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Outlook and Challenges for Chinese Coal

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Executive summary

- China has been, is, and will continue to be a coal-powered economy. The rapid growth of coal demand since 2001 has created deepening strains and bottlenecks that raise questions about supply security.

- Although China's coal is "plentiful," published academic and policy analyses indicate that continued growth in coal output will lead to a peak in production most likely occurring between 2016 and 2029. Given the current economic growth trajectory, domestic production constraints would lead to a coal gap that may not be possible to fill with imports.

- Urbanization, heavy industrial growth, and increasing per-capita consumption are the primary interrelated 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 for the power sector.

    - If China follows Japan in terms of per capita steel use, steel production would peak by 2015, and cement is likely to follow a similar trajectory.

    - A fourth 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 450 million tonnes of coal demand by 2025.

    - Even with more efficient growth among these drivers, China's annual coal demand will reach 4.2 to 4.7 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 of 200 million tonnes would require over 107 billion cubic meters of natural gas, 48 GW of nuclear, or 86 GW of hydropower capacity.

- 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.

- 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's is short of high-quality reserves, but is producing its best coal first. Declining quality will further strain production and transport. 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.

- 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. Within the Asia-Pacific region, China's coal gap is likely to bring about increased competition with other coal-importing countries including Japan, South Korea, Taiwan, and India. As with petroleum, China may respond with a government-supported "going-out" strategy of resource acquisition and vertical integration. Given its population and growing resource constraints, China may favor energy security, competitiveness, and local environmental protection over 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 growth and improve energy efficiency.

1. Overview

This study seeks to answer the following questions:
What are the major drivers of China's future coal demand?
Can coal use be decoupled from economic growth?
How can China overcome resource constraints and transport bottlenecks to meet demand and sustain growth?
Can coal be substituted with other energy forms?
What are the carbon- and environmental implications of China's forecast coal demand?

The following six sections address these questions by identifying particular characteristics of China's coal industry and factors driving supply and demand. Section two reviews the range of Chinese and international estimates of remaining coal reserves and resources. Section three reviews key characteristics of China's coal industry including historical production, resource requirements, and prices. Section four quantifies the largest drivers of coal usage to produce a bottom-up projection of 2025 coal demand. Section five reviews production scenarios to estimate the extent of China's looming coal gap, including analysis of international coal trade and potential mitigation tools. Section six examines the feasibility of substituting coal with other fuels or reducing coal usage through efficiency policies. Section seven examines the environmental and economic implications of prolonged coal dependence. Finally, section eight presents conclusions on the role of coal in China's ongoing energy and economic development.

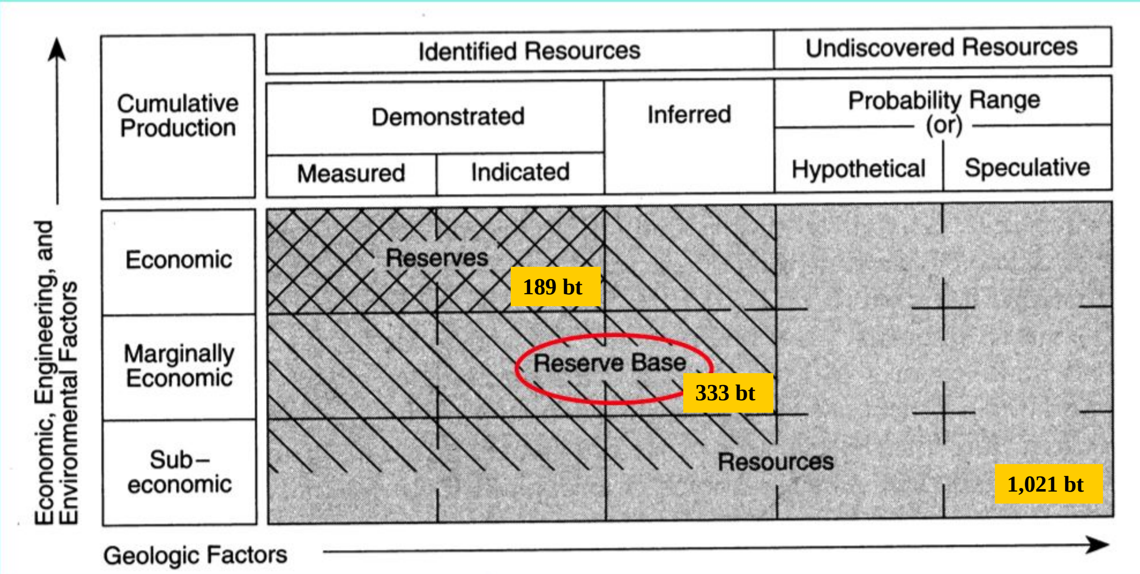
2. China Coal Resource Estimates

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. Total 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 to 700 billion tonnes in the 1950s to 300 billion tonnes in the 1970s, prior to a series of extensive national resource surveys since the 1970s. In 1992, China reported their reserves to the World Energy Council (WEC) as 114.5 billion tonnes, and WEC has continued to use this number in spite of 25 billion tonnes of Chinese domestic coal consumption since then. The implication of the WEC's frozen reserve estimate is that resources were converted into reserves at a rate equal to annual consumption—or that the Ministry of Land and Resources has not formally reported revised numbers. 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. Figure 1 breaks down China's coal resource and reserve estimates, from 189 billion tonnes of indicated economically-viable coal, 333 billion tonnes as reserve base, on a 1,021 billion tonnes estimate of total resources.[2]

Figure 1: China Coal Resources and Reserves, 2006



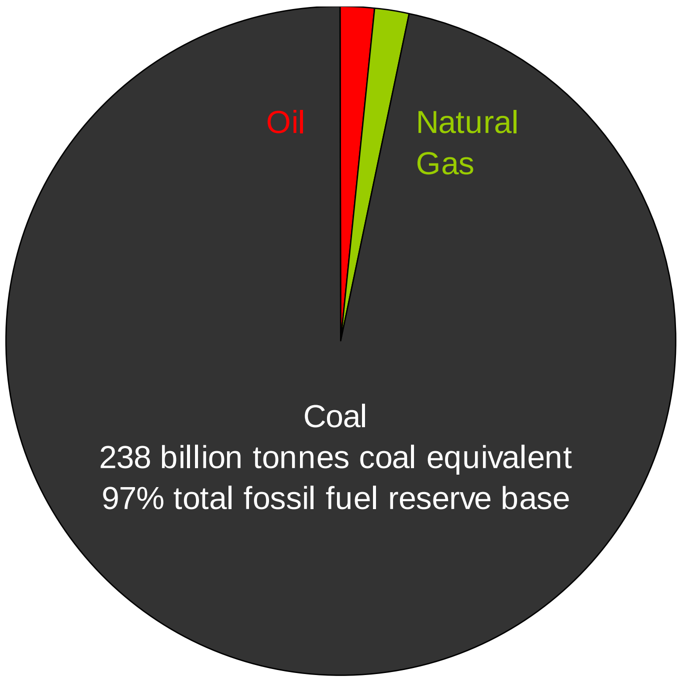
[1] World Energy Council. 2007 Survey of Energy Resources. London: WEC Press.

[2] 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.

Source: http://fti.neep.wisc.edu/neep533/SPRING2004/lecture2.pdf; NBS 2007.

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 of coal, oil and natural gas (基础储量; translated in Chinese sources as "ensured reserves") published in the 2007 China Statistical Yearbook. Here NBS reports estimate of 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 333 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.

Figure 2: Energy Content of China's Fossil Fuel Reserve Base, 2006

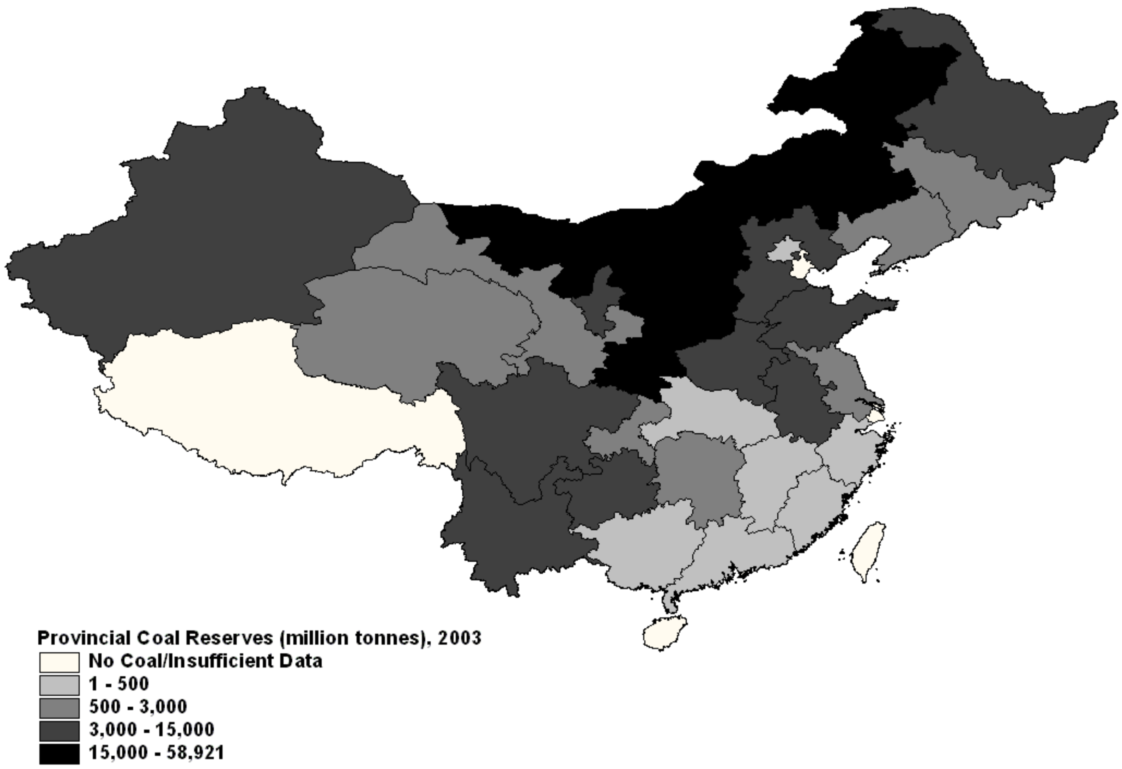


2.2. Reserves by location, quality, and depth

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

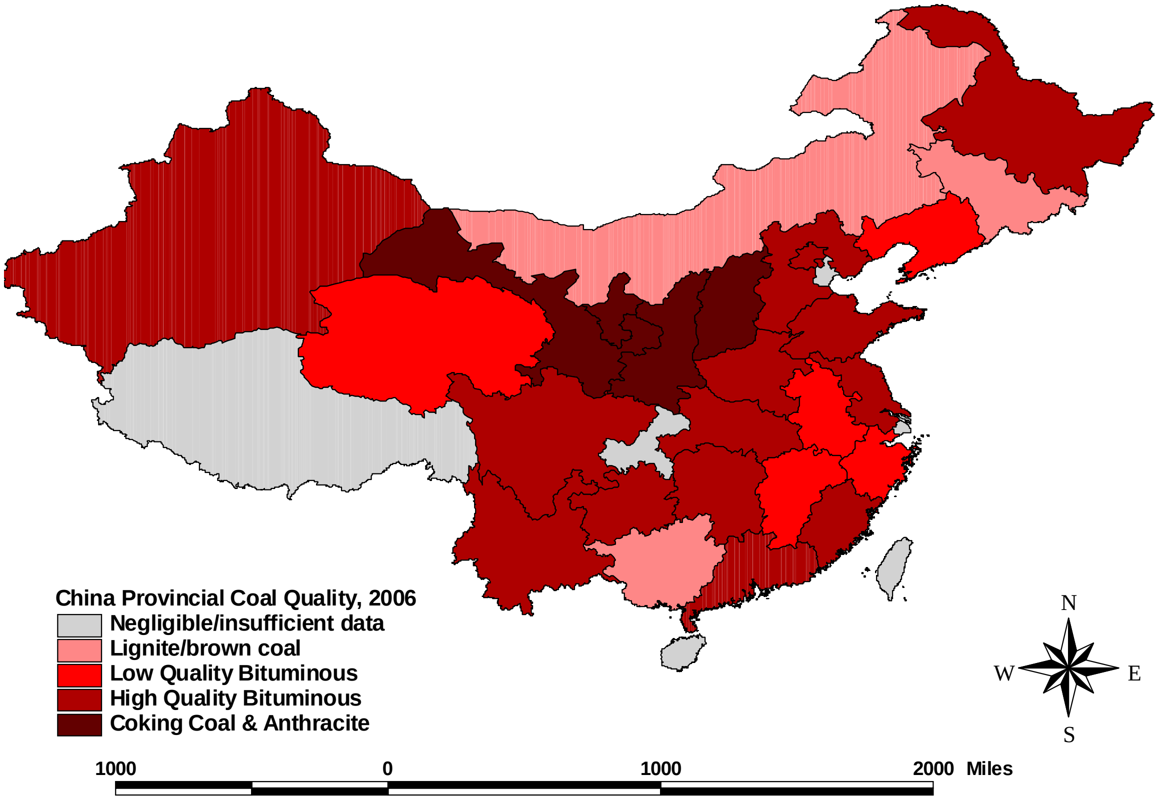


The quality of China's coal production ranges from 3,446 kcal/kg in Guangxi to 6,245 kcal/kg for Ningxia coal.[3] Map 2 shows the average heat value of coal for each province. Provinces with an average heat value less than 4,000 kcal/kg are labeled as lignite/brown coal; low quality bituminous coal provinces are in the range of 4,000-5,000 kcal/kg; high quality bituminous coal provinces are in the range of 5,000-6,000 kcal/kg; and provinces with an average heat value above 6,000 kcal/kg are labeled "coking coal and anthracite". 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, versus 29% sub-bituminous and 16% lignite.[4]

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

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

Map 2: China Coal Quality by Province, 2006[5]



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.[6] Only 27% of northern Chinese coal is located less than 1,000 meters below the surface, compared to 40% of total Chinese coal.[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. Mines in eastern China are particularly deep, with an average depth of 600 meters. Although the 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.[8] Due to deep coal

[5] Ghee Peh, Wei Ouyang. (2007) *UBS Investment Research: China Coal Sector*. (17 January 2007; www.ubs.com/investmentresearch)
[6] IEA. (2007) *World Energy Outlook 2007*.
[7] Pan Kexi. (2005) "The Depth Distribution of Chinese Coal Resource," Fudan University, School of Social Development and Public Policy. August 22, 2005.
[8] IEA. (2007) *World Energy Outlook 2007*.

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 affects the rate of ultimate coal recovery from the mine reserves, and increases the costs of mining relative to open-pit mining.

3. Characteristics of China's Coal Mining Industry

The coal mining industry serves as the foundation of China's energy system and economy. This section describes five aspects of China's coal industry: the type of coal produced; the structure of mine ownership; the geography of coal production; water and resource requirements for coal production; and coal prices. The defining aspects of China's coal industry have played a central role in facilitating, and sometimes restraining, rapid economic development.

3.1. Production by coal type

In recent years, China has maximized its high-quality coal production by primarily focusing on the production of bituminous coal, with much smaller degrees of anthracite, lignite and brown coal production. From 1980 to 2005, the production volume of all three major types of coal has increased, with the exception of decreasing production between 1998 and 2001. At the same time, each coal type's relative share of total production has remained constant, with bituminous coal composing the majority of production, followed by smaller shares for anthracite, lignite and brown coal. The general production trends of each type of coal and its relative share of total production can be seen in the two figures below.

Figure 3: China Production & Reserves by Coal Quality, 1980-2005

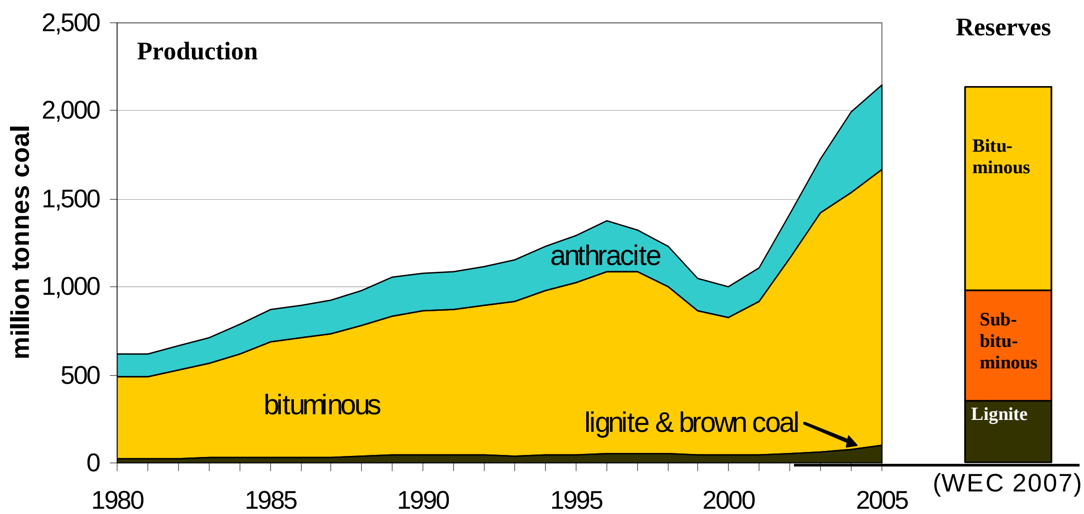
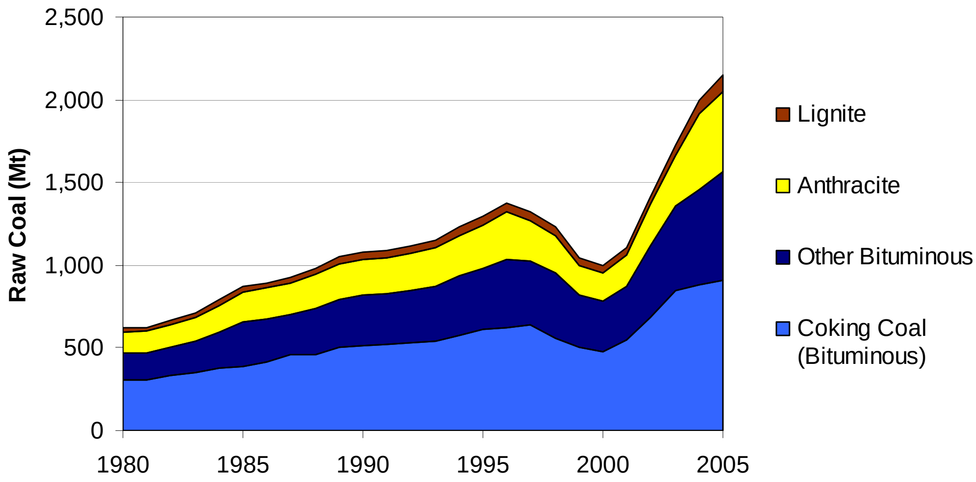
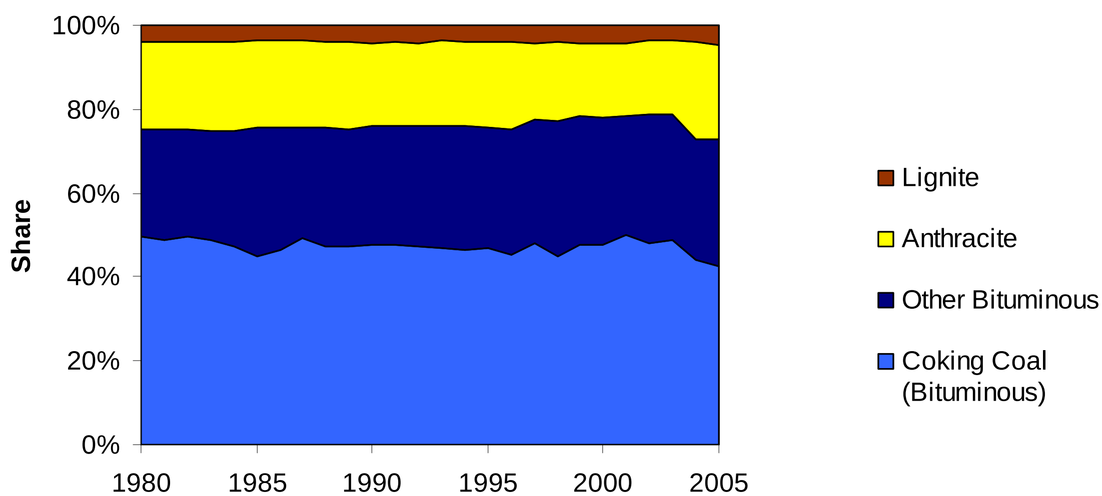


Figure 4: Raw Coal Production by Type of Coal



Note: production data are reported by coal quality rather than end use.

Figure 5: Raw Coal Production Shares by Type of Coal



Note: production data are reported by coal quality rather than end use.

As illustrated in the figures above, China's production of bituminous coal has risen steadily, with comparable increases in both bituminous coking and other bituminous coal. As the largest share of total coal production, bituminous coal consisted of 76% of China's total coal production. With the exception of a dip in the late 1990s, bituminous coal production has increased each year, rising from 467 million tonnes in 1980 to 1567 million tonnes in 2005. During this period, an average of 47% of China's total coal production was composed of coking coal while 29% composed of other general bituminous coal. There were no major fluctuations in the relative proportions of coking and other general bituminous coal, except a slight decrease in coking coal in 2004 and 2005.

Anthracite coal production follow 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 487 million tonnes in 2005. This was followed by the production of lignite and brown coal, which also increased four-fold in production volume from 24 to 98 million tonnes. However, lignite and brown coal only composed of a 4% share of total coal production.

3.2. Production by mine ownership

Institutional restructuring in the initial reform period was driven by fiscal decentralisation and the gradual expansion of rural property rights. In 1983, 'township and village enterprises' began to replace 'commune and brigade enterprises,' thereby increasing local fiscal autonomy and introducing incentives for growth. Within the coal industry, these reforms stimulated the expansion of small collective and private mines from 18 percent of total production in 1980 to more than 48 percent in 1996.

During the 1980's the central government enacted a series of laws, measures, and plans to stimulate coal production, thereby compensating for disappointing returns in the domestic petroleum sector (Levine and Sinton, 2004: 18). In 1983, the Ministry of Coal Industry issued a 'Report on Eight Measures to Accelerate the Development of Small Coal Mines,' as well as a 'Notice of Further Relaxation of Policies and Development of Local Coal Mines' the same year. Gradual price liberalisation and regulatory 'relaxation' encouraged local and small scale coal production. A three-tier system of 'plan,' 'indicative,' and 'negotiated' (market) prices was established, and in 1984 state-owned coal mines were permitted to sell 5 percent of their output at negotiated prices. Small coal mines, on the other hand, were free to determine amount of production and level of product pricing. Regulatory decentralisation further benefited small and local producers insofar as the local governments that supervised small mines were also dependent on them to generate scarce tax revenue—a situation that persists in many localities.

Beyond the structural implications of fiscal and regulatory decentralisation, coal industry production was stimulated by central government investment and industry subsidies. For example, the Sixth Five Year Plan, which was adopted in 1982, articulated investment and production goals for the expansion of a Shanxi Energy Base for national coal production. Industry-wide production incentives were provided by low taxes and subsidies, including the central government's 'coal replacement of oil' program. According to government budget statistics, these coal subsidies grew from 940 million RMB in 1983 to 2.3 billion RMB in 1990.[9]

While industry subsidies grew, the passage of the Mineral Resource Law in 1986, and the coal industry corporatization in 1988, extended the central government's withdrawal from energy sector management. The Mineral Resource Law constituted an ex-post-facto reassignment of coal exploration rights from central to local governments and local entrepreneurs. Rather than defining a strong institutional framework, this law codified

[9] All RMB values are in deflated year 2000 RMB unless otherwise noted; source: China Energy Industry Yearbook (1991).

central government non-intervention—the Rules for the Implementation of the Mineral Resources Law were not published until eight years later, in 1994. In 1988 the Ministry of Coal Industry (MOCI) was transformed into the China National Coal Corporation, the Northeast Inner Mongolia United Coal Industry Corporation, and the China National Local Coal Mine Development Corporation, thereby echoing the transfer of property rights to small collective and private mines on a national level. The regulatory functions of MOCI were transferred to a newly created Ministry of Energy under the State Planning Commission. Given the dearth of rural capital, coal corporatisation encouraged the establishment of small, low technology/investment mines with minimal overhead.

During the initial reforms and into the 1990s, a rough balance was achieved between the costs and benefits of small coal mine proliferation. Aside from dramatically increasing aggregate low-cost energy production, small mines stimulated rural employment and economic growth while reducing bottleneck pressure on limited rail and water transport capacity. However, the environmental, human safety, and market distortion costs of local mining became more evident as the coal sector continued to boom in the 1990's. In raw cost-of-life terms, the perilous nature of small, local coal mining is reflected in its average death rate of 10.33 miners per million tons of coal produced between 1995 and 2003, compared to 1.27 for miners in large, centrally-administered state-owned mines during the same period.[10] Coal consumption is also associated with a range of health problems, primarily caused by combustion of mineralised coal, which can lead to arsenic, fluorine, selenium, and mercury poisoning (Finkelman et al, 1999: 3427). Anecdotal evidence also abounds on the deleterious impacts of mines on land and water resources, which have been the cause of numerous environmentally-motivated disputes. Moreover, local governments' dependence on small mines for revenue resulted in lax regulation. Exclusive focus on production and revenue led to sub-optimal levels of investment and poor environmental, health, and safety performance, thereby undermining the market for coal produced by larger, properly regulated mines.

When export demand began to wane with the 1997 Asian financial crisis, the central government initiated a spate of structural reforms intended to improve government cost-effectiveness and state-owned enterprise (SOE) competitiveness. Within the energy sector, the 1998 reforms were oriented around bureaucratic restructuring and industry consolidation, including an extensive campaign to close down small unregistered coal mines. Flagging demand and more rigorous government regulation combined to steeply reduce coal production, particularly from small collective and private mines, between 1996 and 2000. Changes in the coal sector were reflected in structural reform of the central government bureaucracy. China's energy bureaucracy had been marked by periodic decentralisation and reconsolidation: in 1993 the Ministry of Energy was dissolved in favour of more specialised oversight by the Ministry of Coal Industry, only to be taken over the by State Administration of Coal Industry (SACI), an office of the State Economic and Trade Commission (SETC), in 1998 (Levine and Sinton, 2004: 14). In addition to cutting government costs, the 1998 reforms were intended to separate economic regulation (SETC), strategy (State Development Planning Commission (SDPC)), and management (local governments and the Ministry of Land and Natural

[10] Mortality data are derived from *Coal Economic Research*, 2005 Edition, p.24, chart 23.

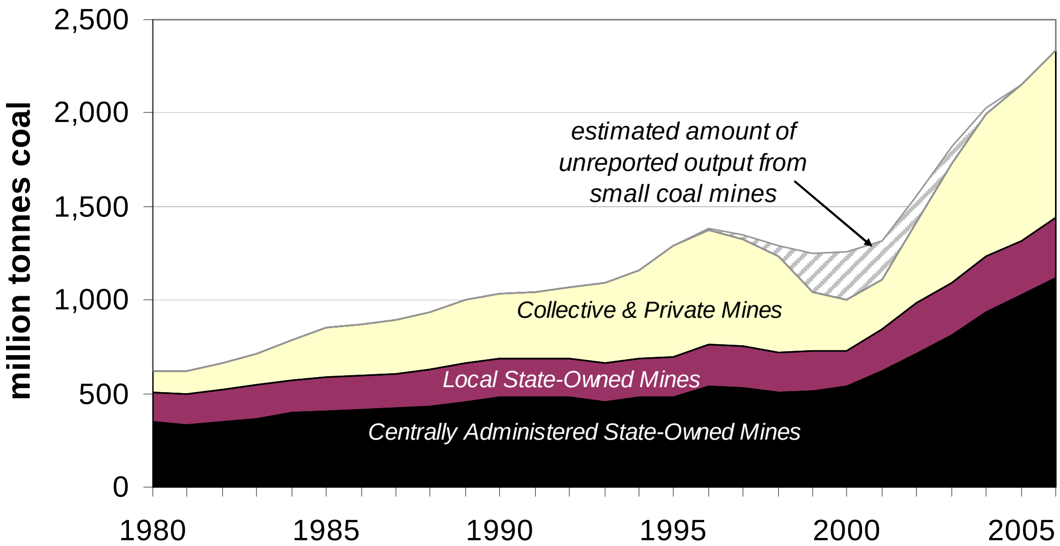
Resources (MLNR)) of the energy sector, and particularly the coal industry. As such, the reforms included the transfer of large SOE coal mines from SACI to provincial authorities. Although the 1998 reforms served to reduce central government costs rather than introduce effective local regulation per se, they did provide impetus for subsequent measures to increase competitiveness and level the producer playing field.

The principal thrust of the 1998 reform process was an enforced consolidation of mining enterprises into larger conglomerates. Agglomeration complemented the transfer of large mining assets to provincial governments and the hardening of budgetary constraints. The 1998 reforms, as well as more recent central government enforcement of mine safety regulations, have facilitated the gradual internalisation of health and environmental externalities into China's coal pricing system. By increasing producer competition and strengthening local regulatory mechanisms, these reforms presented an opportunity to improve the environmental performance of China's coal sector, provided that local state ownership, policy-making, regulation, and management functions were kept separate (Andrews-Speed, 2004: 183).

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 have decreased, from a share of 56% in 1980 to 47% in 2005, while the shares of collective and private mines have both increased. Moreover, 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.

The specific trends of total coal production shares of centrally administered state-owned mines, local state-owned mines and collective and private mines have all fluctuated greatly over the last two and half decades. On one hand, centrally administered state-owned mine ownership experienced decreasing shares of total production throughout the 1980s and 1990s, followed by a brief increase from 2000 to 2003. On the other hand, collective and private mines witnessed the opposite trend, with rising shares of production through the 1980s and 1990s, before decreasing in the last decade and then most recently increasing again in the last few years. In fact, production shares from centrally administered state-owned mines reached its lowest share of 37% in 1995 while collective mines' share reached its highest at 46% of total production.

Figure 6: Coal Production by Mine Ownership, 1980-2006



Source: Coal Industry Yearbook, various years.

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 can be attributed to almost all of the gains in national coal production. 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%.[11] NDRC-mandated mine closures were expected to reduce production by 200 million tonnes—perhaps a key reason that mines were re-opened in 2008. Industry consolidation and mechanization are key efforts in the NDRC's target of raising average recovery rates from the 2005 official average of 46% to 50% by 2010.[12]

In the 2005 *China Energy Statistical Yearbook*, NBS published revised energy production, consumption, and usage data covering the years 1998 to 2003. Most of these revisions relate to coal production and consumption, though natural gas data have also been adjusted. The official ex-post facto revisions are not reflected in Figure 6 because the *Coal Industry Databook* has not been retrospectively revised.

[11] International Energy Agency (IEA). 2007. *World Energy Outlook 2007*. Paris: IEA.
[12] National Development Reform Commission (NDRC). 2007. *11th Five Year Plan on Energy Development*, NDRC, Beijing.

Figure 7: Coal Production Data Revisions

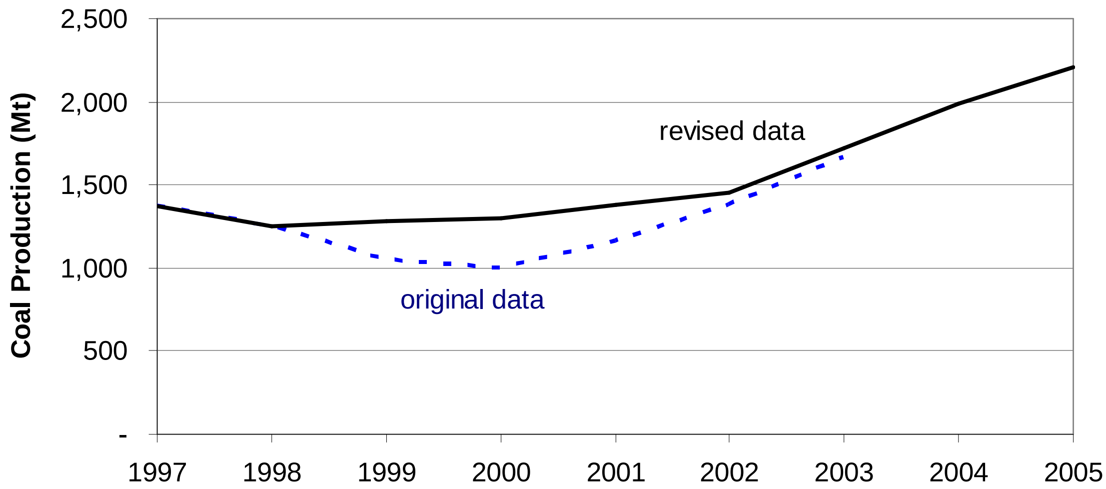
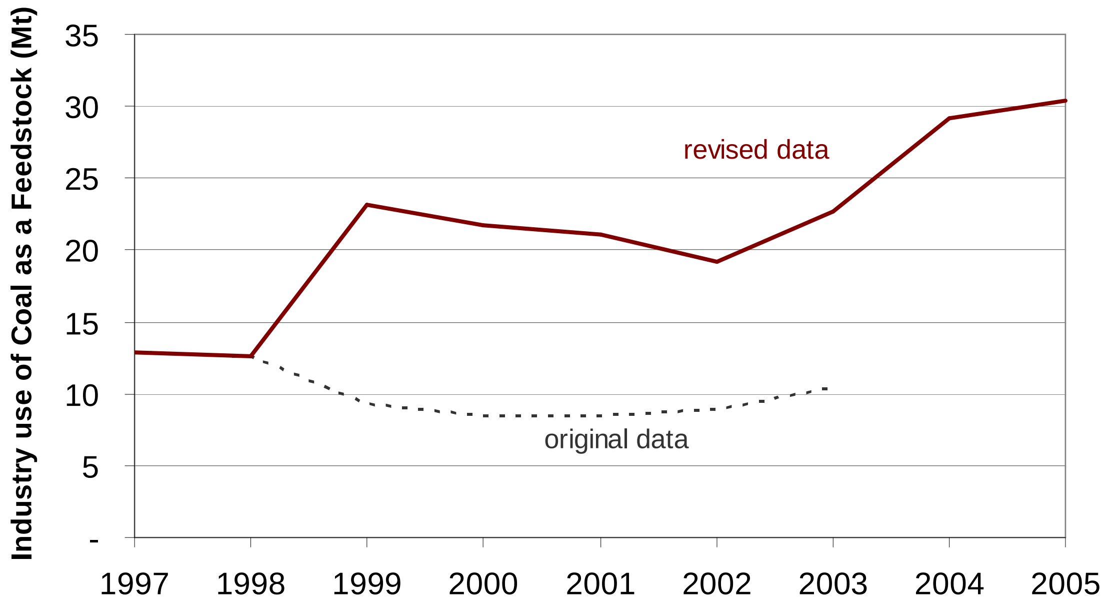


Figure 8: Data Revision for Industry Use of Coal as a Feedstock



The upward revision of coal production data served as an acknowledgement that many small and locally-owned mines continued to operate during China's mine closure campaign in the late 1990's. The upward revision of industry feedstock use of coal is likely to have been driven by surging fertilizer and chemical production from unofficially produced coal. These revisions underscore the difficulty of rapidly adjusting China's coal industry structure using national policy directives.

Nonetheless, the national government has announced a bevy of policies designed to consolidate and strengthen China's coal mining industry. In 2006, the National Development Reform Commission (NDRC) announced that only mines producing at least 300,000 tonnes per year would be considered for approval. In an attempt to raise recovery rates and increase safety, the NDRC has also announced that it intends to reduce the number of small mines to 10,000 by 2010.[13] China's average coal recovery rate is 30% nationally and 40% in Shanxi province.[14] Low coal prices, lack of government or market-based mechanisms to encourage resource conservation, and antiquated mining technology suppress China's coal recovery rate. The government has announced plans to raise the average recovery rate above 40% while increasing total coal production. 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 ability to encourage small mines to reopen in an attempt to ameliorate China's current coal shortages. As in the post-1997 campaign to shut down small coal mines, there are tradeoffs between improved aggregate coal recovery rates and local-scale investment and regulatory costs.

3.3. Production by province

The geographic distribution of coal production is characterized by a high concentration in northern China, followed by the eastern, southwestern and southern central provinces. In 2000, for instance, the north was responsible for 37.8% of total coal production, followed by the east with 17.6%, the southwest with 13% and the northeast and south central with 11% each. More specifically, the first, fourth and fifth largest coal producing provinces of Shanxi, Inner Mongolia and Hebei, respectively, are located in north China while the second largest province of Shandong is located in east China and third largest province of Henan is located in south-central China.

In 2005, the regional rankings in terms of coal production remained the same, but the north's production share increased to 40.9% while the east's share decreased to 13.6%. The regional shifts in production were also reflected in the production rankings of provinces, with Inner Mongolia becoming the second largest producing province while Shandong fell from second to fifth largest production share. Specifically, Mongolia's share of national production increased from 6.9% in 2000 to 11.5% in 2005, while Shandong's share decreased from 7.6% to 6.2%. Henan and Shaanxi province also experienced growth in output share, making them the third and fourth largest coal producing provinces.

Table 1: Coal Production and Consumption by Regions and Key Provinces

	2000			**2005**		
	Production (Mt)	% of Total Production	Consumption (Mt)	Production (Mt)	% of Total Production	Consumption (Mt)
East	185.91	17.6%	373.12	300.91	13.6%	743.37
Shandong	80.39	7.6%	87.05	140.3	6.3%	251.41
North	398.36	37.8%	256.4	906.18	40.9%	547.58
Hebei	67.47	6.4%	118.9	86.39	3.9%	205.42

[13] National Development Reform Commission (NDRC). 2007. *11th Five Year Plan on Energy Development*, NDRC, Beijing.
[14] See for example http://www.cnmn.com.cn/Show_26346.aspx.
[15] See for example http://www.guardian.co.uk/business/feedarticle/7644650.

Inner Mongolia	72.47	6.9%	59.73	256.08	11.5%	137.07
Shanxi	251.52	23.9%	26.62	554.26	25.0%	136.81
Northeast	116.94	11.1%	192.53	190.92	8.6%	275.58
Northwest	100.27	9.5%	84.71	260.23	11.7%	221.29
Shaanxi	37.75	3.6%	27.66	152.46	6.9%	107.28
Southcentral	116.05	11.%	227.3	276.21	12.5%	483.25
Henan	75.78	7.2%	52.79	187.61	8.5%	169.07
Southwest	136.55	13.0%	134.15	283.83	12.8%	254.66
Total	1,054.08	100%	1,268.21	2,218.28	100%	2,525.74

If provincial production is considered in terms of net trade by accounting for intra-provincial consumption, then the western provinces of Shanxi and Inner Mongolia emerge as clear leaders in export volume, followed by Shaanxi and Guizhou provinces. In spite of its sizable production share, Shandong, in contrast, is a net importing province.

3.4. 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 in this region have posed problems for increased production and coal washing. Specifically, North China contains the vast majority of domestic coal reserves and more than half the population; however, North China 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 have been 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.

In terms of water requirements for the coal mining industry, it has been estimated that the extraction of 1 tonne of coal requires 53 – 120 liters of water.[17] Furthermore, 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 this high water requirement for coal washing, the proportion of washed coal production has remained low. Finally, water is also needed for cooling at thermal electric mine-mouth power plants.

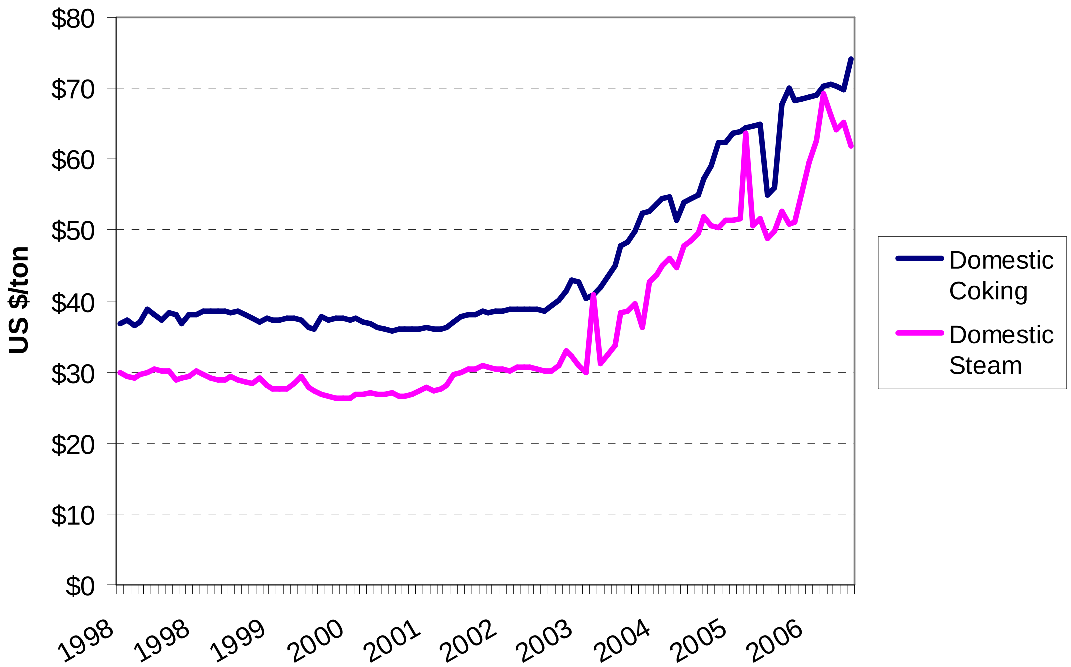
3.5. Domestic and international coal prices

In the past decade, Chinese domestic coking and steam coal prices have generally increased but differ in the specific price trends. From 1998 to 2002, domestic prices for coking and steam coal were relatively stable, as seen in Figure 9 below. Domestic coking

[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.

coal prices decreased slightly from 1998 to mid-2000 from USD $38 per tonne range to the lowest of $36 per tonne, and then increased slightly back to the $38 per tonne range by 2002. Domestic steam coal prices, on the other hand, fluctuated a bit more without any general trends through early 2002 but prices remained in the range of USD $26 to $29 per tonne.

Figure 9: Chinese Domestic Prices for Coking and Coal, 1998 - 2006



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

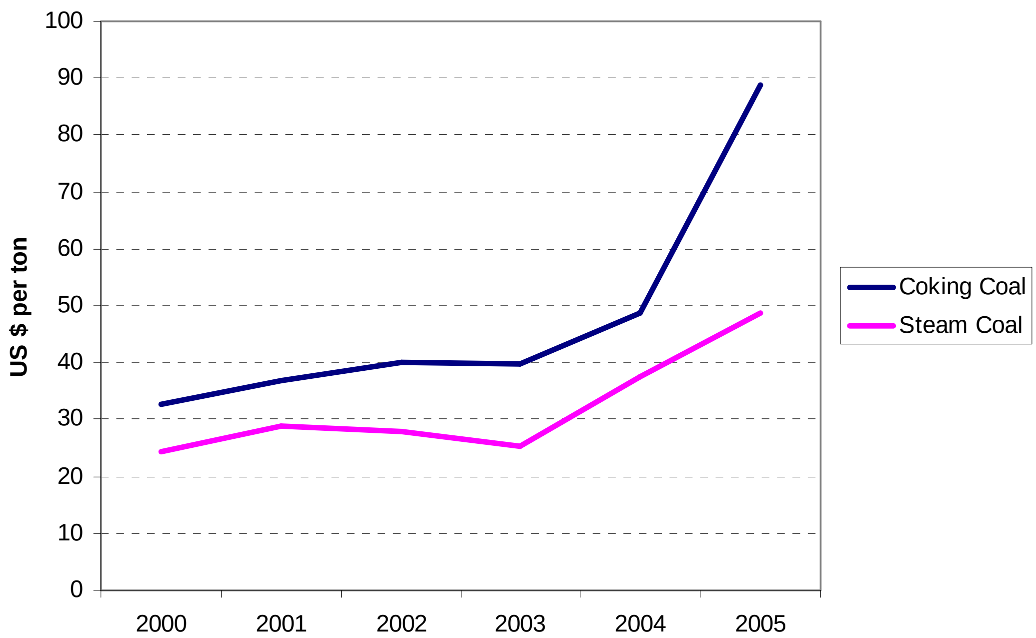
From 2002 to late 2003, however, the domestic prices for coking coal increased significantly, rising by $6 per tonne to $44 per tonne by the end of 2003. This price increase was more notable by 2004, with prices reaching a high of $70 per tonne in early 2006. In general, prices increased during this period with some exceptions. In October of 2005, for examples, prices dropped significantly from $64 per tonne to the mid-$50s before increasing back to $68 per tonne range by December. Price remained stable until the end of 2006, when demand growth driven by rapid expansion in the iron & steel industry pushed prices higher. Since then, prices have risen further. 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.[18] Datong premium blend (6,000 kcal/kg) traded in May 2008 at 655-670 RMB per tonne FOB ($94-96/tonne).[19]

From an international perspective, China's domestic coal prices after 2000 have been increasing more consistently than other countries, like Australia. In contrast to Chinese domestic prices, Australia's FOB export value for coking coal was relatively stable

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

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 (see Section 5.1), 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.

Figure 10: Australia FOB Coal Export Values

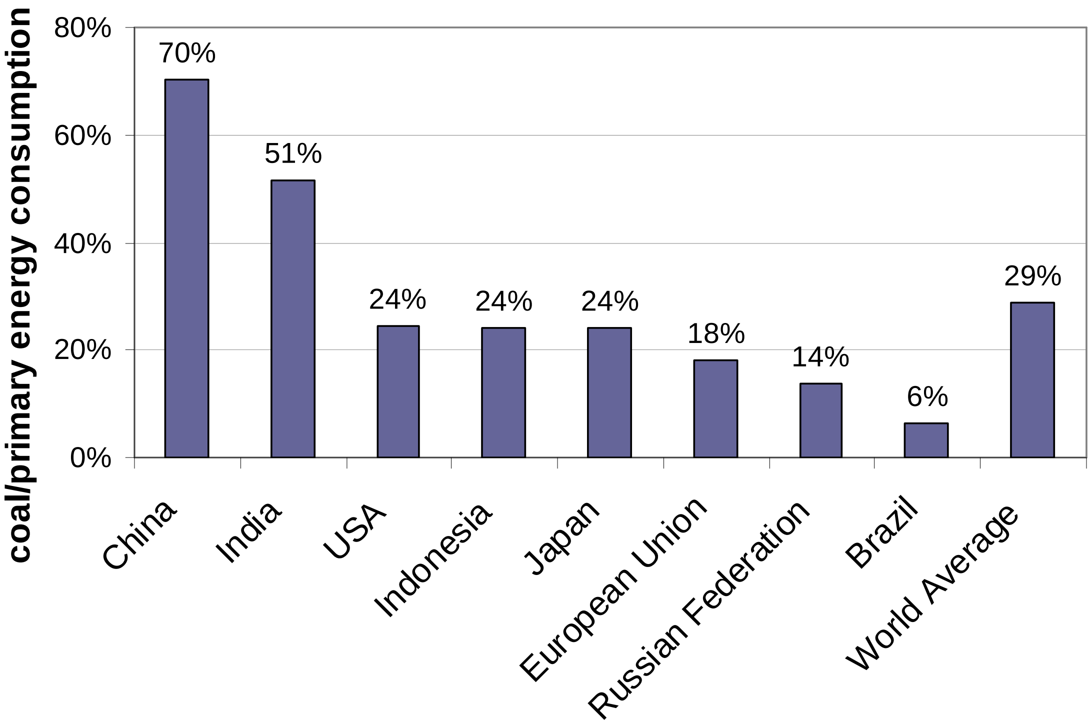


Data Source: IEA Coal Information, various years.

4. 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.[20] Coal's dominant share of primary energy ultimately derives from its 97% share of total fossil fuel endowments (Figure 2). Figure 11 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 11: Comparative Coal Dependence of Primary Energy Consumption, 2007

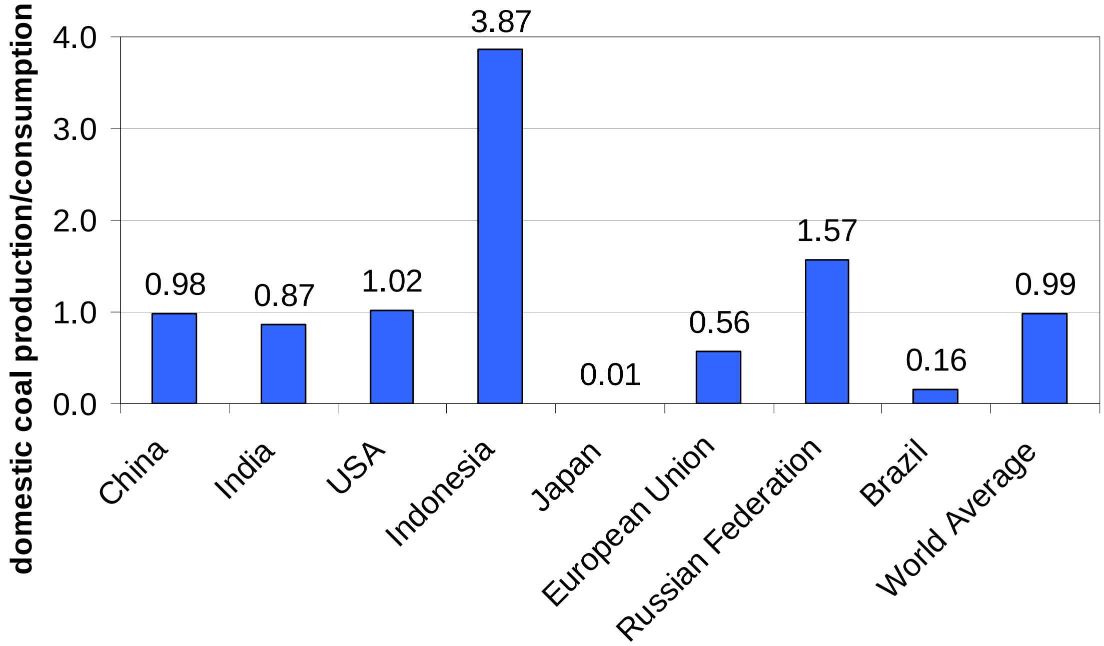


Source: BP Statistical Review of World Energy 2008.

The high level of domestic coal dependency in China is partly a result of their high degree of coal resource self-sufficiency (Figure 12). However, as shown in Figure 2, China possesses few other fossil fuel resources. 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.

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

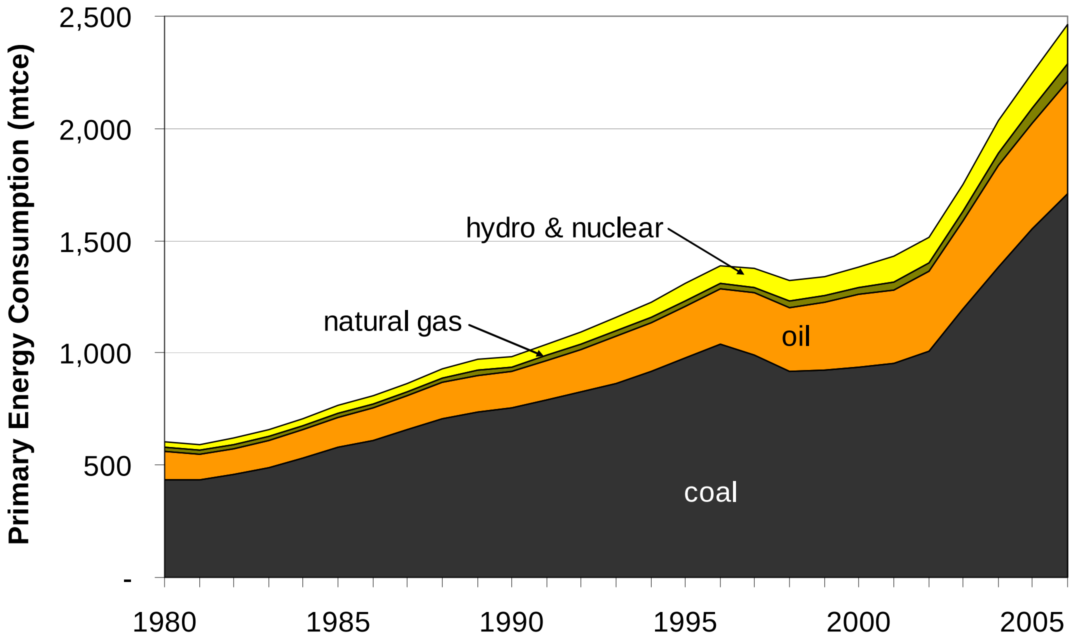
Figure 12: Ratio of Domestic Coal Production to Consumption, 2007



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 as demand surged. In the face of climbing oil and natural gas prices, coal's share is likely to 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.

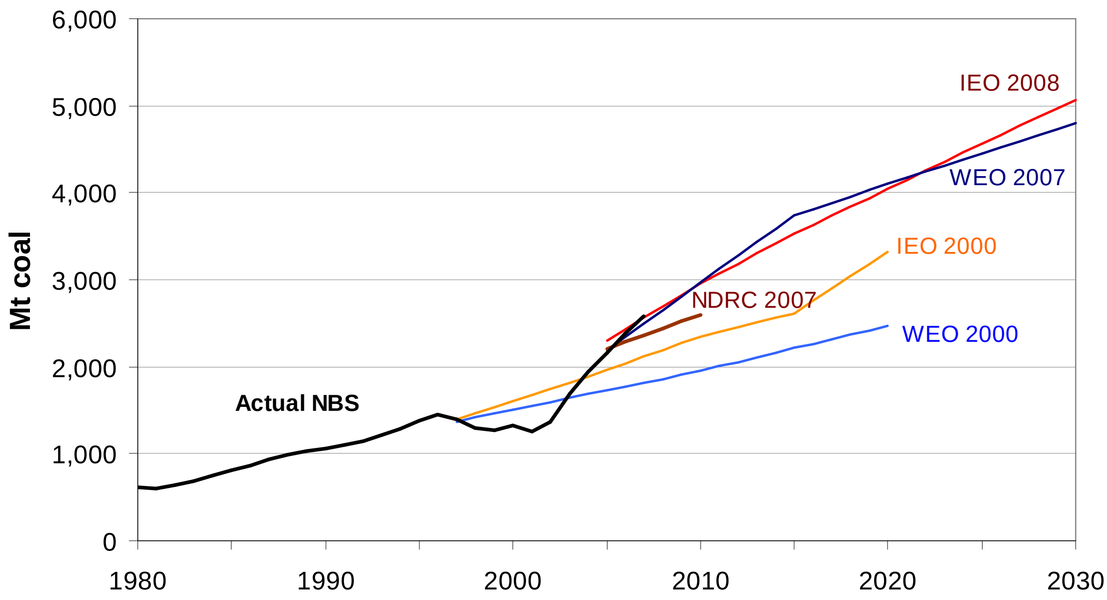
Figure 13: China Primary Energy Consumption, 1980-2006



4.1. 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 14, 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 nearly reached in 2007. In their most recent forecasts, the IEA and US EIA forecast China 2030 coal consumption at 4.8 and 5.1 billion tonnes, respectively (Figure 14).

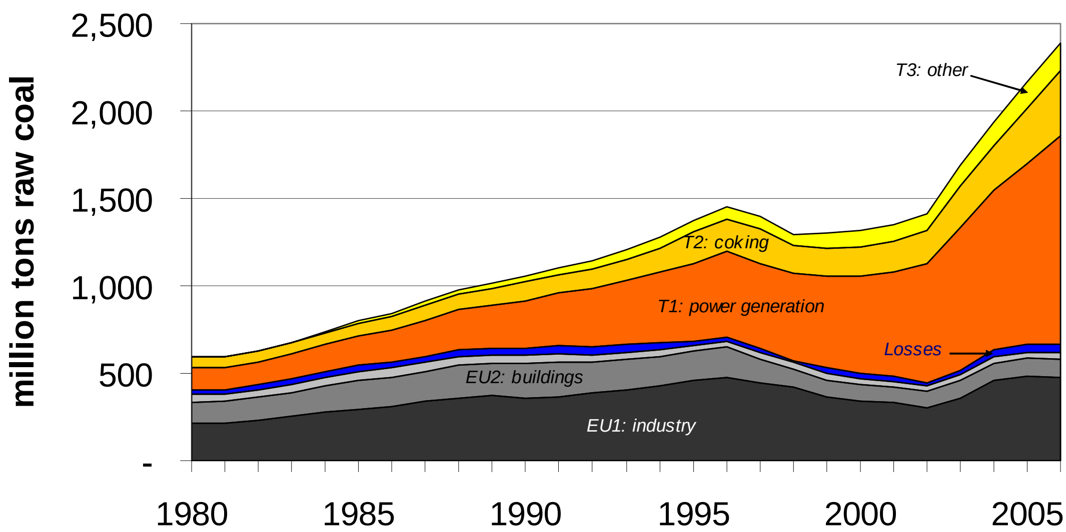
Figure 14: Historical and Forecast Chinese Coal Consumption, 1980-2030



4.2. Drivers of coal demand: urbanization, heavy industry, rising incomes

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.

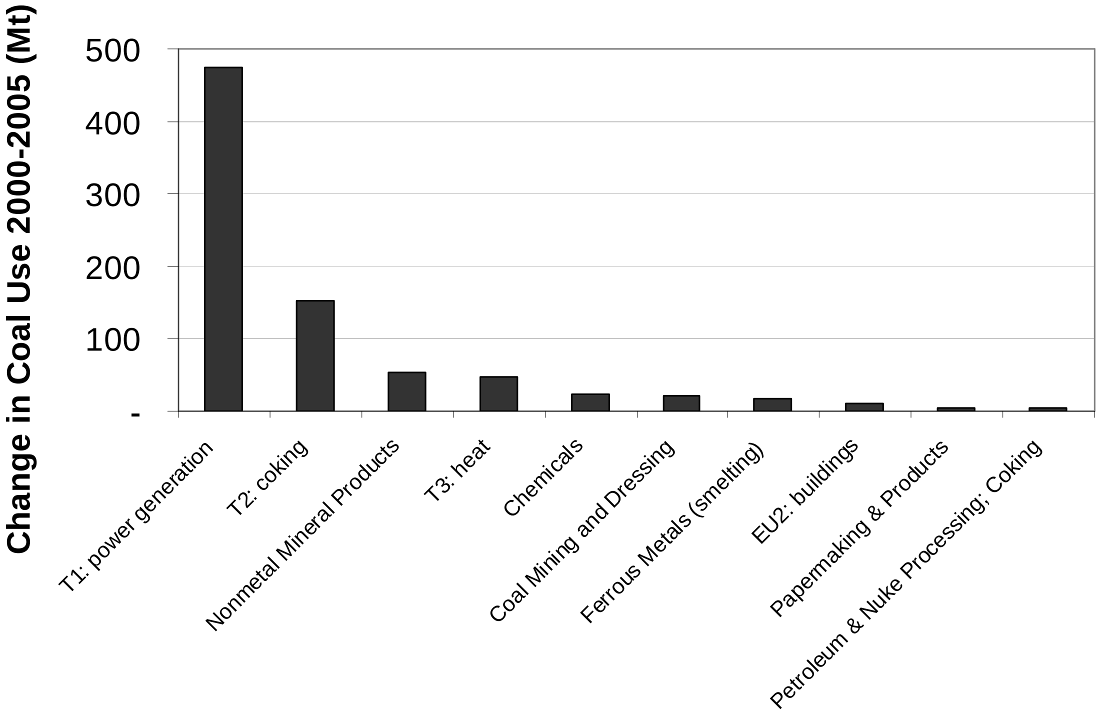
Figure 15: Chinese Coal Consumption by End Use and Transformation, 1980-2006



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

As shown in Figure 15, the surge of coal consumption between 2000 and 2006 was largely driven by the rapid rise in electricity demand, which accounted for 56% of the marginal increase in coal use between 2000 and 2005 (Figure 16). 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 16: Drivers of Growing Chinese Coal Use, 2000-2005



With 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 McKinsey has forecast 66%, out of a total population of 1.403 billion.[21] Unlike urbanization trends historically in developed countries, where there were large population movements from rural to urban areas, China's urbanization is characterized by a combination of economically-motivated rural-urban migration as well as establishment of new urban centers in formerly rural areas. The requirements of urbanization—infrastructure, housing, services, transportation, and a shift to full commercial energy use by residents—will sustain growth in the heavy industries that supply the materials, products and energy for urban construction and living.

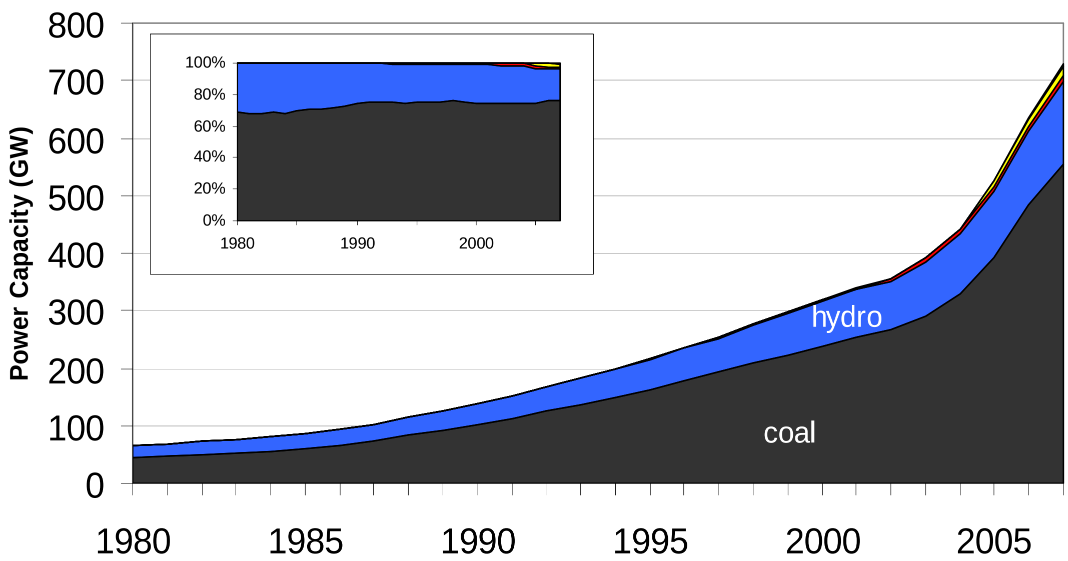
4.3. Power generation

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 17, 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

[21] 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.

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. As a point of reference, this study examines the implications of China reaching a 1.1 kw per person electricity capacity by 2025.

Figure 17: Electricity Generation Capacity by Fuel, 1980-2007

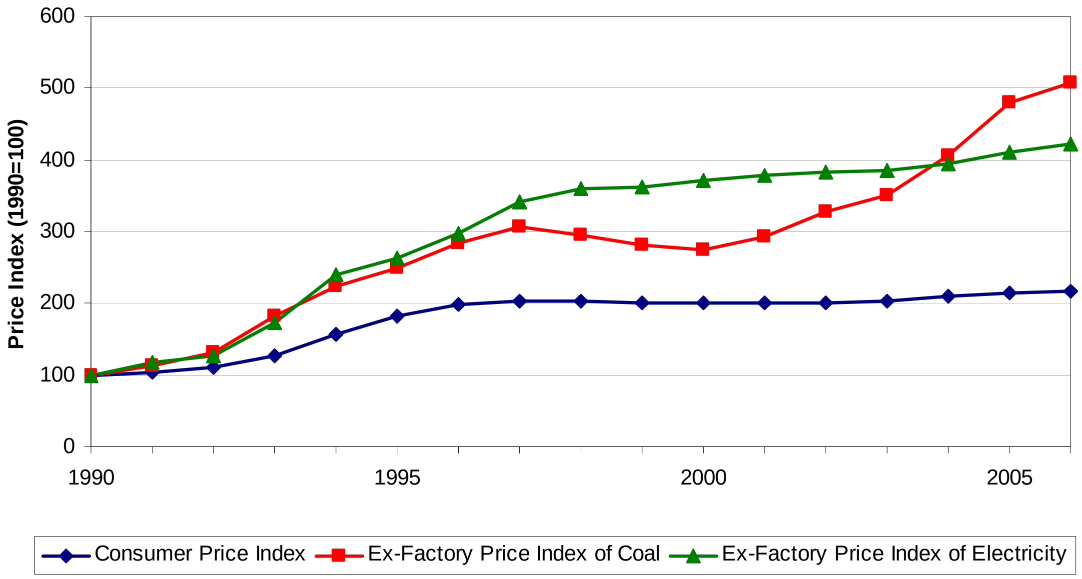


4.3.1. Electricity pricing

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.[22] 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.[23] 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.[24] In practice, however, electricity prices have not been 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.

[22] *Interfax China Energy Report Weekly*, April 3, 2008, Vol. 7:14, p. 5.
[23] Lam, P., 2004, "Pricing of electricity in China," *Energy* 29 (2): 287-300.
[24] Wang, B., 2007, "An imbalanced development of coal and electricity industries in China," *Energy Policy* 35 (10): 4959-4968.

Figure 18: Price Indices of Coal and Electricity



Source: Data from China Statistical Yearbook, 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.[25] 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 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, however, is unlikely sufficient to cover 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. Sustained high prices both domestically and internationally may stimulate a return to Chinese domestic coal price controls in order to stem electricity generators'

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

financial losses if inflation is considered too serious to allow large increases in electricity pricing.

4.3.2. Thermal technology: efficiencies and capital 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.[26] 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 2 shows the average heat rate and efficiency for each type.

Table 2: Average Heat Rates & Efficiencies for New Coal Thermal Power[27]

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

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.[28] 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% from 2006.[29] 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.[30]

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

[26] Mi Jianhua. 2006. "Analysis of Energy Efficiency Status of Power Generation Industry in China," *Electrical Equipment*, 7(5): 9-12. (*in Chinese*)
[27] 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.
[28] China Daily (July 2, 2007) "Being Supercritical," (http://www.zoomchina.com.cn/new/content/view/26601/266, accessed May 2008).
[29] Sun Guodong. (2008) *Coal in China: Resources, Use, and Advanced-Coal Technologies*. Pew Center on Global Climate Change. Mi (2006).
[30] China Daily (July 2, 2007) "Being Supercritical," (http://www.zoomchina.com.cn/new/content/view/26601/266, accessed May 2008).

scenarios also include 10 GW per year of retired coal-fired capacity between 2009 and 2015, and 5 GW per year thereafter. The efficiency of the retired capacity is estimated at the average fleet heat rate from fifteen years prior to retirement.

The S1 scenario simulates current trends in thermal electricity generation efficiency improvements. Between 2008 and 2015, the S1 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 S1 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 S1 scenario improves from 357 kilograms coal equivalent per kilowatt-hour (kgce/kWh) in 2007 to 323 kgce/kWh (38% efficiency) in 2025.[31] The S2 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 S3 scenario assumes that all new build between 2008 and 2025 will use ultra-supercritical technology. S4 is the 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 19: Historical and Forecast Efficiency of China's Coal-Fired Electricity Generation, 1990-2025

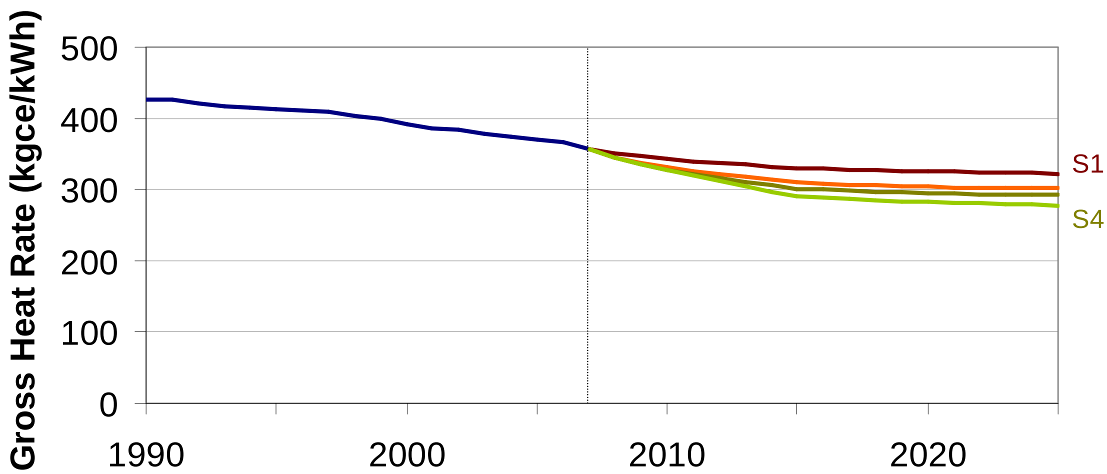


Figure 19 shows that the most aggressive adoption of the highest-efficiency coal combustion technology will only improve total fleet efficiency by 14%, from 323 kgce/kWh to 278 kgce/kWh. Beyond its high thermal efficiency, there are a number of obstacles to large-scale deployment of IGCC technology.

Costs and Benefits of IGCC Development[32]

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

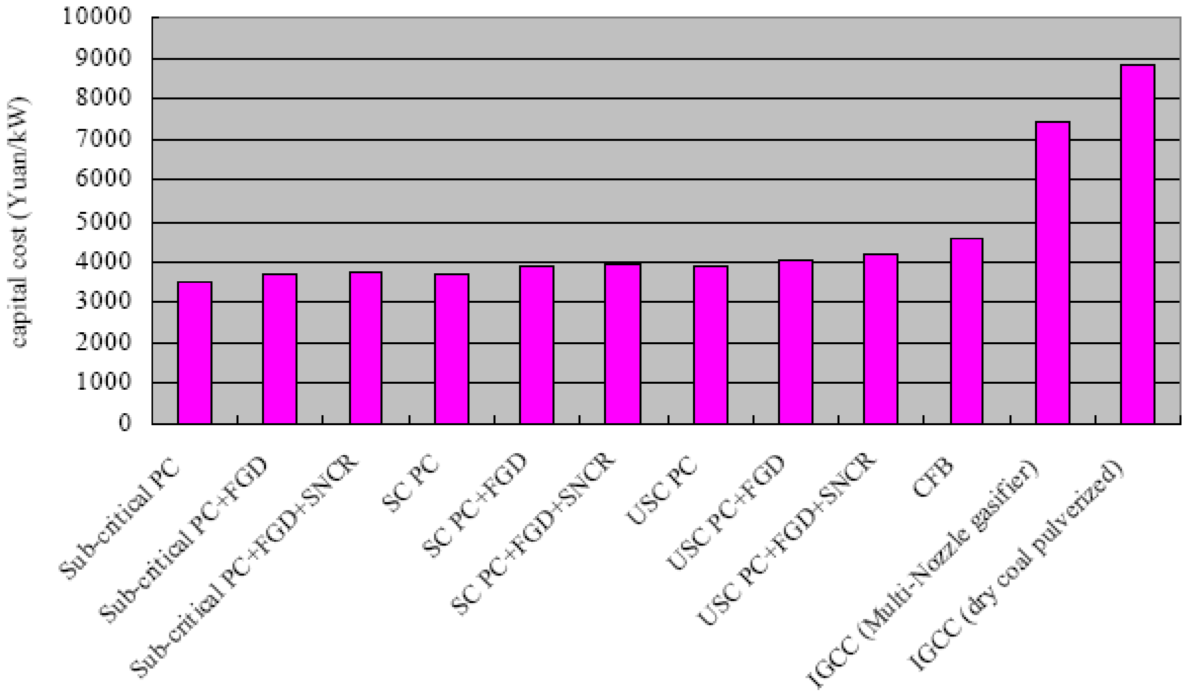
[32] Liu Hengwei; Ni Weidou; Li Zheng; Ma Linwei. (2008) "Strategic thinking on IGCC development in China," *Energy Policy* 36 (2008)1-11.

- Investment costs are almost twice those of ordinary PC boiler power plants: capital investment $900/kw (Lin et al, 2005 via Liu et al, 2008); Liu et al (2008) also cite Jiao (2007) estimate of construction cost of coal IGCC plan at more than $1,500/kW.
- IGCC plants have low reliability: availability is only ~80%.
- IGCC plants require a long construction period.
- IGCC plants are expensive and difficult due to lack of established operating experience.
- IGCC offers production flexibility through poly-generation.
- IGCC offers more cost-effective CCS possibilities.
- IGCC offers higher fuel input flexibility (including biomass & high sulfur coal).
- IGCC requires 33-50% less water than conventional coal power generation.

Under the current regime of lax environmental enforcement, IGCC is more costly to build and operate than ultra-supercritical plants with slightly lower fuel efficiency. At a coal price of 300 RMB/tonne, the cost of electricity for an ultra-supercritical plant is 280 RMB/MWh (4 cents per kWh), versus 350 RMB/MWh (5 cents per kWh) for IGCC technology.[33] Without heavy government support, IGCC will have difficulty competing with ultra-supercritical or perhaps oxy-fuel technology. Figure 20 shows the capital costs of sub-critical, supercritical, ultra-supercritical, and IGCC coal thermal electricity generation in China.

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

Figure 20: Capital Costs of Thermal Electricity Generation Technologies (RMB/kW)[34]



Note: PC = pulverized coal; FGD = flue gas desulphurization; SNCR = selective non-catalytic reduction; SC = supercritical; CFB = circulating fluidized bed.

4.3.3. 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 CH_4 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.[35]

CBM development was historically was under the China United Coal-bed Methane Corporation (CUCBM) established in 1996. Because of the slow pace of development

[34] Figure sourced from Zhao LF, Xiao YH, Gallagher KS, Wang B, and Xu X. 2008. "Technical, environmental, and economic assessment of deploying advanced coal power in the Chinese context," *Energy Policy*, 36(2008): 2709-2718.
[35] *Interfax China Energy Report Weekly*, March 27, 2008, Vol. 7:13, p. 13.

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 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.[36]

4.3.4. 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.[37]

The State Electricity Regulatory Commission (SERC) has estimated that power generators will face a shortage of 250 to 300 million tonnes of thermal coal in 2008 due to transport bottlenecks and closures of small-scale mines.[38]

4.3.5. Demand scenarios

In order to quantify the potential savings of high-efficiency thermal power generation, this section examines coal requirements for the four technology scenarios discussed in Section 4.3.2 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 21). If China were able to improve its fleet efficiency from the S1 path to the S4 path, 14% less coal (349 million tonnes) would be required for electricity generation in 2025. Figure 21 shows that the S1 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.

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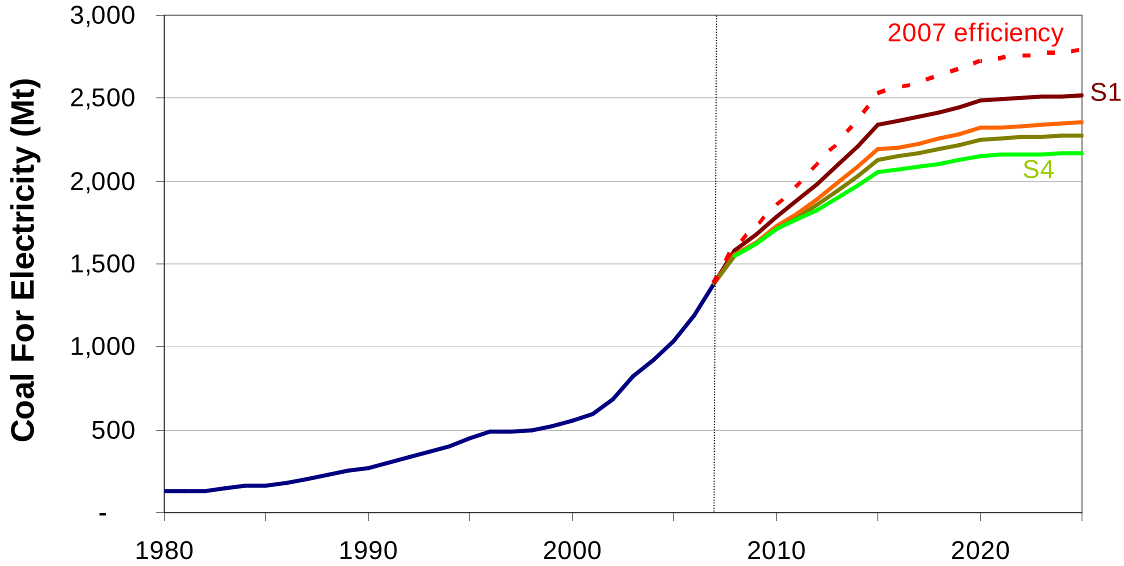
[36] Fridley, David, "Natural Gas in China", in Jonathan Stern, ed, *Natural Gas in Asia*, Oxford: Oxford University Press, 2008

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

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

Figure 21: Coal Demand for Electricity Generation in Four Technology Scenarios, 1980-2025



The limited improvement between S1 and S4 demonstrates that currently available thermal power generation technology does not offer a silver bullet for mitigating, much less reversing, rapidly growing thermal coal demand.

4.4. 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 3 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 reach 390 kg, thereby surpassing the US level in 2005.

Table 3: Aggregate and Per-Capita Steel Consumption (2005) [39]

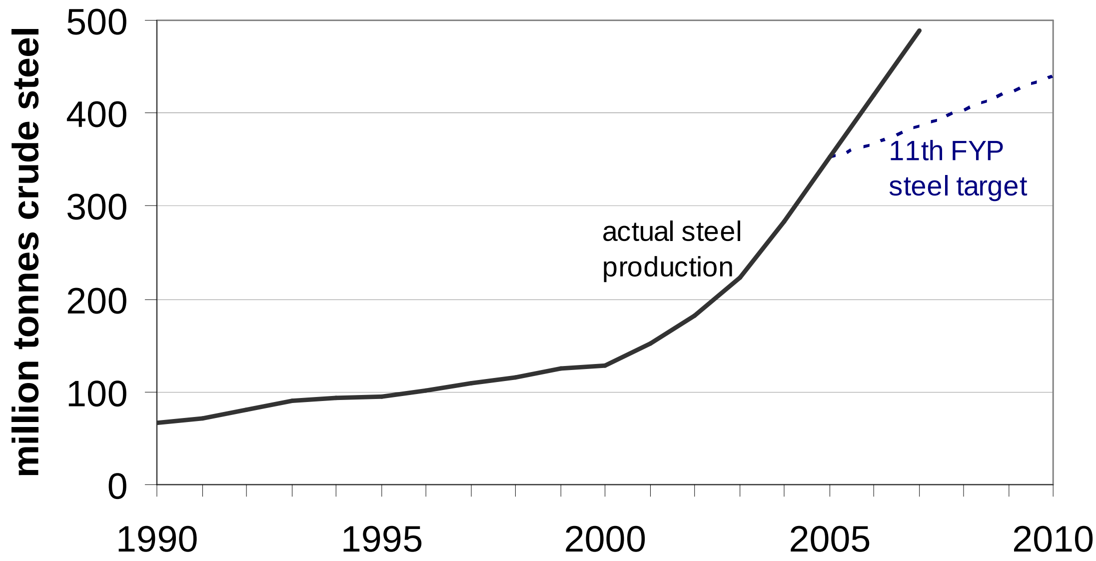
Country	*Million tonnes*	*Kg per capita*
China	350 mt	270 kg
United States	113 mt	382 kg
United Arab Emirates		1,314 kg
Taiwan	-	1,044 kg
Japan	83 mt	649 kg
India	41 mt	38 kg
World	1,013 mt	189 kg

Previous forecasts of China's future steel production have been exceeded years ahead of schedule, similar to coal production as illustrated in Figure 14. Figure 21 shows that

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

actual production exceeded Chinese Tenth and Eleventh Five-Year-Plan forecasts years ahead of schedule. In 2007, total rolled steel production reached 570 million tonnes.[40]

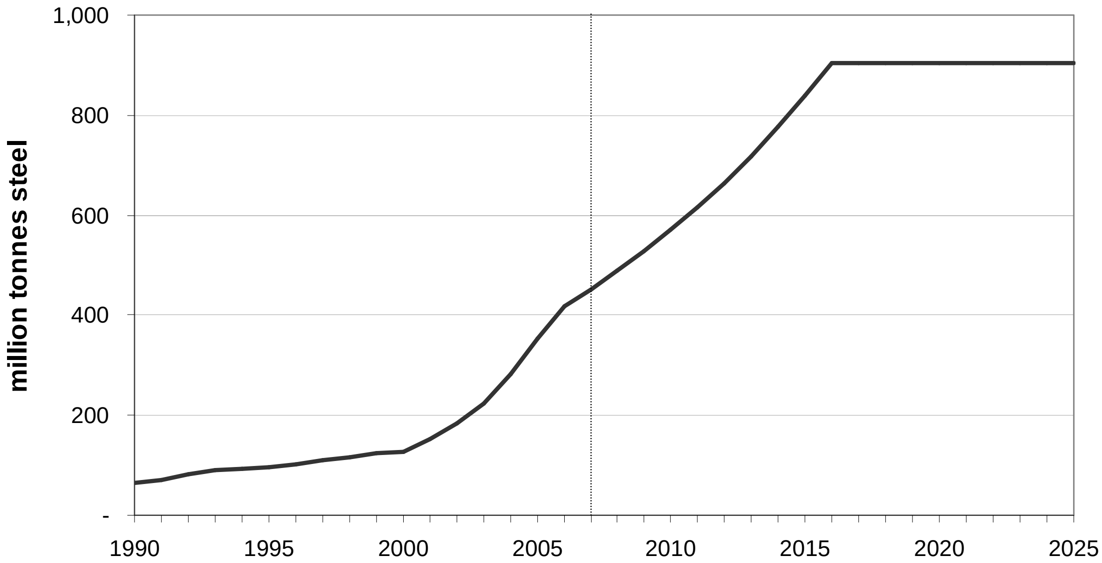
Figure 22: China Historical and Forecast Steel Production, 1990-2010



Given China's ongoing urbanization and heavy industrialization, this study examines the coal implications of steel production growth to a 650 kg per capita level—equivalent to Japan's consumption per person in 2005. As a major industrial power with a large share of industry in its economy, Japan presents a manufacturing-oriented model of steel consumption. The average annual growth of steel production in China between 2000 and 2006 was 22%. If steel production growth were to fall to an annual average rate of 8% starting in 2008, China would reach Japan's level of per-capita steel consumption in 2016, with total annual steel production slightly over 900 million tonnes. Figure 23 shows the path of steel production from 2008 under these assumptions and the maintenance of flat per-capita usage for the following decade.

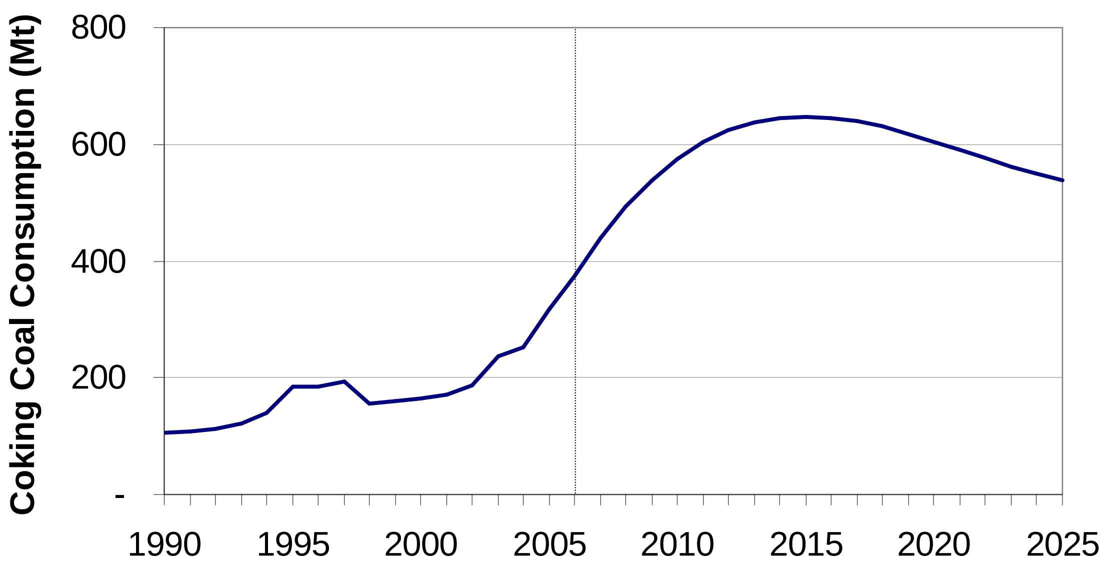
[40] 2007 steel products production reported by NBS (2008) *China Statistical Abstract 2008*. Beijing: NBS.

Figure 23: Historical and Hypothetical Chinese Steel Production, 1990-2025



As China continues to improve the efficiency of its primary steel smelting operations and increases the amount of recycled steel input to more efficient electric arc furnaces, the coal intensity of steel production will diminish. If steel production levels off at the Japan 2005 per-capita level, coal demand for steel will peak and decline with ongoing efficiency improvements. Figure 24 shows the peaking of coking coal demand at 650 million tonnes in 2015 with 2025 demand falling to 540 million tonnes.

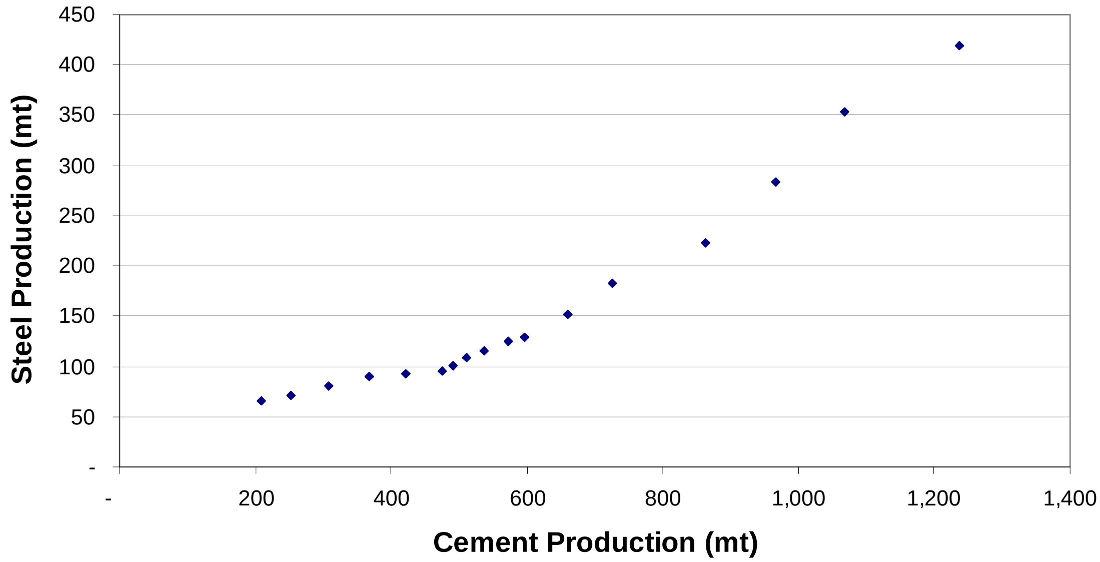
Figure 24: Historical and Hypothetical Coal for Coke, 1990-2025



4.5. Cement & building materials

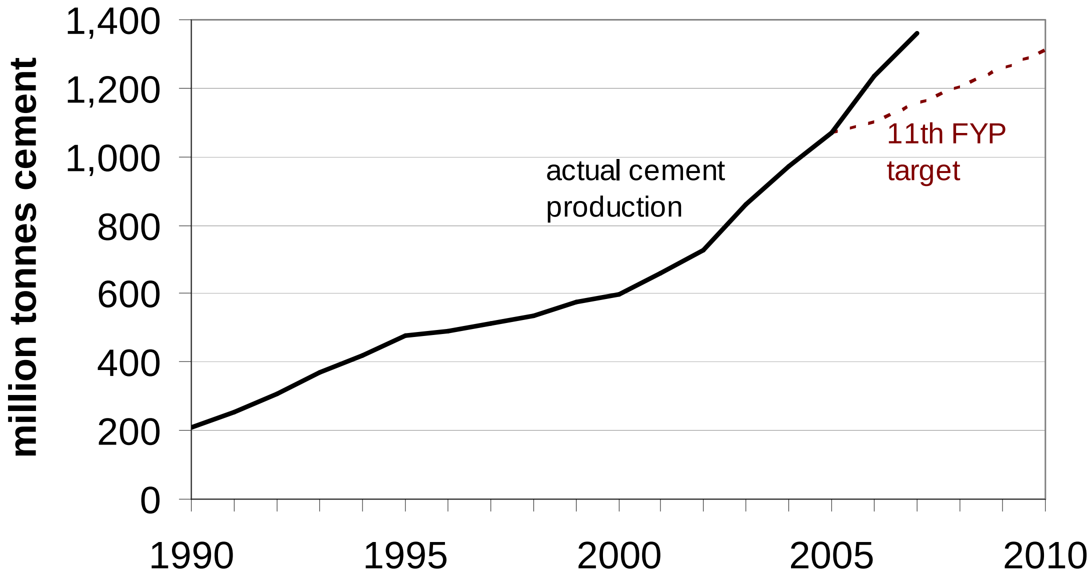
Cement and steel are used together in building and infrastructure construction, especially in the production of reinforced concrete. As a consequence, there has been a high correlation of annual production growth of the two products, as shown in Figure 25.

Figure 25: China Steel and Cement Production, 1990-2006



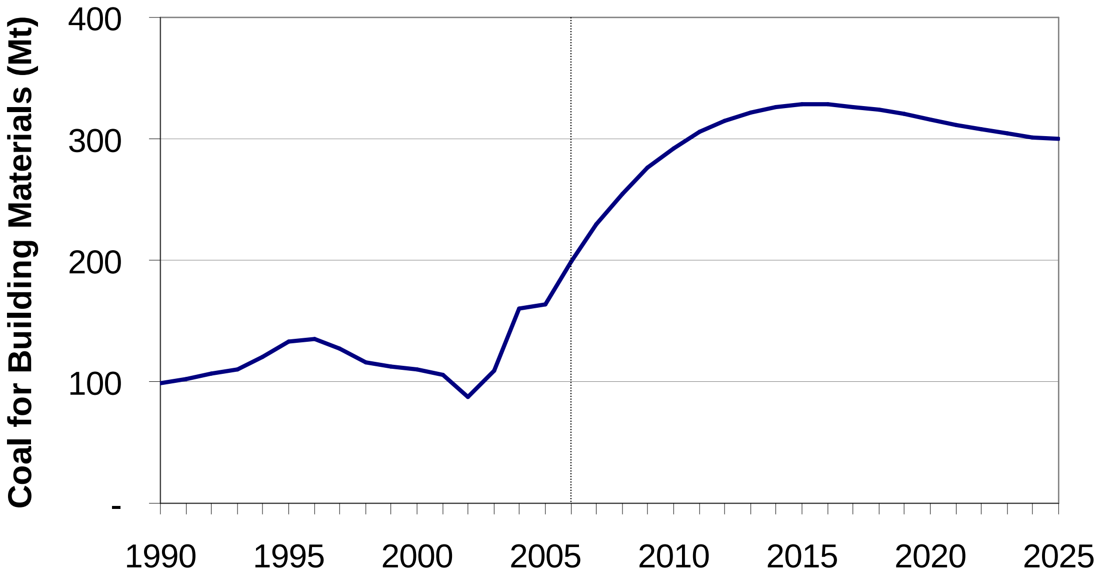
As with coal and steel, cement production has also exceeded targets set out in the Tenth and Eleventh Five-Year Plan years ahead of schedule. Fig 25 shows the growth of Chinese cement production to over 1.2 billion tonnes in 2006. In 2007 Chinese cement production of 1.36 billion tonnes accounted for half of all world production.

Figure 26: Actual and Forecast Chinese Cement Production, 1990-2010



A growth trajectory for cement production similar to that of steel, falling to 8% a year from recent growth rates, production in 2015 would reach a peak of 2.67 billion tonnes. Similarly, continued improvements in the efficiency of coal production and the consequent reduction in coal intensity would result in a gradual decline of coal use in this sector. Building-materials-related coal consumption would peak at 330 million tonnes in 2015 and decline to 300 million tonnes in 2025.

Figure 27: Historical and Forecast Coal Use by Building Materials Producers, 1990-2025



4.6. 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. Based on current process efficiencies, this scale of development would require an additional 450 million tonnes of coal to be supplied in 2025.

Coal-to-Liquids production, targets, and requirements

- Shenhua is commissioning a 1 million tonne direct coal liquefaction plant in 2008
- Total CTL capacity is forecast to reach 50-60 mt by 2020
- Current CTL resource requirements:
  4-5.5 t coal per t product; 10 tonnes water per tonne product.

Coal-to-chemicals production, targets, and requirements

- Methanol production has begun to displace ethanol production from grains and other feedstocks
- Coal is increasingly viewed as a chemical feedstock

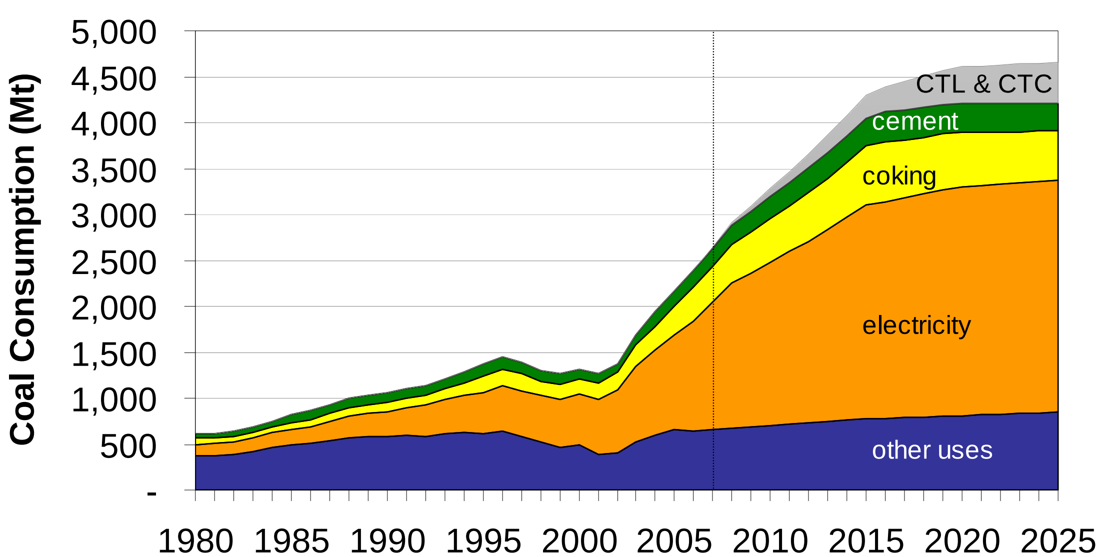
- In 2007 China consumed 9 mt of methanol, of which 2.7 mt was blended with gasoline
- Methanol is a feedstock for the production of dimethyl ether (DME) which is being piloted as a diesel fuel substitute in buses in Shanghai
- 2010 production capacity is expected to reach 39 mt
- Current CTC resource requirements:
  1.5-1.7 t coal per t methanol; 2-2.5 t coal per t DME

There are now specifications for M5, M15, M85, and M100.In 2008, in order to regularize the introduction of methanol to retail gasoline stations, the government directed Shanxi province (where there are 800 methanol stations) to label them in a standard way of M5/90, M5/93, M15/90, M15/93, M15/97, M85, and M100.

4.7. Total forecast demand

Based on the development outlook of the basic drivers described above, China's total coal demand is expected to grow to 4.65 billion tonnes in 2025. 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 displace the growth of electricity generation from 50% of total use in 2006 to 54% in 2025. Figure 28 illustrates the dominant role of electricity generation in driving Chinese coal demand.

Figure 28: Historical and Forecast Coal Demand, 1980-2025



Growth in the "other uses" category of Figure 28 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 a key 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.

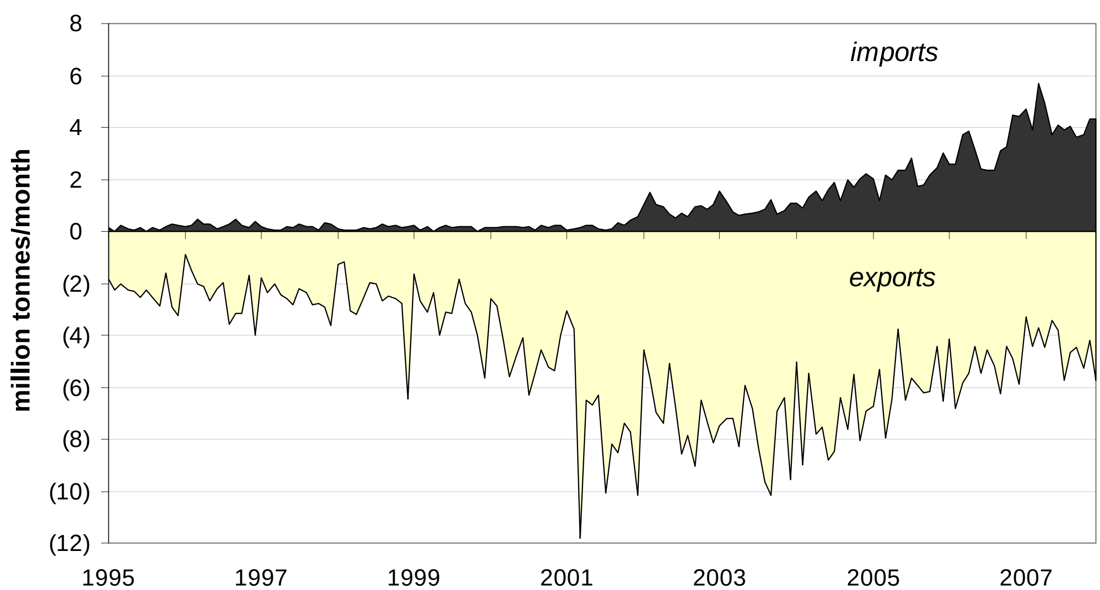
5. Coal Gap Forecasts, Trade Implications, and Constraints

Rising domestic and international prices, ongoing incidences of electricity shortages, and rapidly rising coal imports signal the emergence of a coal gap in China. This section examines historical coal trade, the extent of the coal gap under three scenarios, possible trade implications, and domestic constraints to expanded coal supply. Coal gap scenarios suggest that Chinese shortages will have near-term regional implications.

5.1. Historical coal trade

China's international coal trade exploded when it acceded to the World Trade Organization (WTO). From 2000 to 2001, the gross volume of China's international coal trade jumped 62%, from 57 to 93 million tonnes per year. Imports have grown every year since WTO accession; meanwhile, exports peaked at 94 million tonnes in 2003. Within coal trade, China's growing imports are largely composed of metallurgical coal and anthracite. Figure 29 illustrates the volume of China's monthly international coal trade.

Figure 29: China Monthly International Coal Trade, January 1995- December 2007[41]

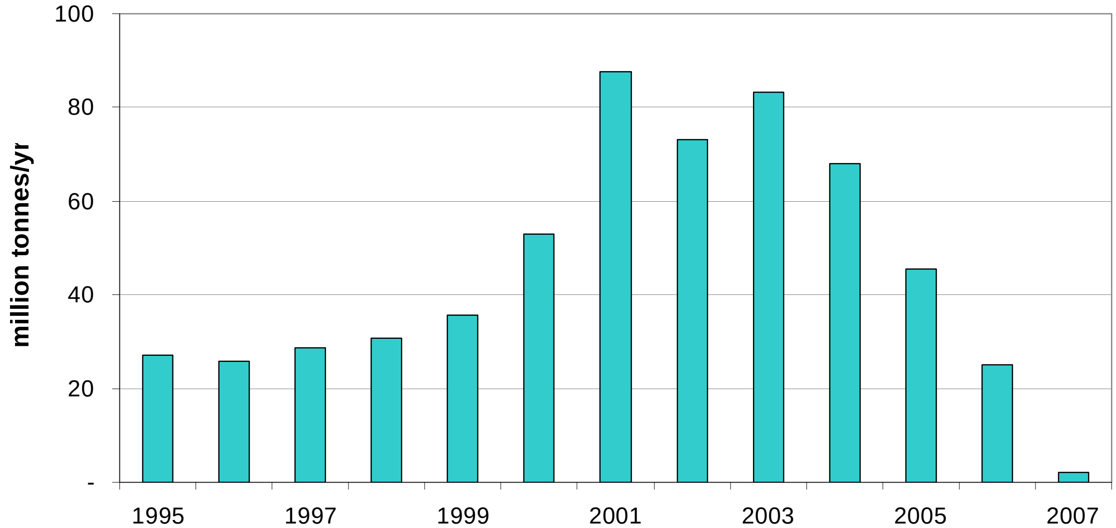


China became a net coal importer on a monthly basis for the first time in 2007. However, on an annual basis China was a net exporter of two million tonnes of coal in 2007. Figure 30 shows the decline of China's net annual coal exports from their peak of 88

[41] Data sourced from China Customs Bureau via World Trade Atlas.

million tonnes in 2001. Exports as a proportion of total annual production also peaked in 2001 (at 7%), and declined to a ten-year low of 2% in 2007.

Figure 30: China Net Annual Coal Exports, 1995-2007



Given that China's largest coal ports are located in the north, it is not surprising that Japan and South Korea are the top export destinations. Table 4 shows that the volume of Chinese coal exports has generally declined among all export destinations in the past two years; overall world exports dropped by 26% between 2005 and 2007. At 53 million tonnes, China's 2007 coal exports remained well below the annual export quota of 70 million tonnes. Nonetheless, the National Development Reform Commission (NDRC) lowered the 2008 export quota to 53 million tonnes to further accelerate the shift to domestic utilization.[42]

Table 4: Export Destinations of Chinese Coal (Mt/year)

Rank	Country	2005	2006	2007
0	*World Total*	71.72	63.30	53.17
1	South Korea (ROK)	21.22	19.16	19.24
2	Japan	23.18	20.60	15.58
3	Taiwan	16.23	13.26	12.69
4	Turkey	1.65	1.87	2.28
5	Philippines	2.03	1.04	1.03
6	Hong Kong	0.95	0.86	0.67
7	India	3.86	5.00	0.54
8	Brazil	0.28	0.19	0.28
9	North Korea (DPRK)	0.15	0.21	0.23
10	France	0.01	0.00	0.19

On the other hand, Chinese coal imports—particularly from Vietnam and Indonesia—have grown steadily over the past two years. Total international imports roughly doubled

[42] See for example "China issues first batch of coal export quota for 2008," (http://www.chinamining.org/Policies/2008-03-18/1205828820d12215.html).

between 2005 and 2007. Table 5 shows that more than 75% of 2007 imports came from Vietnam and Indonesia. Both countries have forecast diminished future exports in light of growing domestic demand, with Vietnam explicitly planning to end coal exports altogether.[43]

Table 5: Sources of Chinese Coal Imports (Mt/year)

Rank	Country	2005	2006	2007
0	*World Total*	26.13	38.24	51.00
1	Vietnam	10.19	20.08	24.61
2	Indonesia	2.40	5.17	14.06
3	Australia	5.88	6.90	4.52
4	North Korea (DPRK)	2.80	2.48	3.74
5	Mongolia	2.54	2.35	3.24
6	Russia	0.90	0.99	0.27
7	Canada	1.23	0.15	0.22
8	Philippines	-	0.00	0.21
9	New Zealand	0.17	0.11	0.06
10	Malaysia	-	0.00	0.04

Even as China has come down from its peak gross coal trade of 105 million tonnes in 2004, rising international prices have meant that the value of trade, and particularly the value of imports, has grown each year. Between 2006 and 2007, for example, the value of gross international trade grew from $5.3 to $5.7 billion—7.5% growth, compared to only 2.6% growth of total coal trade volume.

Table 6: China's Top Coal Ports, 2007

	Imports		Exports	
	Port	**Volume (mt)**	**Port**	**Volume (mt)**
1	Nanning	14.04	Shijiazhuang	34.77
2	Huangpu	10.45	Tianjin	12.02
3	Hohhot	3.24	Qingdao	4.85
4	Jiangmen	2.71	Nanjing	0.94
5	Hangzhou	2.66	Changchun	0.22
6	Qingdao	2.15	Nanning	0.14
7	Zhanjiang	2.09	Shenyang	0.11
8	Shantou	1.93	Dalian	0.06
9	Ningbo	1.43	Kunming	0.04
10	Dalian	1.36	Shenzhen	0.03
Total	--	51.00	--	53.17

As suggested by the trading partners listed in Table 4 and Table 5, China's largest export-oriented ports are in the north while the largest coal-importing ports are in the south. Table 6 shows the reported 2007 trade volume of China's ten largest coal ports.

5.2. Demand-supply gap under three scenarios

[43] See for example "Vietnam to halt coal exports: industry ministry" (http://www.thanhniennews.com/business/?catid=2&newsid=26939).

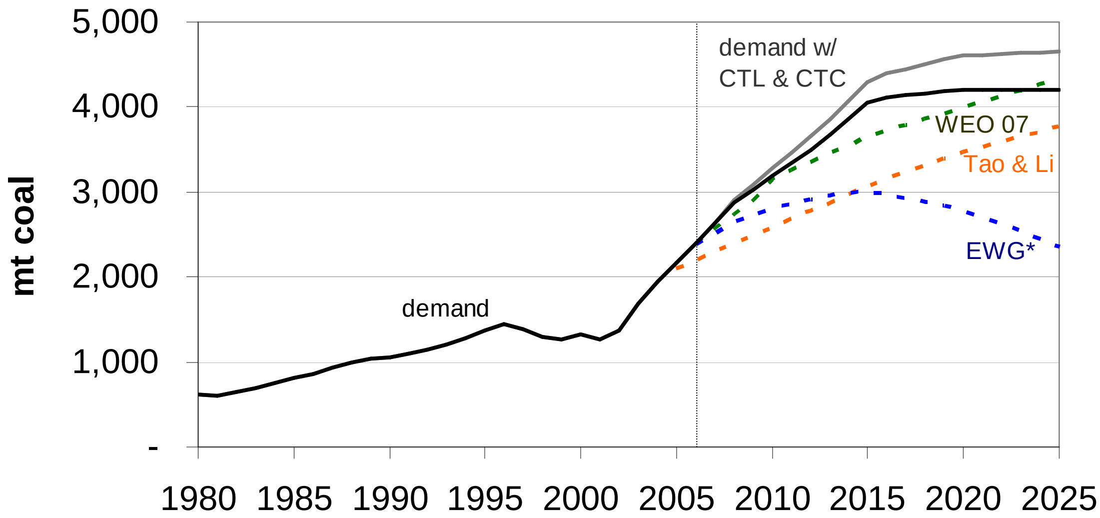
The number of published forecasts for Chinese coal production is limited. On the near-term end of the spectrum, coal production targets of the Tenth and Eleventh Five-Year Plans were exceeded shortly after their publication. In the long term, the China Academy of Sciences has targeted zero growth of energy consumption after 2040.[44] Between China's official short and long-term projections, three Chinese and international coal production forecasts provide a foundation for analyzing coal gap potential between 2008 and 2025.

Each of the three forecasts uses separate reserve estimates and future coal production projection methodologies. The Energy Watch Group (EWG) is an independent group of scientists and experts commissioned by the German parliament. In March 2007 the EWG published *Coal: Resources and Future Production*—a global investigation that included specific country-level analysis of China and the United States. The EWG estimated China's 2006 coal reserves on the basis of 1992 World Energy Council (WEC) data, corrected for 1992-2006 domestic production. Future production was projected by fitting a logistic growth curve to historical production and reserve data. The EWG found that Chinese coal production will peak around 2015 and decline steeply after 2020.

Researchers at China's Northeastern University in Shenyang used scenario analysis to explore the limits of domestic coal supplies. In 2007, the researchers Tao and Li published their analysis of future Chinese coal production in the journal *Energy Policy*.[45] On the basis of the Chinese Ministry of Land and Natural Resources 2002 reserve estimate of 186.6 billion tonnes of coal and a STELLA model of future production, Tao & Li forecast peak production of 3.3 to 4.5 billion tonnes between 2025 and 2032. Figure 31 shows Tao and Li's middle case scenario, where Chinese coal production peaks at 3.8 billion tonnes in 2029.

[44] 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)
[45] 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.

Figure 31: Coal Demand Gap under Three Supply Scenarios



* In lieu of specific data points, the shape of the EWG projection was fitted to historical data.

The third Chinese coal production forecast is from the International Energy Agency (IEA) World Energy Outlook (WEO) 2007. The WEO cites a range of proven reserve estimates from 115 to 192 billion tonnes. Based on continued restructuring and modernization of China's coal mining industry and related transport infrastructure, the WEO does not forecast any decline of coal production before 2030, when total production is expected to reach 4.7 billion tonnes. Figure 31 shows that the WEO 2025 supply estimate is still 330 million tonnes short of total forecast demand if China maintains its coal liquefaction and coal-to-chemicals development plans.

Table 7: China Coal Gap Scenarios

	2015	2020	2025
EWG	1.1-1.3 billion tonnes	1.4-1.8 billion tonnes	1.9-2.3 billion tonnes
Tao & Li (2007)	990 million-1.2 billion tonnes	740 million – 1.1 billion tonnes	440-890 million tonnes
WEO 2007	400-650 million tonnes	220-620 million tonnes	0-330 million tonnes

Table 7 shows the scale of China's domestic coal supply deficit given demand growth as described in Section 4. Deficit quantities for each year and supply scenario show a range of amounts, with and without development of coal liquefaction and coal-to-chemicals industries. If demand for coal continues to grow and include coal liquefaction and coal-to-chemicals development, China's coal deficit in 2025 is forecast to range between 330 million and 2.3 billion tonnes of coal—13% and 92% of 2007 production, respectively.

5.3. Trade implications of China's forecasted coal gap

The scale of China's 2025 coal gap dwarves current coal imports, which reached an historic high of 51 million tonnes in 2007. Given the growth of domestic coal demand in Vietnam and Indonesia, it is not clear that Asian regional coal supplies will be available to meet Chinese coal deficits without dramatic increases in Australian production and export capacity. Projected Indian coal import demand is likely to further tighten Asian regional coal markets, and Japanese demand may remain strong or increase depending on the operational situation of its nuclear power plants and the renegotiation of its long-term LNG contracts

The 2007 World Energy Outlook (WEO) forecasts a 2030 Chinese coal gap of 137 million tonnes coal (98 mtce). However, the WEO estimates 2030 net imports will only reach 129 million tonnes. Such precision among long-term forecasts may be illusory; rather, the disparity suggests that even if export supplies are available from Indonesia, Australia, South Africa, Mongolia, Vietnam, and Russia, it will be difficult for imports to cover China's coal gap. Imports are also likely to become more expensive as freight transport costs rise with crude oil prices. Insofar as coal is used to generate electricity, the growth of China's coal gap may curtail electricity exports and increase demand for electricity imports, particularly from Mongolia and Russia.

As international coal market prices rise, Chinese exports may also be curtailed by policy if the government seeks to re-impose domestic price controls. Effective long-term control of retail electricity prices requires that generators not be faced with long-term losses on their fuel purchases against their electricity revenues.. By creating a price disparity with international market prices, domestic price controls present a financial incentive to export that the central government would then be compelled to counter with export limits. Diminished Chinese coal exports to South Korea, Japan, and Taiwan will displace demand to other regional suppliers, putting further pressure on prices.

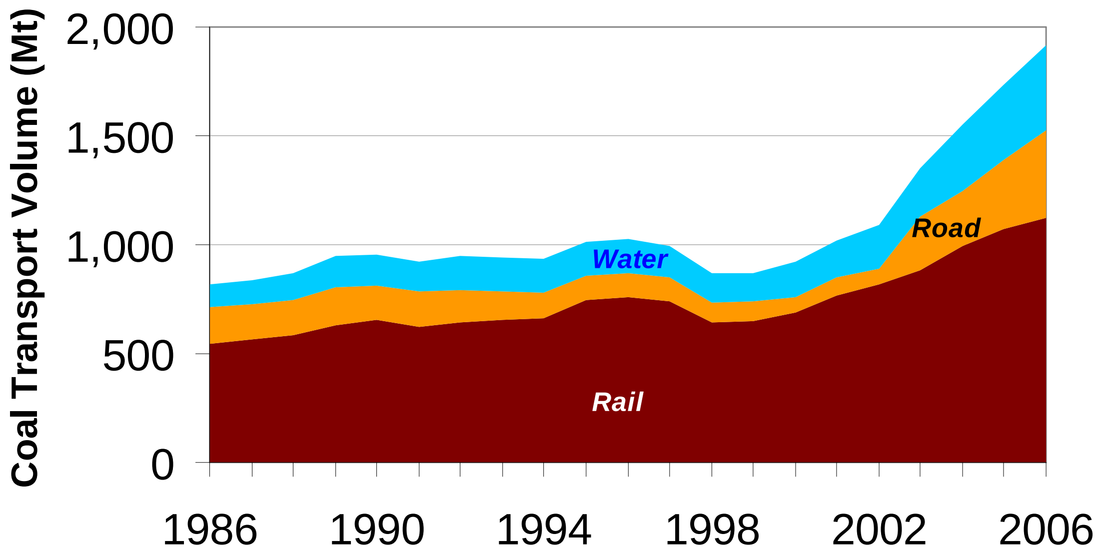
5.4. Constraints to expanded supply

In order to minimize the negative impacts of its growing coal gap, China is seeking to maximize domestic coal production. However, the rapid depletion of China's accessible, high-quality coal 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, limited electricity grid capacity to transmit coal by wire, and the diminishing quality of China's remaining coal reserves.

5.4.1. Transport bottlenecks

As illustrated in Map 1 (page 10), 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 32 shows that the estimated rail share of total transported coal surged to 75% in 2002 before receding to 60% in 2006.

Figure 32: Coal Transport by Mode, 1986-2006



In 2006, 1.1 billion tonnes of coal were transported by rail, 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).[46] Furthermore, the lack 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 are often 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 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 to0.8 RMB per tonne-kilometer, but still do not curb demand for journeys of up to 300 km by truck.[47] 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.

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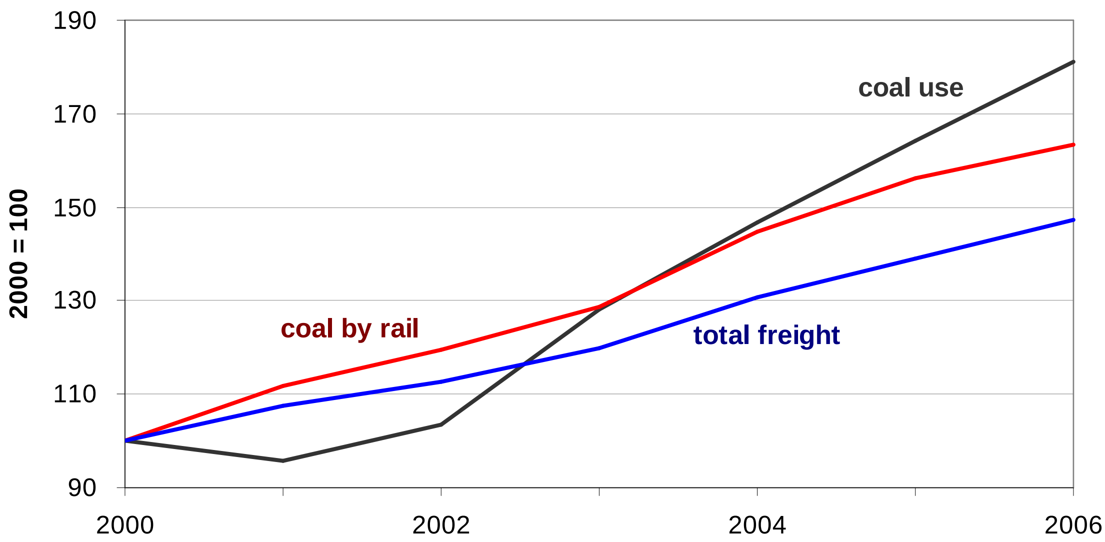
[46] IEA. 2007. WEO 2007. Paris: IEA.
[47] IEA. 2007. WEO 2007. Paris: IEA.

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.[48] The national government's ambitious rail expansion targets appear to be insufficient to support the rapid growth of coal demand. Figure 33 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.

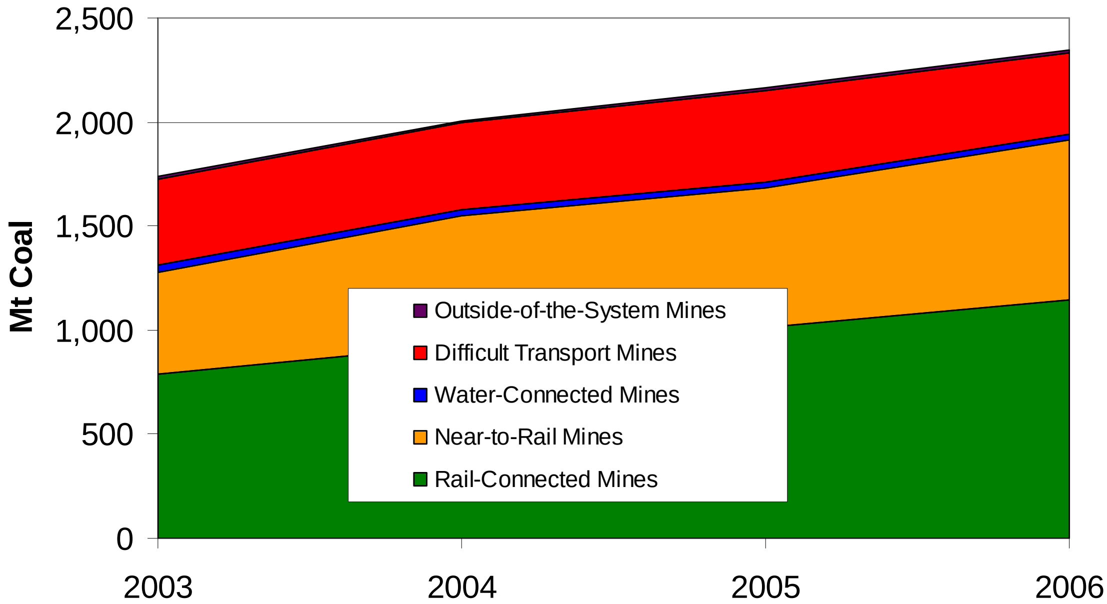
Figure 33: Index of China Coal Use, Coal Transport by Rail, and Total Rail Freight, 2000-2006



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, Figure 34 shows that 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 production in 2006. The prevalence of small coal mines distributed in mountainous terrain complicates efforts to efficiently transport more Chinese coal to markets.

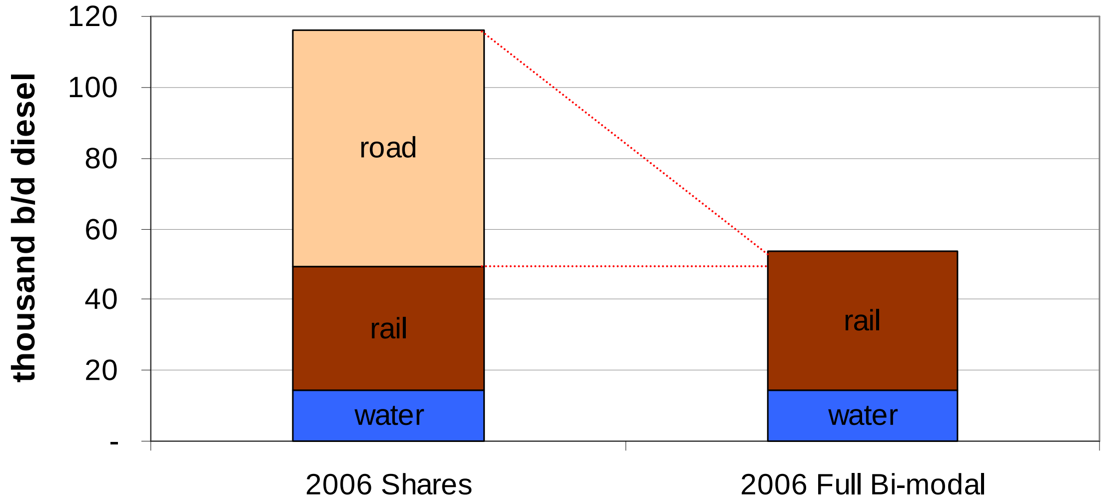
[48] Target announced in the 'Mid and Long-Term Railway Development Plan,' quoted in WB China Quarterly Update 2.2008.

Figure 34: China Coal Production by Mine Transport Infrastructure, 2003-2006



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 35 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

Figure 35: Actual and Hypothetical Bi-Modal China Coal Transport, 2006



5.4.2. Grid options

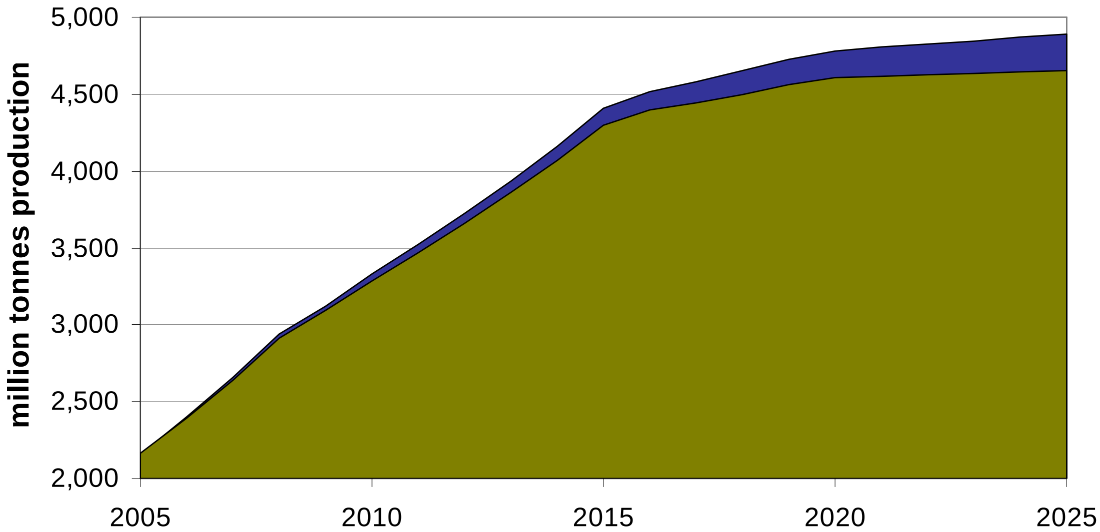
China's divergent distribution of coal resources presents attractive policy potential for increasing the use of coal by wire, whereby energy from coal is extracted by combustion at mine-mouth thermal power plants and then delivered long-distance to demand centers. Given China's current electricity grid 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 losses are currently relatively high at 6.5%. Another major setback of coal by wire in China is the high water requirement of mine-mouth thermal power plants, which could be on the order of 300 million gallons of water per day for a thermal power plant with 500 MW installed capacity. This is a particularly significant disadvantage for China given the existing water shortage concerns in the Northern and Western regions.

5.4.3. 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 240 million tonnes of additional coal would have to be mined to compensate for the lower energy content of the lignite (Figure 36). 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.[49]

Figure 36: Additional Production Requirements with 12% Lignite, 2005-2025



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.

6. Domestic Mitigation Options

Given its current development path China has limited options for addressing potential coal gaps from the supply side. Alternatives to coal have limited scalability and international coal, oil, and natural gas markets have already shown signs of tight supply. Meanwhile domestic efforts to reduce demand and improve energy efficiency are hampered by institutional diffusion, the lack of administrative personnel and insufficient, though growing, budgets for efficiency and conservation.

6.1. Fuel switching & efficiency policies

China's 11th Five-Year Plan is an ambitious plan for improving energy-efficiency by reducing the country's energy intensity, defined as energy use per unit of gross domestic

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

product (GDP), by 20% between 2005 and 2010[50], an average annual reduction rate of 4.4%. Achieving this goal would result in a total reduction from a growth baseline of 560 million tons of coal equivalent (Mtce) (16.4 EJ) over the five years of the plan. The 11th Five Year Plan was approved by the 5th Plenary Session of the 16th Communist Party of China (CPC). It is a binding energy conservation target for local governments and key central government departments, requiring all government divisions at different levels to ensure the achievement of the target through the rational disposition of public resources and effective administration organization and oversight.[51]

One key industry-focused energy policy is the Top-1000 Energy-Consuming Enterprise Program. In April 2006, China's Central government launched the Top-1000 Energy-Consuming Enterprises Energy-Efficiency Program (Top-1000 program), the goal of which is to improve industrial energy efficiency by targeting China's 1000 highest energy-consuming enterprises. These enterprises currently account for approximately 50% of total industrial sector energy consumption and 30% of total energy consumption in China. During the summer of 2006, energy-saving agreements with targets for 2010 were signed with all Top-1000 enterprises. Further, Premier Wen Jiabao again called for the establishment of a new National Energy Conservation Center to oversee provincial energy conservation centers and to provide technical outreach and support to Top-1000 Program enterprises.

The Top-1000 enterprises have been selected from nine sectors: iron and steel, petroleum and petrochemicals, chemicals, electric power, non-ferrous metals, coal mining, construction materials, textiles, and paper. Estimated 2004 final energy use for the Top-1000 enterprises was 673 Mtce (19.7 EJ, 18.7 Quads), and the energy reduction goal for these enterprises after five years is 100 Mtce (2.9 EJ, 2.8 Quads). The target of the Top-1000 program is designed as one of the tools to realize the 11th Five Year Plan goal of reducing energy consumption by 20% per unit of GDP.

The Top-1000 program is modeled after a Shandong Province pilot program. In 2001 and 2002, China's government launched a policy pilot program using energy efficiency agreements with two steel mills in Shandong Province. Targets were established and agreements between the two steel mills and the government were signed on April 24, 2003. The steel mills committed to achieve energy intensity reduction targets by 2005, implement energy-efficiency management practices, and report energy use and other relevant indicators annually. The Shandong Province Economic and Trade Commission committed to provide the enterprises with assistance in obtaining loans for energy-efficient technologies, the services of government-backed technical experts free of charge to the enterprises, and positive media publicity. Both steel mills met their targets for energy savings and CO_2 emissions reductions, implemented strong energy management programs, established monitoring and reporting protocols, and enjoyed extensive positive

[50] National Development Reform Commission (NDRC). 2007. *11th Five Year Plan on Energy Development*, NDRC, Beijing.
[51] Zhou N, et al. (forthcoming) *Overview of Current Energy Efficiency Policies in China*. LBNL Report.

publicity. The pilot was considered a success and a model for the national-level Top-1000 program.

The Top-1000 program involves a number of key players, including National Development and Reform Commission (NDRC, as lead agency), the Office of the National Energy Leading Group, the National Bureau of Statistics (NBS), the State Owned Assets Supervision and Administration Commission, the General Administration of Quality Supervision, Inspection and Quarantine, Provincial Development Research Councils (or Economic and Trade Commissions), industrial associations, and enterprises in the iron/steel, non-ferrous metal, chemicals, petroleum/petrochemicals, construction materials, textiles, paper, coal mining, and power industries.

The Top-1000 program has clearly identified the responsibilities of each party. The role of the government is to conduct program oversight and management, provide incentive policies and awards, and support information dissemination and a reporting system. The role of the enterprises is to formulate energy conservation targets and energy conservation plans, conduct energy audits, adopt comprehensive energy conservation measures, and submit an "Enterprise Energy Usage Annual Report" every year. The role of the industrial associations is to supply enterprises with information and technical assistance, help establish a reporting and evaluation system, and assist in monitoring and enterprise performance management.

The Top-1000 program target has been established down to the provincial level. All participating enterprises have signed energy conservation agreements with local governments and have promised to reach the energy savings target by 2010. For example, China's National Development and Reform Commission (NDRC) signed an agreement with the Beijing Municipal Government covering ten enterprises within Beijing's jurisdiction. The Beijing Municipal Government, in turn, signed an energy efficiency target contract with each of the ten enterprises that includes energy saving guidelines. Achievement of the energy-saving targets has been added to the provincial government cadre evaluation system wherein the individuals responsible for implementation will be evaluated each year on whether or not the targets under their jurisdiction have been achieved. Use of the evaluation system in this manner provides strong incentives to government officials to assist the enterprises in achieving the energy-saving targets.

The enterprises are required to report their energy consumption by fuel quarterly to the NBS. The Top-1000 reporting is directly to NBS via a website, not through regional statistical bureaus. The data collection is done in this manner to improve accuracy and reliability, to make it easier for the enterprises, and to reduce work for regional statistical bureau staff members. NBS will only release information on average or total energy use or energy use by industry, but not by specific enterprise. It is planned that every July NBS will release energy use statistics for the previous year and in August they will release energy use statistics for the first half of the current year.

In October 2006, NDRC conducted a series of training sessions in five cities across China for the enterprises participating in the Top-1000 program. The sessions covered energy and energy conservation measurement, energy statistics, energy auditing, and major energy saving technologies in nine energy consuming industries, guidelines for energy conservation plans for enterprises, and the application of benchmarking in large scale power plants. In the winter of 2007, enterprises performed energy audits and developed energy action plans outlining how they are going to meet their energy-saving targets. The enterprises found this task difficult due to the lack of qualified auditing personnel and institutions.

NDRC is currently selecting which enterprises' energy conservation projects will receive additional funding. Projects of the selected enterprises will receive energy conservation financial support from a national bond. Many enterprises are preparing proposals for this funding; those enterprises involved in the Top-1000 program will be given priority. Some provinces have extended the Top-1000 program to include key energy consuming enterprises beyond the national Top-1000 enterprises in their provinces. Shandong Province, for example, has implemented a provincial additional Top-1000 enterprise program.[52] Beijing is going to implement a 100 top enterprise and 10 key enterprise program. Guangdong Province has asked 1000 provincial enterprises to reduce their energy consumption.

In July 2007, the Chinese government allocated an additional 10B RMB¥ ($1.4B)[53] to improve energy efficiency and abate pollution, bringing the total annual investment for this purpose to 21.3B RMB¥ ($3B) (NDRC, 2007b). Of this 10 billion RMB, eighty percent of the fund (8B RMB¥ or $1.1B) is for energy efficiency projects and the remainder is for payments for closing inefficient plants. Of the 8 billion RMB, 7B RMB¥ ($1B) is for technology renovation as well as rewards and rebates, while 1B RMB¥ ($140M) is for capacity building. The funding for these areas is 13 times more than the 2006 amount. During the summer of 2007, The Ministry of Finance and NDRC used a portion of this funding to award enterprises 200 to 250 RMB¥ ($28 to $35) for every tce saved (Lu, 2006; Jiang, 2007) related to the implementation of five of the Ten Key Projects. The 2007 port price for coal in China was about 600 RMB¥ to 800 RMB¥ ($83 to $111) per ton. Assuming 2.42 tons carbon dioxide (CO_2) per ton coal equivalent and assuming that industrial energy use in China is predominately coal, this funding is equivalent to $11 to $14 per ton of CO_2 emissions reduced.[54] In 2008, similarly, 7.5B RMB was set aside to reward the Ten Key Projects, and 4B RMB for phasing out inefficient plants (MOF, 2008).

The central government also seeks to address energy challenges through publicly-sponsored research. Both the High-tech Research and Development Program (or the "863" Plan) and the National Basic Research Program (or the "973" Plan) have identified advanced coal technologies as a high-priority area for government support. During the 10th FYP (2001-2005), the "863" Plan invested about 320 million Yuan in clean-coal technologies, which included ultra-supercritical technology, pollution control

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[52] Available at http://www.china5e.com/news/newpower/200611/200611080217.html
[53] Based on a currency conversion factor of $1 = 7.2 RMB¥
[54] 2007 price of CO_2 on Chicago Climate Exchange was $4.5/tCO_2$ and on the European Climate Exchange was $8.4/tCO_2$

technologies for coal-fired power plants, integrated gasification combined cycle technology, and coal poly-generation technology. These highly-competitive “863” grants, which are regarded not only as financial support but also as a recognition of the awardee’s technical leadership, leveraged about one billion Yuan of investment from industry and local governments.[55]

6.2. 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 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.

6.3. Nuclear power

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.[56]

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.

[55] Sun Guodong. (2008) *Coal in China: Resources, Use, and Advanced-Coal Technologies*. Pew Center on Global Climate Change.
[56] 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.

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.[57] At a price of at least $130 per kilogram of uranium, China's identified resources are estimated at 60,000 tons of uranium.[58] 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.[59] Nevertheless, the growth of nuclear power throughout Asia suggests that China's reliance on imported uranium may constrain rapid large-scale development.

6.4. 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%.

7. Economic and Environmental Implications of Chinese Coal Use

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. At the same time, the coal industry serves as a major foundation of rural employment and urban growth though electricity production. After reviewing the environmental costs, this section examines employment and investment aspects of China's coal industry.

7.1. 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,

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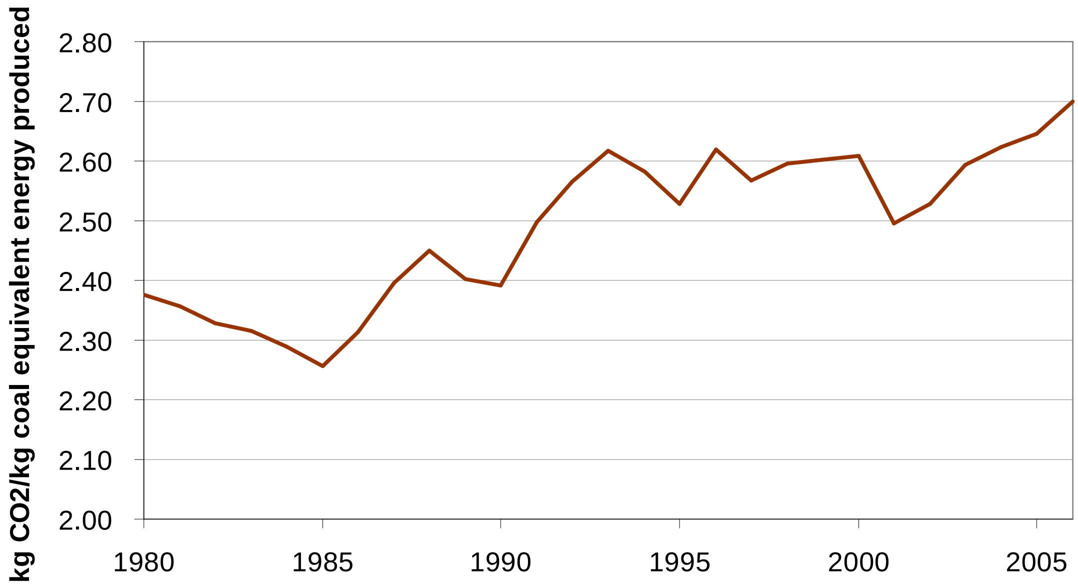
[57] *Interfax China Energy Report Weekly*, March 27, 2008, Vol. 7:13, p. 4.
[58] World Energy Council. 2007 Survey of Energy Resources. London: WEC Press.
[59] See, for example, http://news.bbc.co.uk/2/hi/asia-pacific/4871000.stm.

compared to 73 t CO2/TJ for oil and 56 t CO2/TJ of natural gas.[60] 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 further illustrated in the rising carbon intensity of commercial energy production between 2001 and 2006 (Figure 37).

Figure 37: Carbon Intensity of Energy Production, 1980-2006

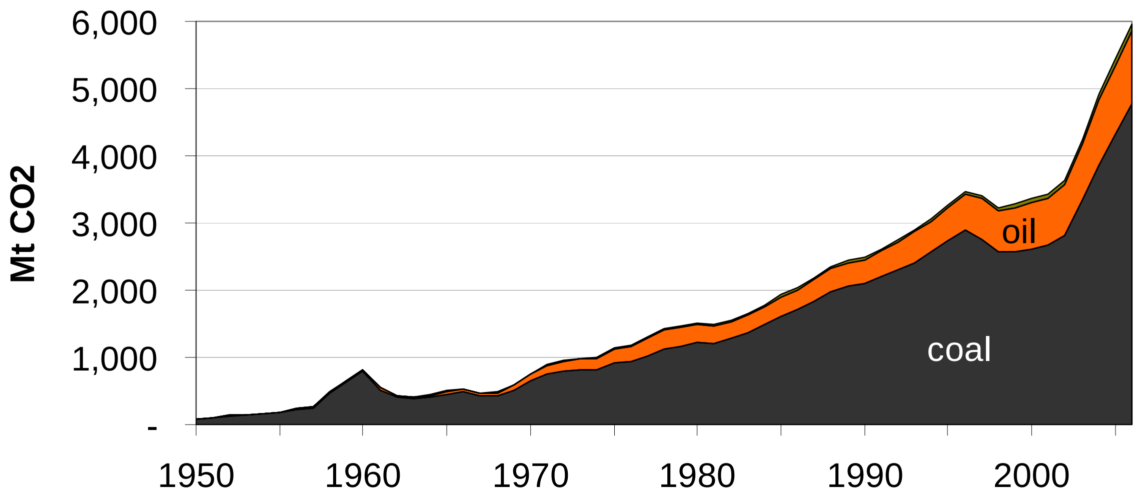


Note: LBNL China emissions are derived from revised total energy consumption data published in the 2007 China Statistical Yearbook using revised 1996 IPCC carbon emission coefficients; energy production data from NBS 2007.

Carbon capture and sequestration (CCS) is the only current option for reconciling continued coal use with emissions mitigation. There are three approaches to CCS: pre-combustion sequestration through coal gasification or liquefaction, or post-combustion sequestration through filtration. Current technology schemes for CCS, however, are fairly energy intensive and would result in an increase in total primary energy consumption. China is researching CCS, but does not expect to have a demonstration project until later in the 2010s.

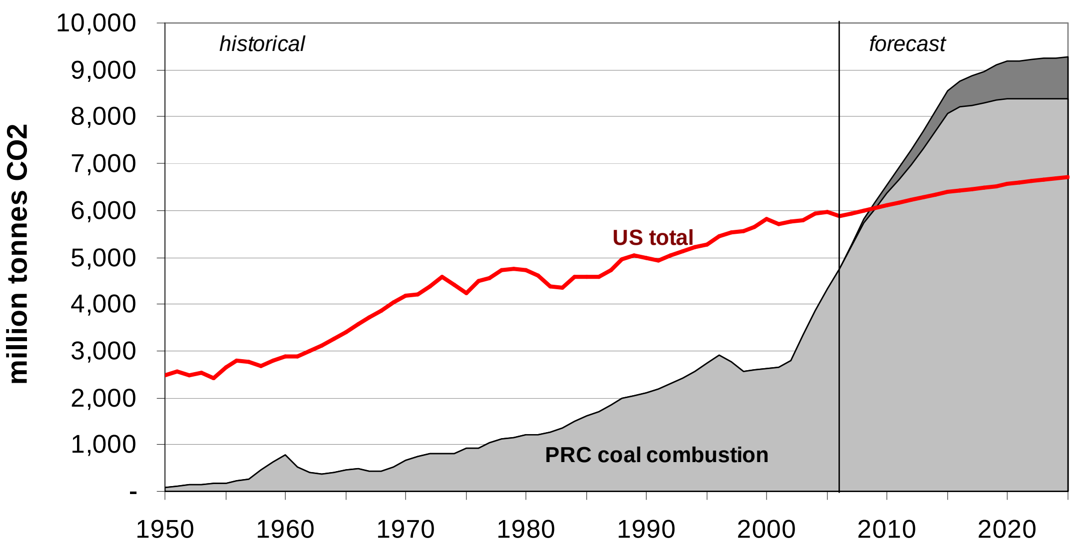
[60] IPCC. 1996. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual, 1.13. (http://www.ipcc-nggip.iges.or.jp/public/gl/guidelin/ch1ref1.pdf)

Figure 38: Energy-related carbon dioxide emissions by fuel type, 1950-2006



China's current growth trajectory indicates that carbon emissions from coal combustion will surpass total US energy-related carbon emissions by 2010. Figure 39 shows that China's coal-related carbon emissions would surge to 9.3 billion tonnes of CO2 in 2025 under the demand trajectory developed in this report (including CTL and CTC; 8.4 billion tonnes without the fourth wedge). In contrast, the WEO 2007 projects total US energy-related carbon dioxide emissions to reach 6.7 billion tonnes in 2025.

Figure 39: China Coal-related Carbon Dioxide Emissions, 1950-2030

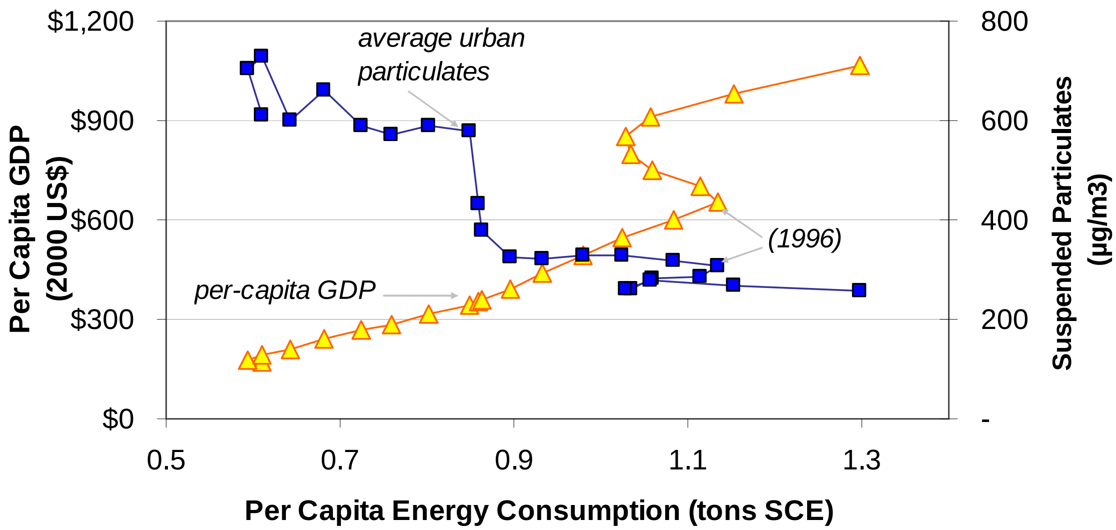


Limited alternatives to coal impede China's flexibility to achieve carbon dioxide emission growth constraints, much less absolute reductions.

7.2. Air and water 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. Three key measures of environmental air quality are the concentration of total suspended particulates (TSP), sulfur dioxide emissions, and carbon dioxide emissions. Within China, TSP levels are measured by city environmental bureaus. Figure 40 illustrates the annual decline of average urban TSP levels as a function of rising per capita energy consumption between 1980 and 2003. According to Chinese government data, average urban TSP levels declined from their peak of 729 µg/m3, at 0.61 tons of standard coal equivalent (SCE) per capita energy consumption (in 1982), to 256 µg/m3 at 1.3 tons SCE in 2003. The data in Figure 40 also illustrate the reported decline of annual per-capita energy consumption between 1996 and 2000 as a result of the central government's program for industrial restructuring and a decline in economic demand that was exacerbated by the 1997 Asian financial crisis. Market competition functioned as a central driver for the declining TSP-intensity of energy consumption by increasing demand for more efficient, higher-quality coal. Other drivers included coal substitution of less-efficient biomass energy sources, increasingly effective end-user regulation, and availability of new combustion technologies.

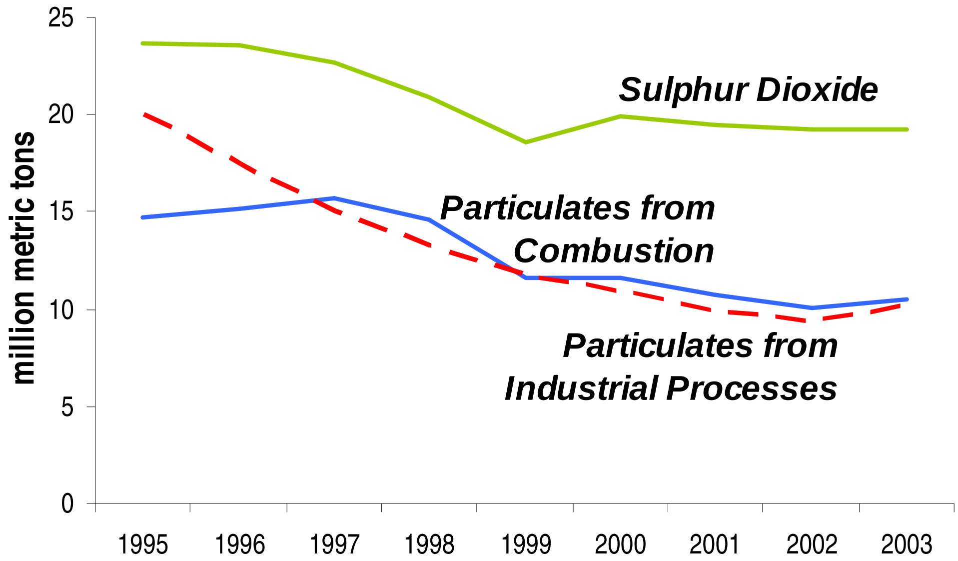
Figure 40: Per capita GDP and suspended particulates as a function of energy consumption, 1980-2003



Sources: National Bureau of Statistics (various years), China Statistical Yearbook (Beijing: China Statistics Press); China Environment Yearbook (various years)

Sulphur 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 41). 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 desulphurisation is only now becoming widespread. However, sulphur content in delivered coal has fallen as efficiencies have improved, and better particulate removal has captured some sulphur dioxide, so overall emissions have fallen. A growing fraction of coal is used in power plants with tall stacks, and less in residential and small industrial applications, and much coal-using industry has been relocated outside cities. Ambient concentrations of sulphur dioxide in cities have consequently fallen; although in many places levels exceed China's air quality standards. Simultaneously, the regional problem of acid precipitation had become more serious. Acid precipitation affects over 40 per cent of the country's land area and causes damages of US$1 to 2 billion annually.

Figure 41: Sulfur dioxide emissions and particulate emissions, 1995-2003



Sources: Editorial Board of the China Environment Yearbook (all years 1996 to 2004) China Environment Yearbook, all editions1996 to 2004 (Beijing: China Environmental Science Press); NBS, (2004).

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. Ambient particulate levels show very similar trends, especially since particulates from motor vehicles and construction activities have replaced falling industrial emissions in many cities. Most residents of China's northern cities live with annual average particulate levels about twice as high as national standards, and some cities experience much higher averages.

The impacts of a coal-dominated energy economy are felt all along the fuel chain. About 5,000 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.[61]

7.3. Employment

In 2005 China had 24,813 coal mines with 3.6 million registered employees. Worker safety has gradually improved with industry consolidation. In 2006, Chinese miner fatalities fell to 2.04 deaths per million tonnes. The NDRC has announced its intention of reducing China's mining death rate to less than 2 fatalities per million tonnes coal produced. An unknown number of miners also die each year from occupational diseases.

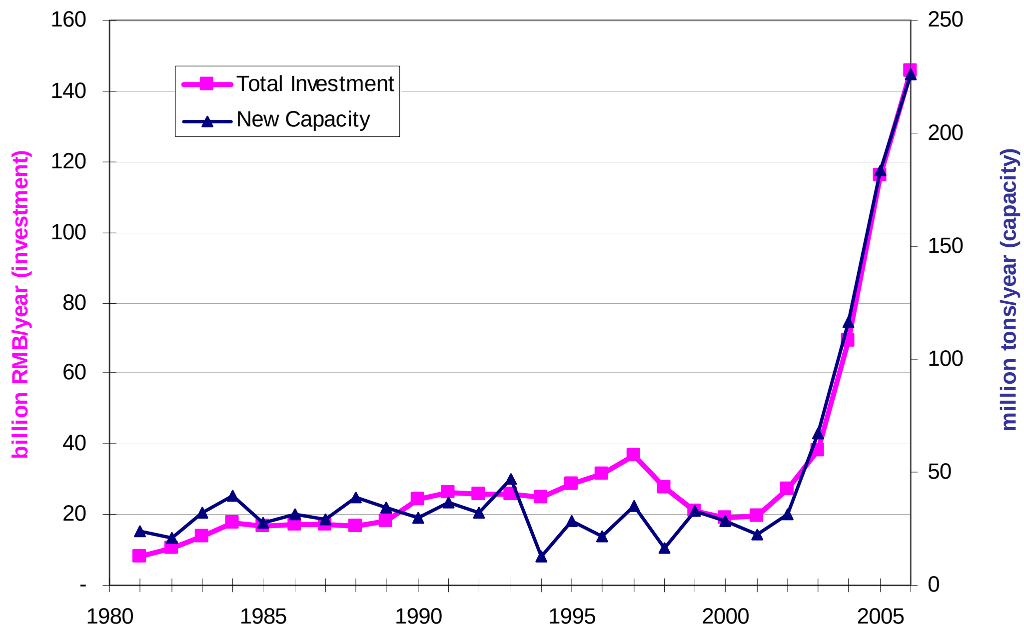
In its discussion of personnel, China's 11th Five-Year Plan for Coal Industry Development targeted an increase of the proportion of coal mining employees to total workers in the economy from 7% to 12%. The Plan also stated that coal miners' shall have an average education level of 11 years and that 50% of employees shall have completed their secondary education by 2010.[62]

7.4. Investment requirements

As the average depth of Chinese mines increases the investment requirement for coal production is also growing.

[61] Ho, Mun S. & Chris P. Nielsen. (2007) *Clearing the Air: The Health and Economic Damages of Air Pollution in China*. Cambridge, MA: MIT Press.
[62] National Development Reform Commission (NDRC). 2007a. *11th Five Year Plan on Coal Industry Development*, NDRC, Beijing. (*in Chinese*)

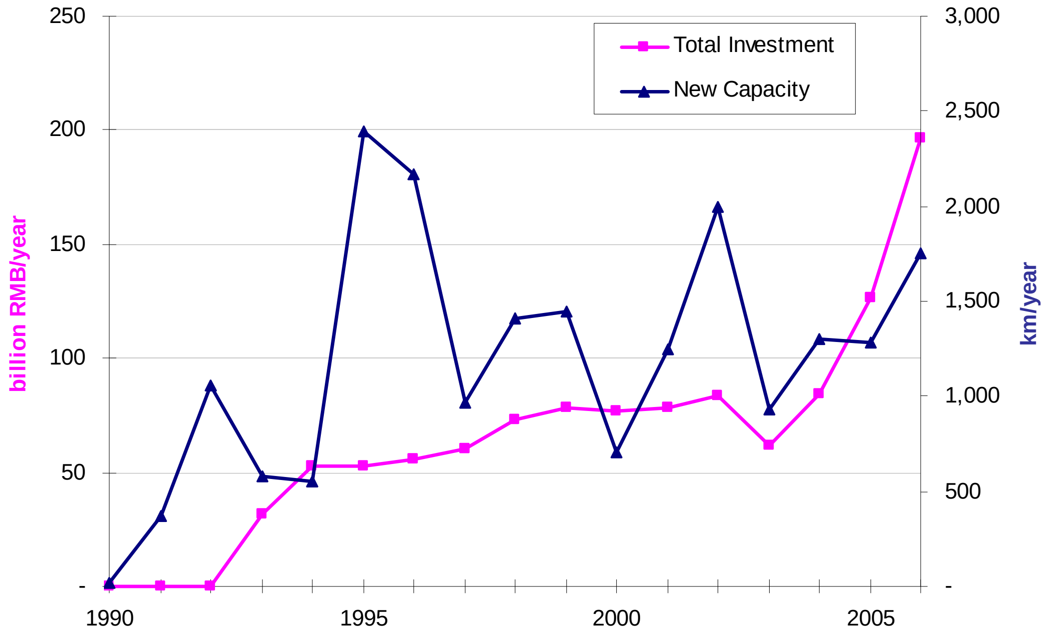
Figure 42: Coal Mining Total Investment and New Capacity



As illustrated in Figure 42 above, China's newly increased coal mining capacity has closely followed the total investment in coal mining from 1980 to present. From 1980 to 2000, both total investment and new mining capacity were relatively constant, with some minor fluctuations in new capacity trend. After 2002, however, both China's total investment in capital construction and innovation for coal mining and newly increased mining capacity significantly increased. Since 2000, the unit investment cost has fluctuated between 600,000 and 800,000 RMB per tonne of new mining capacity.

Total coal mining investment doubled from 2003 to 2004, and then almost doubled again from 2004 to 2005. Similarly, the new mining capacity added in 2006 was six times that of 2002. In fact, the total new mining capacity added from 2000 to 2006 is greater than the capacity added from 1980 to 2000. In comparing the recent growth rate in both investment and in capacity with that of 1980 to 2000, it is unclear whether this scale of increase in capacity can be sustained.

Figure 43: Railway Total Investment and New Capacity



In contrast to the coal mining industry, the investment and capacity increases in the railway industry was less constant prior to 2000. While total investment generally increased from 1990 to the early 2000s, there was much more fluctuation in the annual newly added railway capacity. Since 2003, total railway investment has increased at a higher rate, tripling from 2003 to 2006. However, the amount of new capacity added has increased at a slower rate, and even decreased slightly from 2004 to 2005.

The inconsistent increases in new capacity from 1990 to 2006 have important implications for the Chinese Ministry of Railway's plan to expand its railway capacity to 100,000 km by 2020. In order to meet this plan, China would have to increase its railway capacity by over 17,000 km from now to 2020, or about 1,400 km year. In other words, China must maintain an annual newly increased capacity on par with the 2006 level for the thirteen years in order to achieve its expansion goal.

8. Conclusions

China has been, is, and will continue to be a coal-powered economy.

The rapid growth of coal demand since 2001 has created deepening strains and bottlenecks that raise questions about supply security. Although China's coal is "plentiful," published academic and policy analyses indicate that peak production will likely occur between 2016 and 2029. Given the current economic growth trajectory, domestic production constraints will lead to a coal gap that is not likely to be filled with imports.

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. If China follows Japan, steel production would peak by 2015; cement is likely to follow a similar trajectory. A fourth 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 450 million tonnes of coal demand by 2025. Efficient growth among these drivers indicates that China's annual coal demand will reach 4.2 to 4.7 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.

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 is short of high-quality reserves, but is producing its best coal first. Declining quality will further strain production and transport. Transporting coal to users has overloaded the train system and dramatically increased truck use, raising transport oil demand. Growing international imports have helped to offset domestic transport bottlenecks. In the long term, import demand is likely to exceed 200 mt by 2025, significantly impacting regional markets.

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 is likely to bring about increased competition with other coal-importing countries including Japan, South Korea, Taiwan, and India. As with petroleum, China may respond with a government-supported "going-out" strategy of resource acquisition and vertical integration. Given its population and growing resource constraints, China may favor energy security, competitiveness, and local environmental protection over 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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