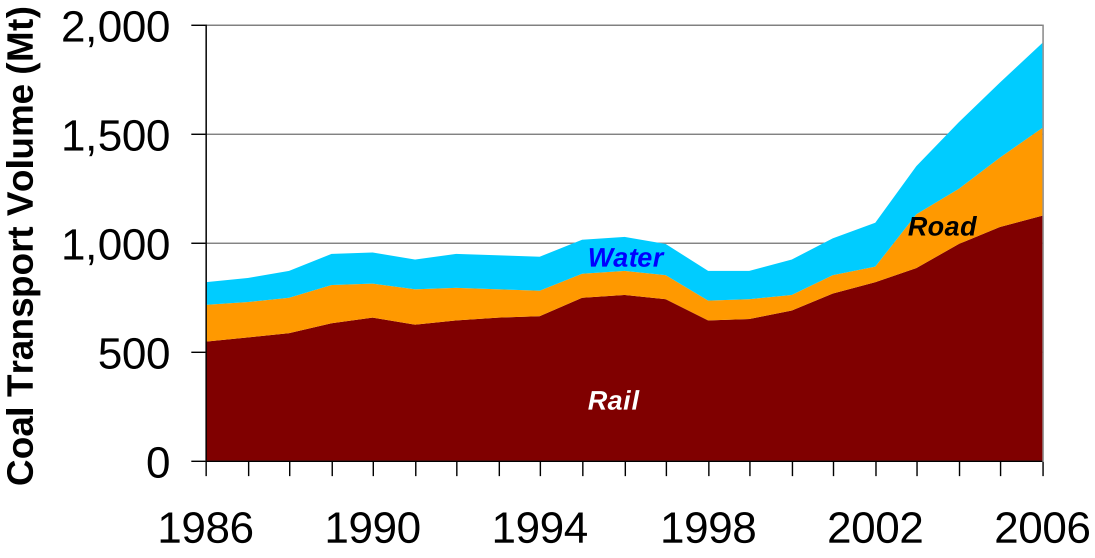
[46] People's Daily Online. 2007. "What will China be like in 2050?" (http://english.people.com.cn/200702/13/eng20070213_349784.html, accessed May 2008)

reserves is likely to hasten the arrival of peak production and accelerate post-peak decline. Aside from the larger resource depletion and strategy issues, China faces immediate practical constraints to further expanding its coal supply. Three key constraints to rapidly expanded Chinese coal production are freight transport bottlenecks, limits on electricity grid capacity to transmit coal by wire, and the diminishing quality of China's remaining coal reserves.

4.1.1. Transport bottlenecks

As illustrated in Map 1, most of China's coal resources are located in the inland northern provinces of Shanxi, Shaanxi, and Inner Mongolia—away from coastal demand centers. Moving coal around the country utilizes a large and growing share of domestic transport capacity. In 2006 it is estimated that 80% of consumed coal was transported by rail, road, or water. Figure 17 shows that the estimated rail share of total transported coal surged to 75% in 2002 before receding to 60% in 2006.

Figure 17: Coal Transport by Mode, 1986-2006



In 2006, 1.1 billion tonnes of coal were transported by rail, an estimated 407 million tonnes by road, and 385 million tonnes by inland and coastal waterways. Although rail is the dominant mode of coal transport in China, it is more expensive and complicated than rail transport in other countries. National west-east rail freight costs for coal, for example, are 0.12 RMB/tonne-km ($0.017/tonne-km).[47] Furthermore, the scarcity of dedicated local rail lines means that coal must often be shipped on local rail links from mines to the national network at roughly double the national per tonne-kilometer rate. Because China lacks an equivalent to the interstate commerce clause of the U.S. constitution, trans-provincial shipments can be taxed several times before reaching their destination. Water provides an efficient mode of coal transport. However, rapid expansion of water transport capacity is limited by use of small and handysize vessels for domestic transport, lack of dedicated domestic coal port facilities, and—most of all—by lack of

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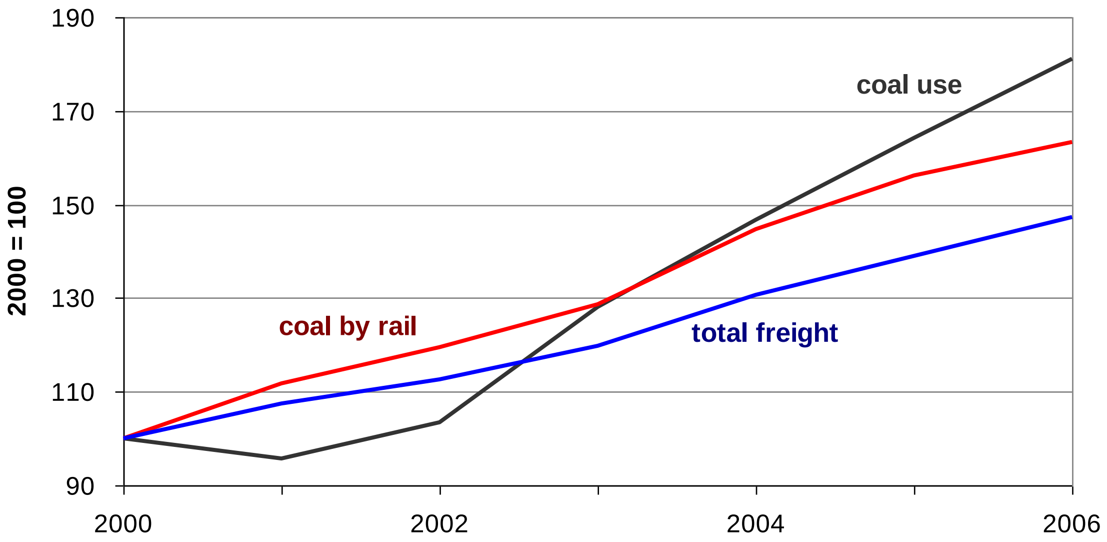
[47] IEA. 2007. WEO 2007. Paris: IEA.

adequate rail capacity to bring coal to ports. When rail and water transportation is impossible, coal is transported by road. Road is the most expensive mode of coal transport in China. Fees range from 0.5 to 0.8 RMB per tonne-kilometer, but still do not curb demand for journeys of up to 300 km by truck.[48] To maximize transport volume and minimize costs, coal trucks—usually in the 20-tonne scale--are often overloaded, exceeding the design capacity of roads and highways and accelerating road deterioration. As with local rail freight, road transport fees are driven up by local and provincial taxes in China. Road, water, and particularly rail transport of coal already constrains current coal production and is likely to limit the rapid expansion of domestic supplies.

Coal transport comprised 46% of total rail freight in 2006. In anticipation of further rail freight transport growth, the government has announced a plan to expand the total commercial length of the national rail network from 77,000 kilometers in 2006 to 100,000 kilometers in 2020.[49] The national government's ambitious rail expansion targets appear to be insufficient to support the rapid growth of coal demand without further displacing other freight from the rail system. Figure 18 shows that growth of total rail freight and coal freight by rail has not kept up with coal consumption growth since 2004. Whereas coal use expanded 81% between 2000 and 2006, coal by rail and total rail freight only grew 63% and 47% respectively.

Figure 18: Index of China Coal Use, Coal Transport by Rail, and Total Rail Freight, 2000-2006



Aside from bottlenecks within China's rail freight sector, coal transport is complicated by the geography and economic structure of the coal mining industry. While most of the key state-owned mines are served by rail lines, less than half the volume of 2006 coal was produced in rail-connected mines. Short-haul trucks are likely to have been used to move the 770 million tonnes of coal produced in near-to-rail mines in 2006. Road transport is likely to have been the only option for outside-of-the-system and difficult-transport mines, which comprised 17% of

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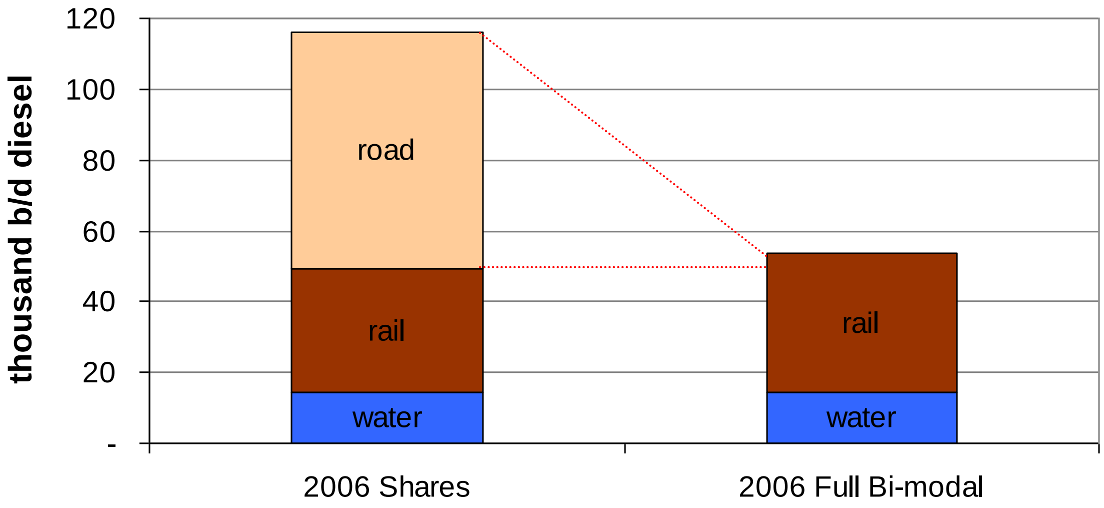
[48] IEA. 2007. WEO 2007. Paris: IEA.

[49] Target announced in the 'Mid and Long-Term Railway Development Plan,' quoted in WB China Quarterly Update 2.2008.

production in 2006. The prevalence of small coal mines distributed in mountainous terrain complicates efforts to efficiently transport more Chinese coal to markets.

Figure 19: Actual and Hypothetical Bi-Modal China Coal Transport, 2006



Strong demand for coal ensures that mined reserves are moved to market, by whatever mode is available. In many cases in China, this means that insufficient or unavailable rail freight capacity is supplemented by overloaded trucks. Not only are road fees on average five times higher per tonne-kilometer than rail fees, but China's trucks are hugely energy inefficient in contrast to the rail system, which rivals Japan's in terms of energy efficiency. Figure 19 shows the estimated energy consumption (in thousand barrels diesel per day, hereafter abbreviated as kb/d) by mode from transporting coal in 2006 on the left and hypothetical consumption on the right, were all of the all coal transported by road actually transported by rail. Whereas 2006 actual coal transport consumed an estimated 116 kb/d (of which 67 kb/d was used for road transport), rail and water transport of the same amount of coal would have required just 54 kb/d. Indeed, the increasing growth of truck-transported, in addition to the shift to truck transport of other goods that have been displaced by the growing proportion of coal on the rail system, has been a major driver for the increase in transport fuels in recent years

4.1.2. Grid options

China's divergent distribution of coal resources presents attractive policy potential for increasing the use of coal by wire, whereby energy from coal is extracted by combustion at mine-mouth thermal power plants and then delivered long-distance to demand centers. Given China's current electricity grid and resource endowments, coal by wire presents significant short-term costs for a potential long-term solution.

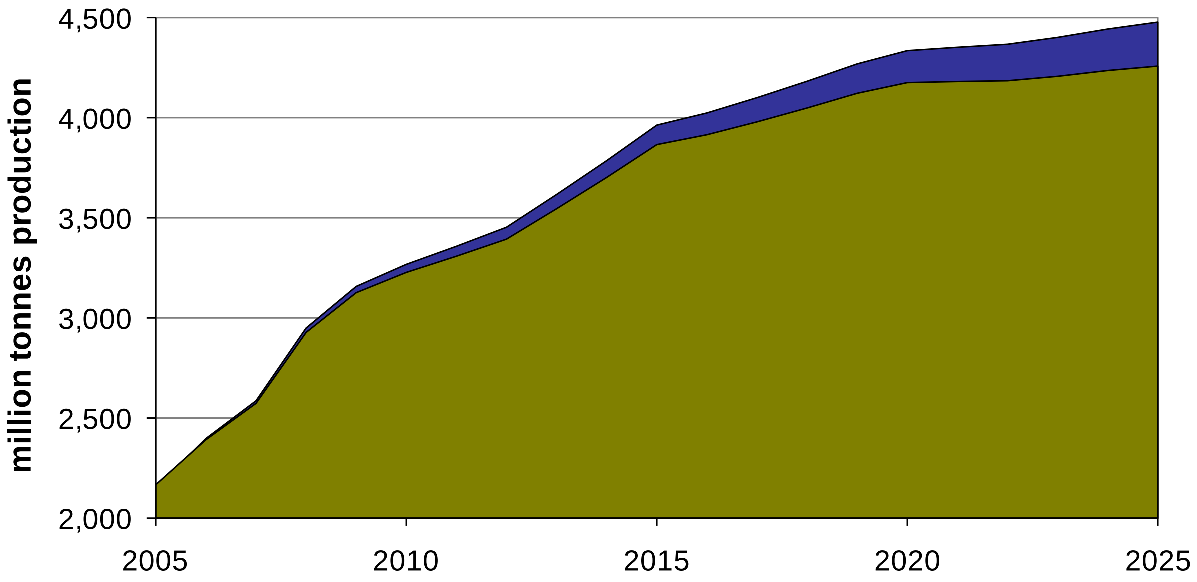
The major benefit of "coal by wire" is the potential reduction of China's coal transport requirements. In addition to allowing other freight to be moved by rail, coal by wire could reduce oil demand by stemming coal road transport. However, coal by wire also has energy losses associated with transmission line losses in delivering the electricity. In China's case, these transmission and distribution losses were reported at 7.04% in 2006, compared to 5.85% for the

US in 2006.[50] Another major challenge to coal by wire in China is the high water requirement of mine-mouth thermal power plants, which can reach 300 million gallons of water per day for a thermal power plant with 500 MW installed capacity.[51] This is a particularly significant disadvantage for China given the existing water shortage concerns in the Northern and Western regions.

4.1.3. Coal quality: lignite substitution scenario

Due to its low energy content, lignite is not as widely used as bituminous or anthracite coal. Although lignite composes 16% of China's coal reserves by mass, only 5% of the volume of China's 2005 coal production was lignite (see Figure 3). As more energy-rich and easily-accessible forms of coal are exhausted, lignite is likely to gain a growing share of national production. However, because the energy density of lignite is lower than that of bituminous or anthracite coal, a greater volume of lignite must be produced in order to deliver the same amount of energy contained in a lower volume of bituminous coal. Under conditions whereby the share of lignite production rises from its current 5% of total production to 12% of the total by 2025, an additional 220 million tonnes of additional coal would have to be mined to compensate for the lower energy content of the lignite (Figure 20). The energy content of U.S. coal production has also been declining: if 2006 coal had the same unit energy content as coal in 2000, the U.S. could have produced and transported 32 million tonnes less coal in 2006.[52]

Figure 20: Additional Production Requirements with 12% Lignite, 2005-2025



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[50] China State Electricity Regulatory Commission (SERC). 2009. http://www.serc.gov.cn/jgyj/ztbg/200903/W020090324593421835268.pdf.

[51] Feeley, T. et. al. 2005. "Department of Energy/Office of Fossil Energy's Power Plant Water Management R&D Program." www.netl.doe.gov/technologies/coalpower/ewr/pubs/IEP_Power_Plant_Water_R&D_Final_1.pdf.

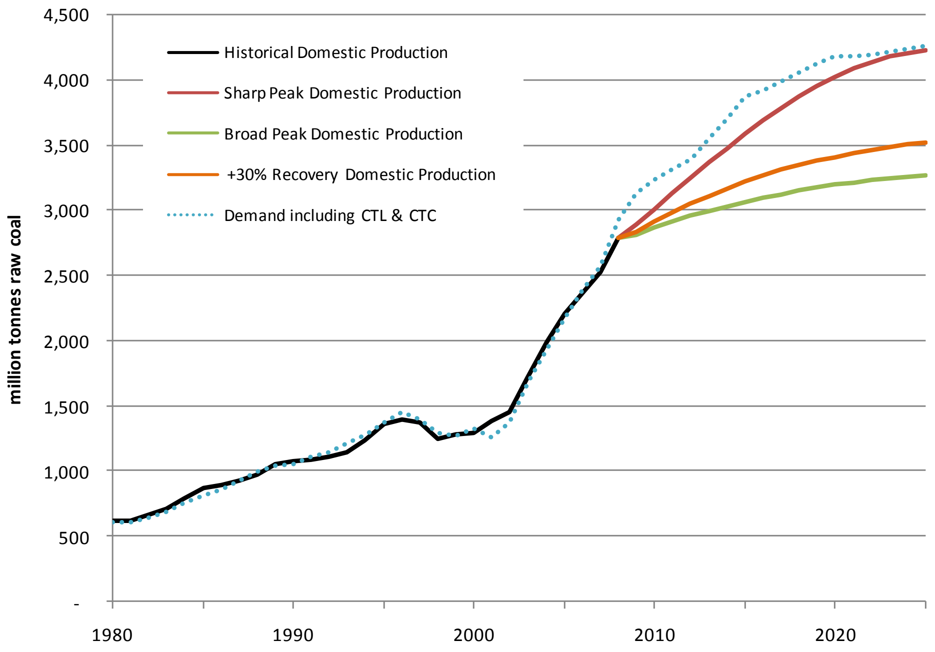
[52] U.S. EIA. 2008. 2007 Annual Energy Review. http://www.eia.doe.gov/aer/coal.html .

The transition to lower energy density coal types will put further stress on rail transport and power generation systems. Coal energy density could be increased by 20%--thus reducing the transport pressures—with more extensive coal washing. However, the high water requirement for coal washing, at 4 tonnes per tonne of raw coal, has constrained expansion of washing capacity in the water-deficit regions of North China.

4.2. Demand-supply gap under three scenarios

The mid-term future of Chinese coal production serves as the physical foundation for economic growth, political stability, and ballooning carbon emissions. Given the Ministry of Land and Resources estimate of 189 billion tonnes remaining domestic coal reserves and the historical production trajectory of other coal-intensive countries such as the United Kingdom, Japan, and Germany, Chinese production is likely to peak in the foreseeable future. The shape and timing of China's coal production peak will depend on technology, investment, and the water availability and geology of new discoveries. This analysis uses modified logistics curve analysis to indicate future production levels according to the Ministry of Land and Resources indicated economic reserve estimate of 189 billion tonnes coal. Three production scenarios are developed: a sharp peak whereby growth and decline are accelerated by aggressive investment, effective technology, and available reserves; a broad peak with more gradual extraction; and a later peak as an additional 30% of the resource base is converted into economically exploitable reserves. Figure 21 juxtaposes these three coal production scenarios with the total demand data illustrated in Figure 16.

Figure 21: China Coal Production Scenarios, 1980-2025



Whereas logistic analysis of reserve data generates 2025 domestic production between 3.25 billion tonnes for a broad peak scenario and 4.16 billion tonnes for a sharp peak scenario, the IEA has forecast 2025 Chinese coal production of approximately 4.33 billion tonnes and Chinese academic analysis posits production of 3.72 billion tonnes in 2025.[53] On the basis of published reserve data, none of the LBNL domestic coal scenarios include a production peak before 2025. If coal demand grows as described in Figure 16 (including coal-to-chemicals and coal liquefaction programs, as illustrated in the dotted line), these production scenarios would lead to a 2025 domestic coal gap between 32 million tonnes and 990 million tonnes. The scale of China's potential 2025 coal gap overshadows international coal imports, which reached an historic high of 51 million tonnes in 2007. A sharp peak production scenario would bring coal supply closer to demand; however, it would also require a more rapid draw down of existing reserves and a potentially more rapid post-peak decline.

4.3. Fuel switching

One Chinese response to the specter of coal deficits is to maximize the growth of alternative and especially renewable energy generation. In 2006, China implemented a Renewable Energy Law that aims to boost China's renewable energy capacity to 15 percent of total by the year 2020 and outlines a commitment to invest $180 billion in renewable energy over that period. However, the scale of coal demand growth in China—between 2003 and 2007 coal consumption growth ranged between 190 and 330 million tonnes per year—presents a challenge for fuel substitution.

Table 3: Energy Requirements for offsetting 200 Million Tonnes of Coal per year (~ one year of growth)

Thermal Equivalent	Generation Equivalent
107 billion cubic meters of natural gas	83 billion cubic meters of natural gas and 63 GW of new capacity @ 70% load factor
	48 GW of nuclear power capacity @ 90% load factor
	86 GW of hydropower capacity @ 50% load factor
	143 GW of wind power capacity @ 30% load factor

Natural gas

Idle natural gas-fired electricity capacity estimated at 10 GW out of 15 GW total indicates that China is already suffering shortages of supply despite a rapid rise in production over the past 5 years. If natural gas were used to offset one year of coal annual demand growth (approximately 200 million tonnes), 107 billion cubic meters of additional natural gas would be required on a thermal equivalent basis (for end use) or 83 billion cubic meters would be needed on a generation equivalent basis, assuming 63 GW of new capacity and a 70% load factor. This additional volume is beyond China's capacity to supply within the next 10 years, and would require the construction of at least two world-scale pipelines of 30 billion cubic meter capacity each as well as a faster ramp-up of LNG terminal construction and the realization of additional supply contracts. In additional, as long as electricity prices remain controlled at levels commensurate with overall coal pricing, natural gas is unlikely to be competitive against coal except in specific circumstances and locations, such as in southern coastal China or near LNG import terminals.

Nuclear power

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[53] IEA, World Energy Outlook 2007. Paris: IEA.
Tao Zaipu; Li Mingyu. 2007. "What is the limit of Chinese coal supplies—A Stella model of Hubbert Peak," *Energy Policy* 35(2007): 3145-3154.

China seeks to rapidly develop its nuclear power industry primarily to increase energy supply. The complexity, social risk, and high capital requirements are further justified by the nuclear power industry's potential to help mitigate problems from uneven resource distribution, coal transport bottlenecks, and environmental pollution. With coal and liquid transport fuel deficits in mind, Chinese researchers have suggested that nuclear power could be used for electricity generation, thereby freeing up coal for liquefaction. A more ambitious goal is to develop nuclear-coal conversion technology to produce liquid transport fuels based on high temperature nuclear process heat.[54]

In order to offset one year of coal demand growth of approximately 200 million tonnes coal, 48 GW of new nuclear power capacity would be required, assuming a 90% load factor for all new plants. At a capacity of 1 GW and a conservative cost of $1.5 billion per reactor, nuclear substitution of coal would cost $72 billion for the core hardware. Given China's announced 2020 target total nuclear electricity generation capacity target of 40 GW, it would take more than a decade to offset one year of coal demand growth.

China's nuclear power capacity reached 9.07 GW in 2007. Although the government has released aggressive plans for nuclear power development, it has not explained how it will ensure adequate domestic uranium supplies. An installed nuclear power capacity of 40 GW would require approximately 7,000 tonnes of uranium on an annual basis.[55] At a price of at least $130 per kilogram of uranium, China's identified resources are estimated at 60,000 tons of uranium.[56] However, China has increasingly close trading relationships with Australia and Kazakhstan, which is estimated to have the world's second largest uranium resources at 816,000 tons. In 2006 China signed an agreement to purchase 20,000 tonnes of Australian uranium per year beginning in 2010.[57] Nevertheless, the growth of nuclear power throughout Asia suggests that China's reliance on imported uranium may constrain rapid large-scale development.

Hydropower and Renewables

Without effective battery or storage technology, hydropower and renewables are imperfect substitutes for coal due to their intermittency. China is seeking to double its hydropower capacity from 145 GW in 2007 to 300 GW. In order to substitute for one year of new coal demand growth, 86 GW of new hydropower capacity would be required, assuming a 50% load factor. This is equivalent to building almost four Three Gorges Dams to offset one year of coal demand growth.

In 2007, wind power capacity jumped to 6 GW; however, wind still comprised less than 1% of China's total electricity generation capacity. Assuming a 30% load factor, 143 GW of new wind power capacity would be required to offset one year of coal demand growth. In 2008 China announced a new 100 GW target for wind electricity generation capacity in 2020—from its 2007 base, this would require an average annual growth rate of 24%.

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[54] Wang DZ, Ly YY. 2002. "Roles and prospect of nuclear power in China's energy supply strategy," *Nuclear Engineering and Design* 218(2002): 3-12.

[55] *Interfax China Energy Report Weekly*, March 27, 2008, Vol. 7:13, p. 4.

[56] World Energy Council. 2007 Survey of Energy Resources. London: WEC Press.

[57] See, for example, http://news.bbc.co.uk/2/hi/asia-pacific/4871000.stm.

4.4. Environmental externalities

Coal in China can be characterized as a cheap and abundant source of energy with expensive externalities. Coal mining and combustion are associated with a range of environmental costs including land subsidence, degeneration of water quality, air pollutant emissions, and acid rain, not to mention the horrific human costs related to more than 5,000 miner deaths per year. At the same time, the coal industry serves as a major foundation of rural employment and urban growth though electricity production. Beyond the immediate human and environmental costs, greenhouse gas emission mitigation provides an international impetus for China to tackle its coal dependence.

4.4.1. Carbon dioxide emissions

Coal is China's most carbon-intensive primary energy source. According to the IPCC, coal generates an average 95 tonnes of CO2 emissions per terajoule (TJ) of energy, compared to 73 t CO2/TJ for oil and 56 t CO2/TJ of natural gas.[58] The coal share of China's energy-related carbon emissions increased from 78% to 80% between 2000 and 2006. China's increasing reliance on coal is reflected in the rise of carbon intensity of commercial energy production from 2.26 kg carbon dioxide emitted per kg of coal equivalent energy produced in 1985 to 2.7 kg in 2006. The root of China's rising carbon emissions is clear: in 2006, coal combustion accounted for 80% of energy-related Chinese carbon dioxide emissions.

China's current growth trajectory indicates that carbon emissions from coal combustion will surpass total US energy-related carbon emissions by 2010. Figure 22 shows that China's coal-related carbon emissions would surge to 8.6 billion tonnes of CO2 in 2025 under the demand trajectory developed in this report (including CTL and CTC; 7.7 billion tonnes without the fourth wedge).[59] In contrast, the WEO 2007 projects total US energy-related carbon dioxide emissions to reach 6.7 billion tonnes in 2025.

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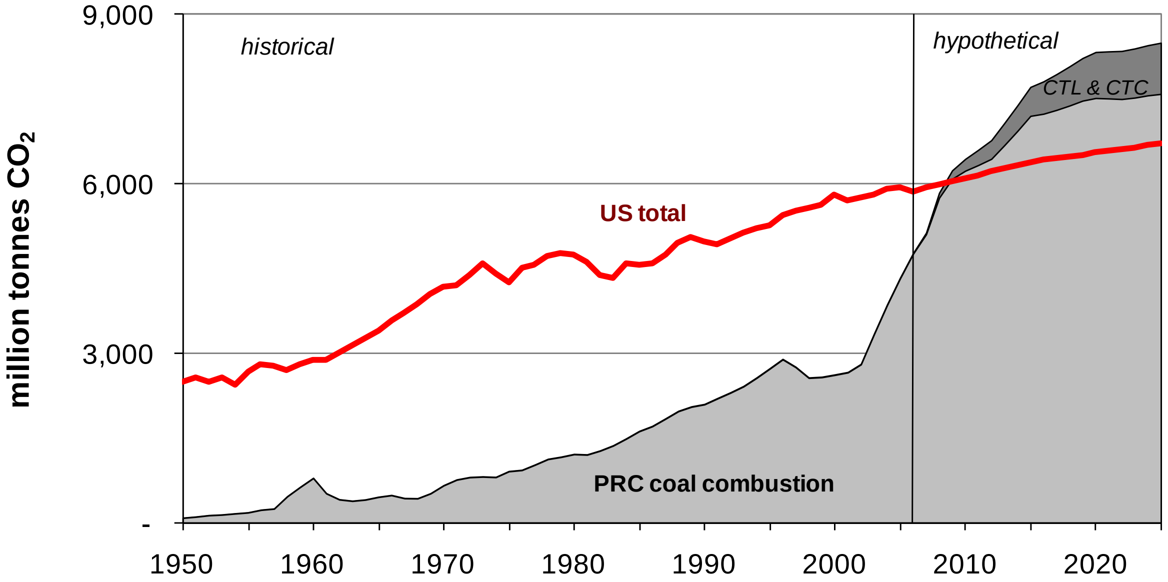
[58] IPCC. 1996. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual, 1.13. (http://www.ipcc-nggip.iges.or.jp/public/gl/guidelin/ch1ref1.pdf)

[59] This emissions scenario does not include potential effects from carbon capture and storage programs.

Figure 22: China Coal-related Carbon Dioxide Emissions, 1950-2030



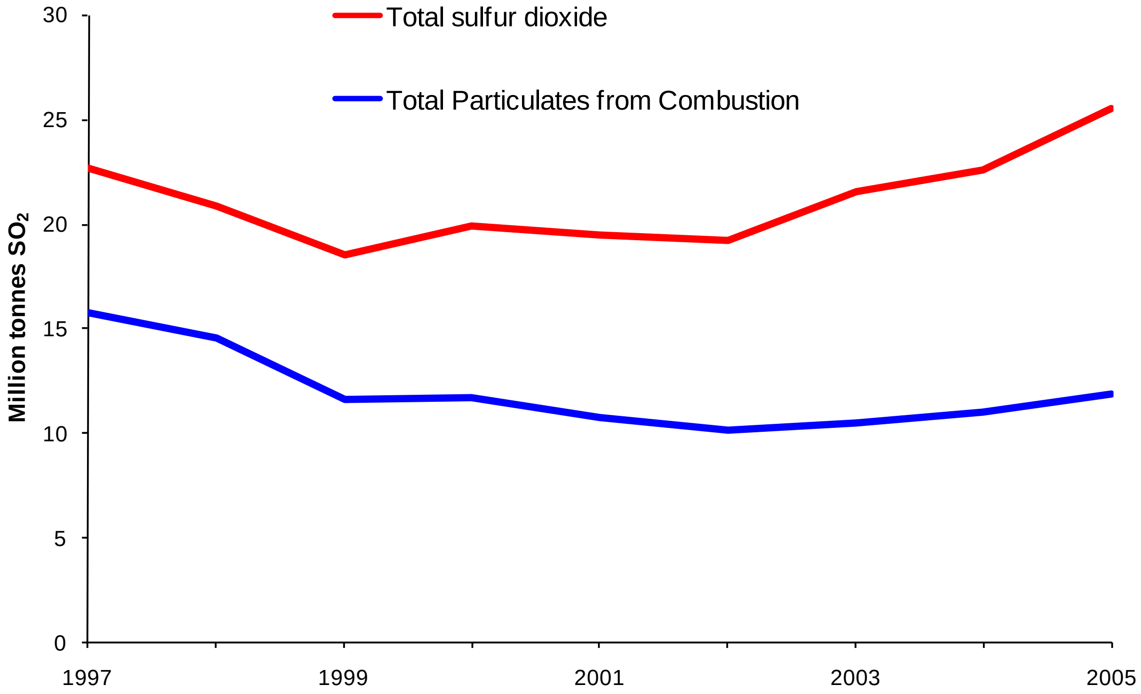
Note: historical and forecasted US emission data are from the IEA World Energy Outlook, 2007.

Limited alternatives to coal impede China's flexibility to achieve carbon dioxide emission growth constraints, much less absolute reductions.

4.4.2 Environmental quality

Coal mining and combustion are associated with a range of environmental costs including land subsidence, degeneration of water quality, air pollutant emissions, and acid rain. Sulfur dioxide and particulates are considered by many environmental experts in China to be the air pollutants of gravest concern, and efforts at controlling air pollution have focused on them (Figure 23). Ash and sulfur levels vary among Chinese coal types: raw ash fluctuates between 20% and 40% and sulfur between 1% and more than 5%. Since the 1980s, the fraction of China's coal that has been washed has been stable, and flue gas desulfurization is only now becoming widespread.

Figure 23: Sulfur dioxide and particulate emissions, 1997-2005



Source: China Environment Yearbook, various years.

As more becomes known about the health impacts of airborne particulates, especially very small particulates that are drawn deep into the lungs, they are considered responsible for a greater share of the world's ill health than previously thought (WHO, 2004). Particulate emissions from combustion and physical processes (like industrial grinding) fell rapidly in China in the 1990s as relatively inexpensive particulate controls were installed on a larger share of industrial facilities. In recent years, however, rising coal use and industrial activity have led to an upturn in particulate emissions.

The impacts of a coal-dominated energy economy are felt all along the fuel chain. About 4,000 miners die each year in accidents in China's coal mines, according to official statistics, though the actual number may be substantially higher. An unknown number also die from occupational diseases. Coal gas and coking plants are also associated with high incidences of cancer. While new combustion technologies and improved regulation will help to abate some of the most egregious health impacts, the ongoing dominance of coal portends continued environmental costs associated with expanded energy usage.

Nationwide damages from air and water pollution have been estimated to have a value between 3% and 7.7% of GDP. The destructive impact of air pollution on human health and physical infrastructure is likely to increase as rapid urbanization and expanding cities locate a growing proportion of the population nearer to pollution sources.[60]

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[60] Ho, Mun S. & Chris P. Nielsen. (2007) *Clearing the Air: The Health and Economic Damages of Air Pollution in China*. Cambridge, MA: MIT Press.

V. Conclusions

China has been, is, and will continue to be a coal-powered economy. The rapid acceleration of coal demand growth after 2001 has raised questions about China's mid-term supply security. If demand continues to grow rapidly and supply develops according to published domestic reserve estimates a coal deficit is likely to emerge.

Urbanization, heavy industry growth, and increasing per-capita consumption are the primary drivers of rising coal usage. In 2006, the power sector, iron and steel, and cement accounted for 71% of coal consumption. Power generation is becoming more efficient, but even extensive roll-out of the highest efficiency units could save only 14% of projected 2025 coal demand. A new wedge of future coal consumption is likely to come from the burgeoning coal-liquefaction and chemicals industries. New demand from coal-to-liquids and coal-to-chemicals may add up to 450 million tonnes of coal demand by 2025. Growth with efficiency improvements among these drivers indicates that China's annual coal demand will reach 3.9 to 4.3 billion tonnes by 2025.

Central government support for nuclear and renewable energy has not been able to reduce China's growing dependence on coal for primary energy. Few substitution options exist: offsetting one year of recent coal demand growth would require over 107 billion cubic meters of natural gas, 48 GW of nuclear, or 86 GW of hydropower capacity. While these alternatives will continue to grow, the scale of development using existing technologies will be insufficient to substitute significant coal demand before 2025. The central role of heavy industry in GDP growth and the difficulty of substituting other fuels suggest that coal consumption is inextricably entwined with China's economy in its current mode of growth.

Ongoing dependence on coal reduces China's ability to mitigate carbon dioxide emissions growth. If coal demand remains on its current growth path, carbon dioxide emissions from coal combustion alone would exceed total US energy-related carbon emissions by 2010. Broadening awareness of the environmental costs of coal mining, transport, and combustion is raising the pressure on Chinese policy makers to find alternative energy sources.

The looming coal gap threatens to derail China's growth path, possibly undermining political, economic, and social stability. High coal prices and domestic shortages will have regional and global effects. Regarding China's role as a global manufacturing center, a domestic coal gap will increase prices and constrain growth. Within the Asia-Pacific region, China's coal gap may bring about increased competition with other coal-importing countries including Japan, South Korea, Taiwan, and India. As with petroleum, China could respond with a government-supported "going-out" strategy of resource acquisition and vertical integration. Given its population and growing resource constraints, it may be difficult for China to balance energy security, competitiveness, and local environmental protection with costly efforts at global climate change mitigation. The possibility of a large coal gap suggests that Chinese and international policy makers should maximize institutional and financial support to moderate demand and improve energy efficiency

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