Natural Gas and China's Environment[1]

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Abstract

Greater utilization of natural gas could dramatically improve environmental conditions in China. Results show that China could cut particulate, sulfur dioxide, and carbon emissions by 1, 3, and 70 million tons, respectively, each year if it boosts gas utilization to 10 percent of total energy demand by 2020. But the government first needs to establish a broad new array of market reforms to make this happen. Developing the natural gas sector makes sense economically, independent of carbon control efforts, but an international agreement to credit reductions in carbon emissions could stimulate significant new foreign investment for gas projects in China.

Keywords: *China, environment, natural gas, sulfur, electricity*

The Role of Energy in China's Economy

China has achieved rapid economic growth over the past two decades using far less energy than other countries at similar stages of development.[2] The economy has expanded nearly twice as

[1] For presentation at the IEA-China Natural Gas Industry Conference in Beijing on 10 November 1999. The author thanks William Chandler, Meredydd Evans, and James Dooley for reviewing earlier versions of this paper.
[2] Economic growth has occurred twice as quickly as energy growth during this period in China. In India, Brazil, and South Korea, for example, growth in energy use has outpaced that of the economy. See *Developing Countries and Global Climate Change*, assorted case studies.

quickly as energy consumption since 1985.[3] (See Figure 1.) China would be producing far greater volumes of sulfur dioxide, carbon dioxide, and particulate emissions if it had not taken steps to improve energy efficiency and conserve energy. Yet environmental pollution, resulting largely from coal combustion with little or no emission controls, has become so bad in many regions that the economy has suffered. Economic momentum has also slowed over the past two years from the dual effects of domestic market reforms and the Asian financial crisis. For the first time in China's modern history, energy supply now exceeds demand.

China's coal and electricity sectors became rapidly oversupplied beginning in 1997. Coal stockpiles totaled nearly 200 million tons in June 1999, despite the closure of 23,000 small coal mines and a reduction in output of almost 200 million tons of coal from the 1997 level.[4] The power generation sector was oversupplied by an estimated 24 gigawatts in mid-1999, a remarkable change from 1997 when China was struggling to keep up with demand.[5] Domestic market reforms have slowed both industrial production and consumer demand, while the Asian financial crisis has affected exports and hence the need for greater energy consumption. Returning to previous levels of rapid economic growth will depend largely on the success of continuing domestic reforms. New energy supplies will be needed in the coming decades, however, regardless of the outcome of domestic reforms or energy efficiency efforts, simply to meet the development needs of hundreds of millions of aspiring Chinese.

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[3] See, for example, "Energy Efficiency in China: Accomplishments and Challenges," pp. 813-829, for an explanation of how China achieved these energy savings. While the quality of China's statistics is questionable, a recent OECD analysis showed that China's energy savings are real. See *Linking China to the World Energy System: China's Global Search for Energy Security*, pp.12-15.

[4] *China Energy Watch*, August 1999, p. 12, and *China Online*.

[5] *China Energy Watch*, August 1999, p. 5. China has also decommissioned approximately half of a planned 8 gigawatts (8 million kilowatts) of small, inefficient plants between the years 1998 and 2000.

Energy Supply Dilemmas

China has abundant energy resources, but none offers an ideal solution to the country's energy problems. Most of China's energy resources lie in the northern and western regions, far from the population centers in the east. Coal pollution has also damaged human health, agricultural output, infrastructure, and the environment, largely because planners ignored these costs over decades of central economic planning.

Coal is China's most abundant source of energy and historical policies have kept prices low. Domestic coal accounts for three-quarters of the country's total energy demand, making China unique among the world's major energy consumers. Hundreds of millions of tons of coal are sent by rail and barge each year to the east coast from the mines in north-central China. Coal prices in the north are as low as $10 per ton at the mine mouth, but transportation costs drive the price of delivered coal to over $35 per ton in the south.[6] Coal from southern China is very high sulfur and ash content, making it less desirable.

As Chinese citizens grow wealthier, they demand higher quality forms of energy, including petroleum products, methane-rich gases, and electricity. China has struggled to expand domestic crude oil production but became a net importer of petroleum in 1994. Imports could account for 40-50 percent of petroleum demand by 2010 given the rapidly growing demand and stagnating domestic production.[7]

China's most favorable hydroelectric sites are located in the southwest, far from energy demand centers. Rivers in the north could also produce more electricity, but heavy silt loads make them

[6] Coal prices fell by approximately 15 percent in 1998 due to oversupply. *Climate Change and Developing Countries: Electric Power Choices for China*.

less desirable hydropower sites. Constructing giant hydroelectric stations--like the Three Gorges Dam project--is expensive and creates social and environmental disruption. Large hydro dams produce power with no emissions, but smaller plants can often accomplish the same goals with fewer social and environmental costs.[8]

China had, until recently, an ambitious plan to boost the use of nuclear power as a source of clean, domestic energy. These plants have high capital costs, however, and are thus difficult to finance in a country with capital constraints. The original plan to add 20 gigawatts of nuclear capacity by 2020 looks increasingly out of reach.

Other forms of energy, largely undeveloped, are also found far from demand centers. Excellent wind resources exist off China's southeastern coast and in the remote northwest provinces of Inner Mongolia, Gansu, and Xinjiang. Wind resources for the entire country exceed 250 gigawatts, but installed wind capacity was less than 300 megawatts by mid-1999 due to high power costs, technical difficulties, and distorted markets.[9] Likewise, solar energy resources in the west are abundant, but thousands of kilometers from dense population centers and still expensive.

China's natural gas and coal bed methane reserves are spread out more uniformly, but supply-demand imbalances remain significant. Domestic gas reserves are unknown to some extent because of limited incentives to find and develop new fields. New pipelines, storage facilities, and distribution networks will need to be constructed to deliver gas to consumers.

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[7] "China's Growing Energy Dependence: The Costs and Policy Implications of Supply Alternatives," p. 26.
[8] See, for example, *The River Dragon has Come!*, for a list of concerns over large dams in China.

Few of the technology options available in China can generate electricity at low cost without damaging environmental emissions. (See Table 1.) China has prioritized the control of sulfur emissions and is trying to commercialize domestic flue gas desulfurization (FGD) technologies. Progress has been slow, and Chinese consider imported FGD technology expensive. So-called clean coal technologies are not yet commercial in China and suffer from high costs and complexity. Many power developers now prefer gas-fired combined-cycle plants because they have low capital costs, short construction periods, and modular flexibility, but China has yet to create the policies and infrastructure needed to make this source of power generation a meaningful option in many regions. Historically, Chinese planners believed that gas was simply too valuable as a feedstock for fertilizer production or residential fuel to be used for power generation.

Environmental Dislocations

Coal has been largely responsible for the abysmal state of China's environment.[10] The World Bank reports that almost 400,000 people suffer premature deaths each year due to poor air quality.[11] The same report estimates that air and water pollution damage to human health, agriculture, and infrastructure cost at least $54 billion a year—or nearly 8 percent of the GDP in 1995. Particularly damaging to human health are the small particles emitted during coal combustion. China's State Environmental Protection Agency estimates that sulfur emissions and acid deposition alone erase 2 percent of GDP by reducing crop productivity, damaging exposed infrastructure, and impacting human health.[12] Simply put, it is no longer in China's economic interest to continue ignoring the effects of pollution.

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[9] Personal communication with Shi Pengfei, China State Power Company, 13 July 1999.
[10] Nitrogen oxide emissions from the growing fleet of vehicles in cities like Beijing, Shanghai, and Guangzhou also account for a significant source of urban pollution. See the World Bank, New Ideas in Pollution Regulation.
[11] *Clear Water, Blue Skies: China's Environment in the New Century*, p. 2.
[12] *Xinhua News Agency*.

In summary, China has relied on coal for much of its energy needs but the environmental impact is now harming economic growth and the health of millions of people. Other sources of energy remain largely undeveloped, expensive, or far from centers of population. Given these choices, Chinese planners have begun to reevaluate the advantages of natural gas and institutional support within the government for greater gas utilization has grown dramatically over the past few years.

Natural Gas Drivers

Natural gas has clear environmental advantages over other fossil fuels. New technologies are also emerging that can reduce the costs of finding, developing, and utilizing new gas supplies. Methane-rich gases could also help address geographic imbalances in energy supply and demand, as well as the increasing reliance on imported petroleum.

Unlike coal or oil, natural gas combustion produces virtually no sulfur dioxide and particulate emissions. In the power sector, a combined-cycle power plant produces less than 40 percent of the nitrogen oxides and carbon dioxide as a standard coal-burning plant. (See Table 2.) Industrial boilers, furnaces, and kilns all operate more efficiently and produce less pollution using gas instead of coal. Converting or replacing even a fraction of China's half million coal-fired boilers to use natural gas could dramatically reduce harmful emissions and save energy due to the higher efficiencies.[13]

In residential applications, coal-burning stoves and heaters produce dangerous mixtures of particulate, carbon monoxide, and toxic emissions, causing extensive damage to human health.

Traditional coal burning stoves have efficiencies of only 10-15 percent, and improved versions only 30 percent. Converting the stoves to use natural gas, as with industrial boilers, would lower harmful emissions and also cut energy consumption due to their higher efficiencies. The potential for accidental leaks and explosions, however, can not be ignored. Typically, the smaller the application, the greater the environmental benefit of switching from coal to gas.

New technologies can lower the cost of finding and using natural gas. Three dimensional seismic imaging and horizontal drilling technologies have raised the chances of finding and developing profitable gas fields.[14] Improvements in conversion technologies, such as combined-cycle power plants, have made gas a cost-effective fuel in many countries. Gas-to-liquids technology also promises to make even small gas fields profitable since the energy can be sent to markets without the need for expensive pipeline infrastructure. If scientists continue to improve this technology over the next decade, it will put downward pressure on natural gas and LNG prices across the globe. In the transportation sector, some Chinese municipalities are experimenting with compressed natural gas vehicles as a way to improve local environmental conditions. Fuel cell vehicles, which can operate on methane-rich gases, could begin playing a significant role in China's transportation mix within one or two decades.

China will not realize the benefits of natural gas unless it expands domestic supplies or begins to import gas from abroad. There is considerable debate about the extent of domestic gas reserves and China appears reluctant to depend heavily on imports. Still, there has been progress on both fronts.

[13] Typical coal boilers in China are 15 percent less efficient than those found in industrialized countries. Large gas boilers operate about 5-10 percent more efficiently than coal units, but smaller units can be 25 percent or more efficient. "Energy Efficiency Opportunities in China," p.4

[14] "Emerging Technology in the Energy Industry and Its Impact on Supply, Security, Markets, and the Environment," pp. 3-5.

China's Methane-rich Resources

China's proven natural gas reserves are stated to range from 1.2 to 5.3 trillion cubic meters, a small percentage of the world's estimated reserves of 141 trillion cubic meters.[15] Only a small fraction of China's reserves have been confirmed, yet many Chinese geologists believe there is far more natural gas remaining to be discovered given the country's large reserves of coal and oil. Complicated geology, remote locations, and incomplete surveying have made it difficult to identify and develop gas reserves in China. Perhaps more importantly, there have been few incentives to find and develop new gas fields.[16]

China has sizeable on-shore gas reserves in Sichuan, Shaanxi, Gansu, Ningxia, Qinghai, and Xinjiang. Output in these provinces is expected to drive most of the future onshore growth. The South China Sea and Donghai regions account for most offshore production, but the Bohai Sea region is also promising as well due to a large new discovery in July 1999.[17]

Coal Bed Methane

China has potential coal bed methane (CBM) reserves of 30-35 trillion cubic meters. Just 10 percent of this gas could fuel 100 large, combined-cycle power plants for 30 years.[18] Over the past 2 years, at least 4 foreign companies have negotiated contracts to explore and test the economics of coal bed methane production in Anhui, Shanxi, and Jiangxi provinces. Results from their pilot tests should be complete within 2 years, after which major new investments could begin to develop the fields. China is particularly interested in developing CBM reserves

[15] "Incentives Needed for Foreign Participation in China's Natural Gas Sector," p. 50.
[16] For a more complete list of incentives needed, See Logan and Chandler, p. 54-55.
[17] "Phillips Discovers Large Oil Reserve in China's Bohai," *China Online*, 13 July 1999.
[18] A 1 gigawatt combined-cycle plant consumes approximately 1 billion cubic meters of gas each year.

because thousands of miners lose their lives in the country's notoriously gassy mines each year. CBM is also a potent greenhouse gas, with 21 times the heat-trapping potential of carbon dioxide on a weight basis. China could improve mine productivity and safety as well as lower greenhouse gas emissions by capturing the methane-rich gas before mining or release to the atmosphere. The United States produces more CBM than China does natural gas, but CBM output in China is projected to grow quickly.[19] (See Table 3.)

Import Options

China recently announced plans to build its first liquefied natural gas (LNG) import facility in Guangdong. The world is currently oversupplied with LNG because new supply facilities are coming on-line while demand from Japan and Korea has fallen due to economic slowdown. Capital costs to build new LNG supply trains have fallen by up to 40 percent this decade, and consumers could soon benefit from the lower costs.[20] Short-term supply contracts could become more popular if LNG production costs continue to fall and supply exceeds demand. China is considering the construction of additional LNG terminals in Fujian and Shanghai. Building LNG import terminals is capital intensive, but this import option avoids the complex security issues of transporting gas via pipeline across international borders. The levelized cost of power generation in China using LNG priced at $4 per gigajoule is competitive with coal-fired plants using sulfur scrubbers and coal priced at $35 per metric ton, as demonstrated later in this paper.

Some of the world's richest gas fields lie less than 3,000 kilometers from Beijing in Siberia, near Irkutsk. China and Russia have held high-level talks over the construction of a pipeline to deliver 30 billion cubic meters of gas annually to northeastern China, but the proposal suffered a

[19] Stevens, S., p. 1
[20] Sandison, G.

setback when the primary Russian gas company, Sidanko, declared bankruptcy in 1998. Additionally, the need for multiparty finance and the risk of sending gas across international borders has further slowed progress. Gas from these fields would, however, be China's cheapest import option.[21] Discussions are also underway for pipeline gas imports from Sakhalin and Kazakhstan.

Natural Gas Reform

China has demonstrated great interest in making natural gas an important new energy source. A major drive for natural gas utilization appears daunting, however, because policies addressing issues ranging from exploration and development to transmission, distribution, and end-use must be established in unison for a viable market to emerge. New incentives must be created if China is to significantly boost gas utilization. The required policy issues are beyond the scope of this paper, but are addressed by other authors in this set of papers.[22] One issue, gas pricing, deserves a brief look.

Domestic Gas Pricing

A two track system of pricing currently exists for natural gas in China. Historically, gas prices were set artificially low as a method of subsidizing fertilizer and industrial production. Low prices offered little incentive for exploration and development of new gas fields. Recent policies have raised the price in some new natural gas markets to 2-3 times the earlier level, mainly to ensure recovery of infrastructure costs. End-use markets for new gas in Beijing, for example, have developed slowly, however, due to consumers' reluctance to pay the higher prices after

[21] A 1996 World Bank study estimated that gas could be brought to China from this distance and priced at approximately $3 per gigajoule for power generators. LNG, on the other hand, is about 30 percent more expensive at $4 per gigajoule.

[22] See Andrews-Speed and Dow for a good discussion of fundamental policy issues.

years of subsidies. Prices for natural gas in China will probably stabilize and then decline as reforms remove market distortions, much as they did in the United States and other countries that liberalized their markets during the 1980s and 1990s.[23]

Impact on Pollution

If China champions greater use of natural gas through successful reforms, gas could account for 10 percent or more of the country's energy mix by 2020. Greater gas use would significantly lower emissions of sulfur and nitrogen oxides, carbon monoxide, particulates, and carbon dioxide. The analysis below demonstrates how greater gas use would reduce these emissions.

An additional 100 billion cubic meters (BCM) of gas would be needed each year to meet the 10 percent goal, compared to the baseline case where gas accounts for 4 percent. (See Table 3.) How the gas is used will heavily influence the amount of pollution avoided. Gas has the highest priority use in the residential sector, where coal combustion causes the most health and environmental damage, but a majority of the gas will probably be consumed in the power sector simply to help create markets for other end users. New supplies may be difficult to develop without the power sector to anchor strong demand in the end-use market. The analysis below assumes that the extra 100 BCM is used to displace coal combustion, and that half of it is used for power generation, with the remainder split evenly in the industrial and residential sectors. Table 4 provides the efficiency assumptions used in the calculations.

The reduction in particulate, sulfur dioxide, and carbon emissions amounts to 1, 3, and 70 million tons, respectively. (See Table 5.) Over 200 million tons of coal combustion would be avoided. These calculations use conservative assumptions so even greater savings could result.

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23 See "Developing China's Gas Markets," p. 4-5.

Power Generation Example

Figure 2 compares the economics of gas and coal-fired plants. The diagonal line indicates where the levelized cost of power from a typical combined-cycle power plant equals that of a coal-fired plant. For a given natural gas price then, if coal is more expensive than the value at which the dashed horizontal line touches the vertical axis, then gas-fired power is cheaper. It should be noted that China does not yet have the capacity to manufacture the gas turbines used in modern combined-cycle systems, and would need to rely on imported units until it could produce them domestically.

On purely economic grounds, gas can compete with coal in southern China where coal costs $35 per ton or more. New natural gas supplies for power generation would likely cost $3-4 per gigajoule. For coal plants using flue gas desulfurization (FGD), gas plants would compete when coal prices exceed $30 per ton. (See "FGD" line in Figure 3.) Gas becomes even more attractive when planners account for the full economic and environmental costs of power generation. (See Environmental Externality "EE" line in Figure 3.) This coal price ($25 per ton) includes many of the heavily populated regions of the country.

Natural gas development makes sense independent of carbon dioxide mitigation. Even greater investment in China's gas sector could result, however, if international negotiations can develop a system for crediting carbon mitigation. China has expressed interest in the clean development mechanism (CDM) as a way of gaining access to advanced technologies and international financing while reducing carbon dioxide emissions. It has not yet decided if it will participate in the process, even if the United Nations successfully establishes it. Investors and host countries would need to agree on a way to define baseline emissions and share carbon credits.

A carbon credit valued between $20 and $40 per ton of carbon would lead to near equality in power prices from coal and gas fired power plants over much of China. (See "$20/ton-C" and "$40/ton-C" lines in Figure 3.) This price for carbon permits would be attractive to potential international investors, but other transaction costs within China might raise the actual price paid.

Conclusions

Natural gas could help alleviate some of China's most pressing energy and environmental problems, but not without significant market and institutional reform. New incentives and technologies could increase the amount of domestic and imported gas brought to market. China could cut sulfur dioxide emissions by 3 million tons if it boosts gas usage to 10 percent of the total energy mix by 2020. In power generation, natural gas already competes with coal when the full economic and environmental costs of generation are considered. Gas markets could attract significant international investment if negotiators agree on the clean development mechanism and China chooses to participate.

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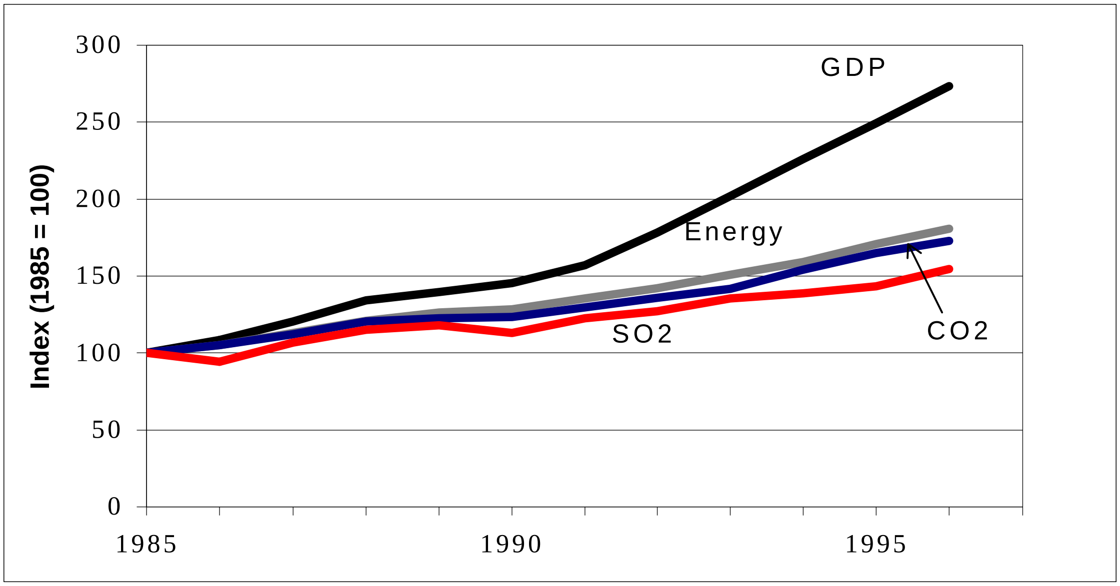
Figure 1 – Growth of China's Economy, Energy, and Emissions, 1985-97



Source: China Statistical Yearbook, BP Statistical Review of World Energy, China Energy Databook.

Table 1 – Electric Power Options in China

Option	*Pollution Costs*	*Carbon Costs*	*Technical Costs*	*Fuel Costs*	*Overall Costs*
"Clean" Coal	Low-Moderate	High	High	Low	Moderate-High
Natural Gas	Low	Moderate	Low	High	Moderate
Hydro	Mixed	Very Low	High	None	Moderate
Nuclear	Mixed	None	Very High	Low	High
Renewables	Low	Very Low	High	None	Moderate

Source: Modified from "China's Electric Power Options," p. 81

Table 2 - Emissions in New Chinese Power Plants, grams per kilowatt-hour

Fuel	*SO_2[a]*	*NO_x*	*TSP[b]*	*CO_2*
Pulverized Coal (PC)	11	3	0.2	857
PC w/ Wet Flue Gas Desulfurization	1	3	0.2	893
Integrated Gasification Combined-Cycle	0.5	0.3	0.05	755
Heavy Fuel Oil	16	1.5	1.0	714
Natural Gas Combined-Cycle	~0	0.5	.03	336

a – Assumes 1.2 percent sulfur content.
b – Assumes fly ash removal efficiency of 99 percent. Solid waste of 74 grams/kWh is also produced.
Note: TSP = total suspended particulates;
Source: Derived by PNNL.

Table 3 – China's Natural Gas Consumption, billions of cubic meters

Source	*1997*	*1998*	*2000*	*2010*	*2020*
Domestic Natural Gas	22.2	22.3	25	70	100
Coal bed methane	0.4	0.5	1	5-15	10-30
LNG	0	0	0	5-10	15-30
Imported Pipeline Gas	0	0	0	20	40-50
Total	22.6	22.8	26	100-115	165-210

Source: Miao and PNNL.

Table 4 – Efficiency Assumptions Used in the Emissions Calculations

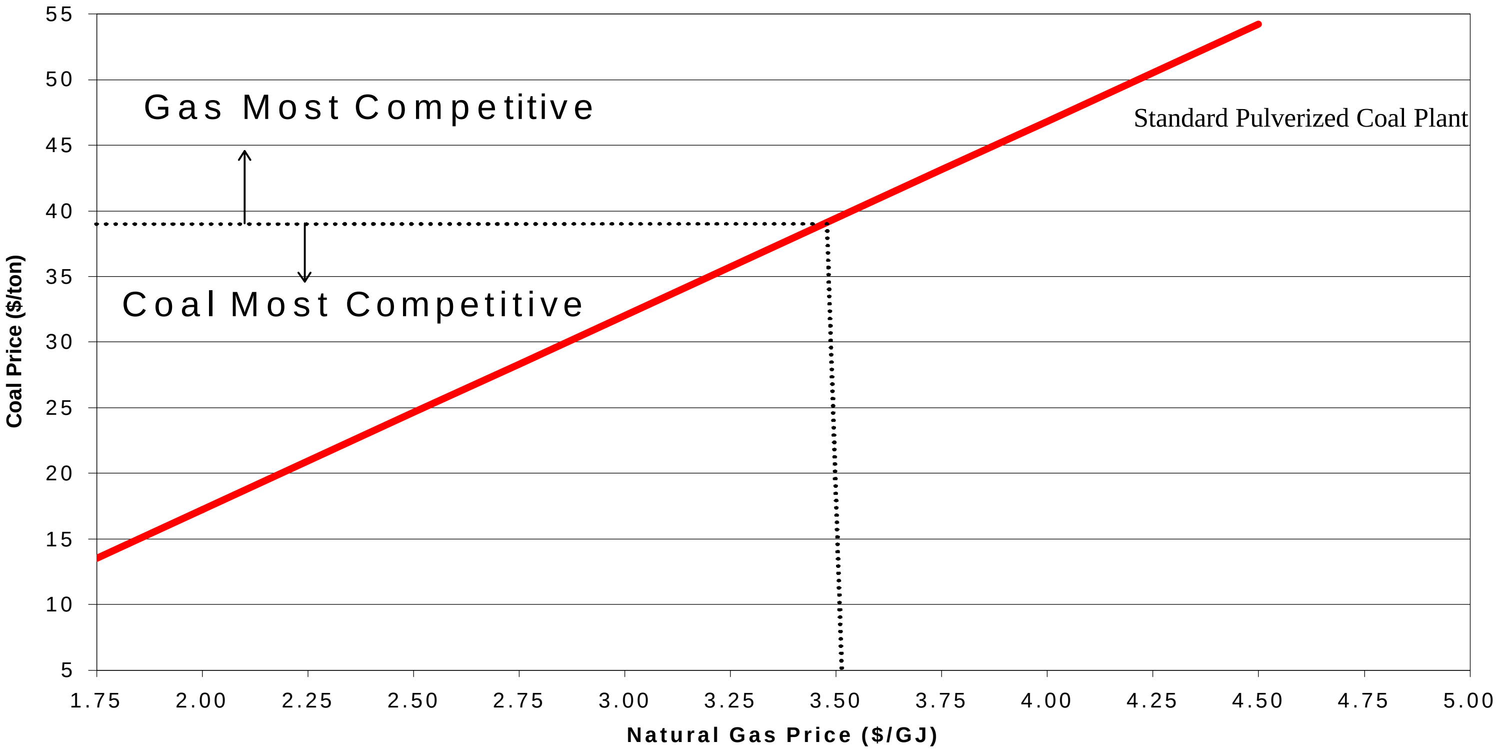
Sector	*Average Gas Efficiency*	*Average Coal Efficiency*
Power	55	37
Industrial	82	70
Residential	50	35

Table 5 – Effect of Boosting Gas Consumption to 9 Percent in Total Demand in 2020

Sector	*Gas Used in place of coal (BCM)*	*Coal Displaced (Mt)*	*SO_2 reduction (kt SO_2)*	*TSP Reduction (kt)*	*Solid Waste Reduction (Mt)*	*CO_2 Reduction (MtC)*
Power	50	86.7	1,235	22	17.4	26.2
Industry	25	53.8	767	269	11.0	16.6
Residential	25	65.7	936	657	5.6	26.9
Total	100	206.3	2,938	948	34.0	69.7

Note: Coal sulfur content is conservatively estimated at 0.75 percent. Particulate capture is estimated at 99.5, 90, and 50 percent, respectively for power, industry, and residential applications. Coal ash assumed to be 25 percent, except for residential applications where it is 10 percent. Bottom ash assumed to be 80 percent and fly ash 20 percent.

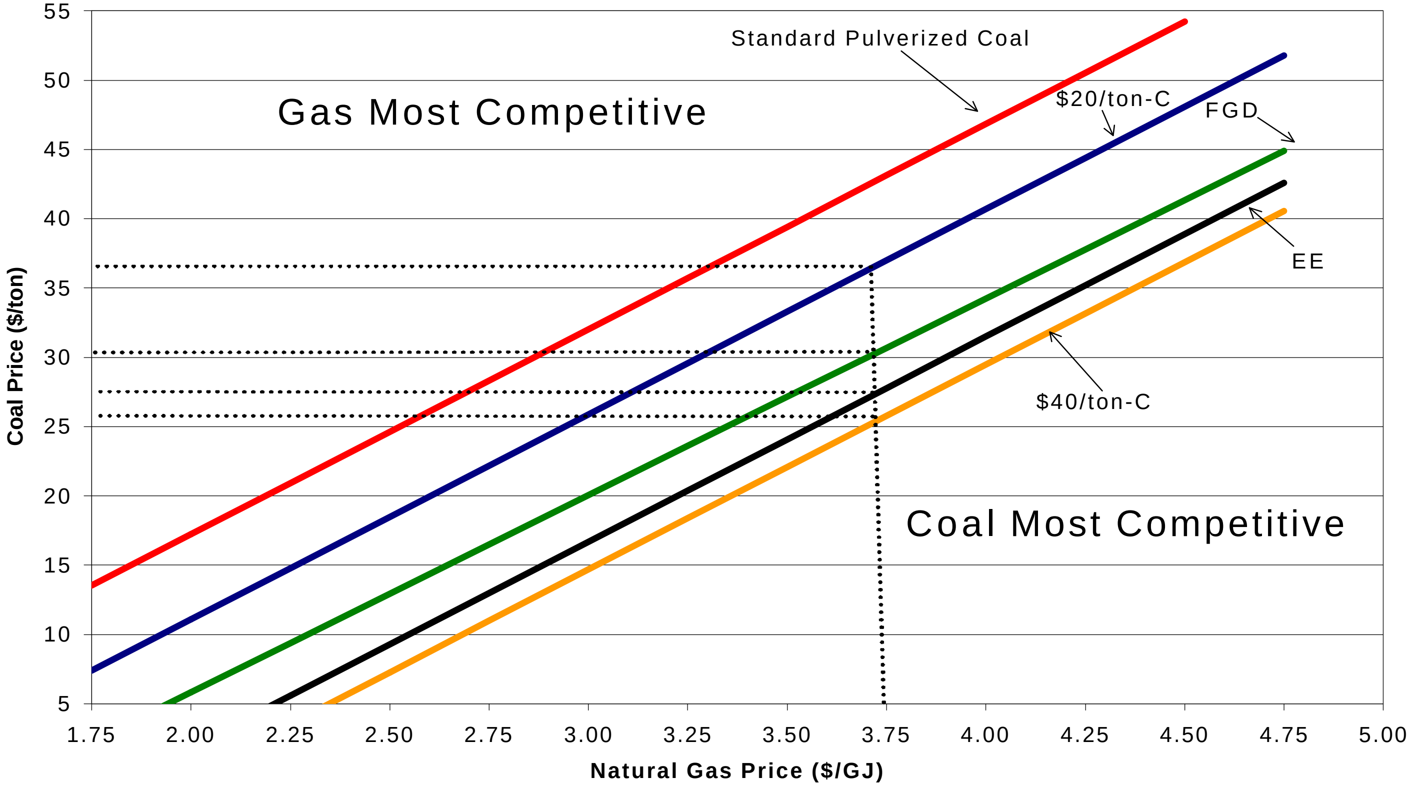
Figure 2 – Economics of coal and gas-fired power generation in China (1999)



To use this graph: Given a price for natural gas ($3.50/GJ), move vertically to the diagonal line. Then move horizontally to the associated coal price ($39/ton). If the actual price of coal is higher (lower) than this, then natural gas provides power at a lower (higher) levelized cost than coal.

Assumptions: Coal plant has high-efficiency electrostatic precipitators and an efficiency of 37 percent. Combined-cycle gas turbine plant efficiency is 55 percent. Capital costs are $500/kW and $650/kW for gas and coal plants, respectively.

Figure 3 – Economics of coal and gas-fired power generation in China with other options (1999)



To use this graph: Given a price for natural gas, move vertically to the appropriate diagonal line. Then move horizontally to the associated coal price. If the actual price of coal is higher than this, then natural gas provides power at a lower levelized cost than coal.

Note: FGD means flue gas desulfurization or wet scrubbers. EE means environmental externalities. $x/ton-C refers to plants offering carbon permits. Assumptions: Environmental externalities for sulfur dioxide, nitrogen oxide, and particulate emissions are $750 per metric ton each. See Figure 2 for other assumptions. For reference, a $20/ton-C charge would add approximately $0.005 per kilowatt-hour to the cost of electricity generation.