

Increased Gas-fired Generation Can Help China Meet Multiple Objectives

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September 2010

At the current pace of renewable energy development, balancing variable energy resources will become a challenge for China's power sector. And the existing low-carbon policy framework may exacerbate the challenge in two ways. First, China's energy plans involve adding new nuclear plants – 70-80 GW by 2020 – and large efficient coal-fired plants, both of which have a limited ability to ramp up and down effectively to accommodate changes in demand or changes in wind and solar generation. Second, smaller coal-fired plants, which do have modest ramping ability, are being shut down as part of a strategy to improve the environment and the overall thermal efficiency of the coal fleet.

Current integration plans focus on using coal and hydro to balance wind, but looking forward other resources with greater operational flexibility, like pumped storage, demand response and natural gas, will likely play a role in integrating renewable energy into the system.

In the US and the EU, the capital and operating costs of natural gas-fired generation has made it a cost-effective resource with, or without, consideration of its superior ability to ramp up or down and start up quickly. Even where the basic economics favored coal, the environmental benefits and risk characteristics of natural gas have made it a popular for investors in both the US and EU.

A number of factors indicate that China's experience will be different from that of the EU and US:

- By the end of 2006, natural gas-fired plants accounted for only 15.6 GW, or 2.5% of generating capacity.
- Given current exploration efforts and technology, China has limited domestic gas supplies.
- The regulatory structure assigns priority fuel-use to other sectors (residential, chemical fertilizer industry, etc.).¹
- High efficiency natural gas-fired generating equipment is largely imported, meaning China has relatively high plant capital costs.²

¹ National Development and Reform Commission, No. 2155 [2007], 国家发展改革委关于印发天然气利用政策的通知, available at http://www.sdpc.gov.cn/zcfb/zcfbtz/2007tongzhi/t20070904_157244.htm. International Energy Agency, "Natural Gas in China: Market Evolution and Strategy," June 2009, available at [http://www.europeanenergyreview.eu/data/docs/natural%20gas%20in%20china%20\(market%20evolution%20&%20strategy\).pdf](http://www.europeanenergyreview.eu/data/docs/natural%20gas%20in%20china%20(market%20evolution%20&%20strategy).pdf).

² In China, the most efficient combined cycle gas generation technology is imported and thus costly. In contrast to the US and EU, gas-fired generation capital costs in China are on par with, or only slightly more expensive than, those of coal, so the economics are not as favorable. Average cost of gas plants built between the years of 2002-2005 was 3385yuan/kW; while the average cost of coal plants with FGD built within the same time frame was 4285 yuan/kW, or 26% more expensive than gas. But the average cost of large gas plants (300-390 MW) was more expensive than coal plants in the same capacity range, 4354 yuan/kW vs. 3823yuan/kW, or 14% more expensive. China State Electricity Regulatory Commission, "十五"期间投产部分电工程项目单位造价排序, July 2006.

If integrating renewable energy were the only objective, building flexible coal plants might be a more cost-effective solution. However, China is simultaneously harmonizing power sector plans with carbon intensity and air pollution goals, which collectively may justify increasing the share of natural gas-fired generation in China's power supply beyond the 70 GW planned by 2020.³

Carbon Intensity Goal

China's carbon intensity reduction target of 40% to 45% below 2005 levels by 2020 will lead to more interest in natural gas-fired generation. As is widely recognized, natural gas-fired plants can produce electricity with substantially less energy input per kilowatt-hour than a typical coal plant. In the US, the CO₂ content of natural gas is 46% lower than that of coal.⁴ On average, a natural gas plant produces half as much carbon dioxide per kilowatt-hour as a coal plant.⁵

Combined cycle plants in the US have an average heat rate of 7,500 Btu/kWh, better performing than the most state-of-the-art coal turbines.⁶ In California, the Best Available Control Technology (BACT) standard for combined-cycle gas turbines – a standard which is guiding national greenhouse gas policy development at the US Environmental Protection Agency – is 7,730 Btu/kWh, and a CO₂ emissions rate of 800 lb/MWh is considered achievable for new plants.⁷ Ultra-supercritical coal generators, of the sort that China is currently building, can have an efficiency of 42% to 43%, whereas combined-cycle gas turbine technologies range from 51%, to as high as 60% efficient (see Figures 1 and 2).^{8,9}

³ By the end of 2006, gas-fired plants provided 15.6GW, or 2.5% of generating capacity, up from 1.7% in 2005. Government plans have aimed to increase gas-fired capacity to 70GW by 2020 and 36GW by 2010. Estimates from Energy Research Institute of NDRC are slightly less optimistic, putting total installed capacity by 2020 at 60GW. Energy Research Institute, "Policy Study: Gas-fired Power Generation in China," 2006.

⁴ Calculated from EIA's CO₂ emissions coefficient of coal and gas. In 2008 in the US, the CO₂ emissions coefficient of coal for electric power generation was 94.7 million metric tons CO₂ per quadrillion Btu, as compared to that for pipeline natural gas which was 53.06 million metric tons CO₂ per quadrillion Btu, representing a 46 percent higher CO₂ content. See: US DOE, Energy Information Administration, US Emissions Data, Carbon Dioxide Emissions Factors, available at <http://www.eia.doe.gov/environment.html>.

⁵ Average coal-fired generation produces 2,249 lbs/MWh of carbon dioxide, where as average natural gas generation produces 1135 lbs/MWh of carbon dioxide. See US Environmental Protection Agency, Climate Change>Clean Energy, available at <http://epa.gov/cleanenergy/energy-and-you/affect/natural-gas.html>.

⁶ MIT, *The Future of Natural Gas*, Interim Report, June 2010.

⁷ CALPINE, "GHG BACT Analysis Case Study," February 2010, Slide #7 and #9, available at http://www.epa.gov/oar/caaac/climate/2010_02_GHGBACTCalpine.pdf.

⁸ US DOE, National Energy Technology Laboratory, Natural Gas Combined Cycle Plant F-Class, available at http://www.netl.doe.gov/KMD/cds/disk50/NGCC%20Plant%20Case_FClass_051607.pdf.

⁹ The Regulatory Assistance Project, "Emissions Rates for Power Generation Technologies," 2001, available at http://www.raponline.org/docs/RAP_DGEmissions_2001_05.pdf. US DOE, NETL, Natural Gas Combined Cycle Plant with and without CCS, 2007, available at http://www.netl.doe.gov/KMD/cds/disk50/NGCC%20Technology_051507.pdf. G-type gas turbine combined plant has an efficiency exceeding 53% (HHV base). Mitsubishi Heavy Industries, Technical Review, Vol. 45 No. 1, March 2008, available at <http://www.mhi.co.jp/technology/review/pdf/e451/e451015.pdf>. GE H-class has an efficiency of 60%. GE Heavy Duty Gas Turbines and Combined Cycle, available at http://www.gepower.com/prod_serv/products/gas_turbines_cc/en/index.htm.

Figure 1. Coal Consumption and Emissions of Coal-fired Generation Technologies¹⁰

Performance	Subcritical	PC/Supercritical	PC/Ultra-supercritical
Heat Rate Btu/kWe-h	9950	8870	7880
Generation Efficiency (HHV)	34.3%	38.5%	43.3%
Coal Use (10 ⁶ t/y)	1.548	1.378	1.221
CO ₂ Emitted (g/kWe-h)	931	830	738
Assumptions: 500 MW net plant output; Illinois #6 coal; 85% Capacity Factor			

For the US and EU, natural gas-fired generation offers the most realistic solution for near-term reductions in greenhouse gases. Fuel-switching from coal to natural gas, in response to declining natural gas prices, was partly responsible for a 4% reduction in CO₂ emissions from the US power sector from 2008 to 2009.¹¹ A recent study estimates that, with the existing fleet, dispatching gas before coal would force more than a 10% reduction in CO₂ emissions from the power sector nationwide, without additional capital costs or risk to system reliability.¹²

Air Pollution Goal

China's SO₂ and NO_x emissions reduction ambitions are also at the top of the list of government priorities for the 12th Five Year Plan period and beyond – and gas would serve this purpose as well.

A natural gas-fired plant in the US has an average NO_x emissions rate of less than one-third that of coal, and the average emission rate for SO_x is roughly 1% that of coal.¹³ New natural gas plants have even superior performance, emitting a negligible amount of SO₂, PM and mercury. Compared to advanced coal technology, they stand out as the cleaner option, emitting only one-tenth as much NO_x (see Figure 2 below).

¹⁰ "Higher Efficiency Power Generation Reduced Emissions," Janos Beer, MIT, National Coal Council Issue Paper 2009, available at, <http://web.mit.edu/mitei/docs/reports/beer-emissions.pdf>.

¹¹ US DOE, Energy Information Administration, US Carbon Dioxide Emissions in 2009: A Retrospective Review, May 5, 2010, available at <http://www.eia.doe.gov/oiaf/environment/emissions/carbon/>.

¹² "The current fleet of natural gas combined cycle (NGCC) units has an average capacity factor of 41 percent, relative to a design capacity factor of up to 85 percent. However, with no carbon constraints, coal generation is generally dispatched to meet demand before NGCC generation because of its lower fuel price. Modeling of the ERCOT region (largely Texas) suggests that CO₂ emissions could be reduced by as much as 22 percent with no additional capital investment and without impacting system reliability by requiring a dispatch order that favors NGCC generation over inefficient coal generation; preliminary modeling suggests that nationwide CO₂ emissions would be reduced by over 10 percent. See: MIT, *The Future of Natural Gas*, Interim Report, June 2010.

¹³ US EPA, Climate Change, Clean Energy, How does electricity affect the environment?, available at <http://www.epa.gov/cleanrgy/energy-and-you/affect/coal.html>.

Figure 2. Emissions Summary for Natural Gas Combined Cycle and Pulverized Coal Supercritical Plants (assuming 85% capacity factor)¹⁴

Pollutant	Natural Gas Combined Cycle	Pulverized Coal Supercritical
CO ₂		
tons/year	1,661,720	3,632,123
lb/MMBtu	119	203
SO ₂		
tons/year	Negligible	1,514
lb/MMBtu	Negligible	0.085
NO _x		
tons/year	127	1,250
lb/MMBtu	0.009	0.070
PM (filterable)		
tons/year	Negligible	232
lb/MMBtu	Negligible	0.013
Hg		
tons/year	Negligible	0.020
lb/MMBtu	Negligible	1.140

Pollution reduction achieved through building gas generation as a substitute for new coal would support China meeting its 11th and 12th Five Year Plan targets for SO₂ and NO_x emissions control. More critical perhaps is the role for natural gas-fired generation in improving air quality and complying with new emissions regulations in key population centers along the eastern seaboard, as laid out in the State Council's Regional Air Quality Management (RAQM) rule issued in May 2010.

The RAQM rule identifies the three major inter-jurisdictional regions – Beijing-Hebei-Tianjin, Shanghai-Jiangsu-Zhejiang, and the Pearl River Delta – for aggressive air pollution prevention and control. Among measures required by the new regulation are the following of particular relevance:

- Apply strict limits on new construction and expansions to coal-fired power plants.
- Set emissions standards for coal-fired power generators that are more stringent than national standards.
- Aggressively reduce NO_x and PM emissions.
- Ramp up deployment of clean energy resources in urban areas, specifically natural gas.
- Pilot a cap on total coal consumption.

¹⁴ This study assumes the operation of pollution control equipment according to the US Best Available Control Technology (BACT) standards for emission requirements of the 2006 New Source Performance Standard for criteria pollutants. US DOE, National Energy Technology Laboratory, Cost and Performance Baseline for Fossil Energy Plants, Volume I, May 2007, available at <http://www.netl.doe.gov/KMD/cds/disk50/index.html>.

In recent years, partly for the benefits to air quality, natural gas plants have been built in and around the coastal cities, such as Guangzhou and Shanghai – though exposure to high global LNG prices and an unfavorable domestic policy structure have reportedly caused these plants to lie idle on more than one occasion.^{15,16} Now, though, particularly to comply with these new environmental restrictions on coal, additional natural gas generation will likely be needed to keep supply on pace with demand in these fast-growing urban areas.

It is broadly understood that natural gas performs better environmentally than coal. Less well understood is the effect on conventional plants of more frequent cycling to accommodate the fluctuations of variable generation such as wind. The problem is two-fold. Running a plant at a lower capacity factor and with more up and down cycling than what it was designed for reduces plant efficiency, and thus increases emissions and fuel costs, and potentially reduces the plant life and plant reliability.¹⁷ At the same time, running the plant at variable, sub-optimal temperatures causes complications with the pollution control equipment, resulting in increased emissions rates. These two factors may lead to greater amounts of SO₂, NO_x and CO₂ than if the plant had been operated consistently at a higher load factor.¹⁸

In light of China's carbon and environmental goals, the emissions impact of cycling coal plants – even those designed with greater operational flexibility – should be duly analyzed and incorporated into strategies to integrate renewable energy and planning for natural gas generation.

In addition, consideration should be given to flexibility and the ability of generating plants to tolerate frequent cycling, as newer gas turbines from GE and Siemens are able to do. For a coal plant, there are significant financial costs associated with the damage caused by routine cycling and by running below optimal capacity levels. These include increased maintenance costs, equipment repair and replacement expenses, as well as an potential shortened plant life. As with emissions, the precise cost of cycling damage will vary according to the age, type and other specifications of the plant. And while some coal plants have better ramping capabilities than others, these costs are estimated to be significant enough at a high rate of renewable energy penetration to change the bottom line for marginal coal plants in the US.¹⁹

¹⁵ Existing gas plants are concentrated in Shanghai, Zhejiang, Fujian, Guangzhou, and Jiangsu. Energy Research Institute, "Policy Study: Gas-fired Power Generation in China," 2006; DOE's Energy Information Administration, <http://www.eia.doe.gov/cabs/China/NaturalGas.html>. "China's Natural Gas Industry and Gas to Power Generation," Chun Chuni, Institute of Energy Economics, Japan (EIJ), 2007. "Fuel oil power plants wethering away in China with increasing gas utilization," *Reuters*, June 6, 2010,

<http://www.glgroupp.com/News/Fuel-oil-power-plants-wethering-away-in-China-with-increasing-gas-utilization-48804.html/>. "China in 'great leap forward' for gas," *Reuters*, March 17, 2010, <http://www.reuters.com/article/idUSTRE62G0UM20100317>.

¹⁶ Because users in Guangdong are tied to import prices, they seem to be especially vulnerable to the global market. "NG-fired generators in Guangdong suffer from lasting fuel shortages," *CBI China*, April 24, 2008, <http://en.cbichina.com/Common/1530301,0,0,0,1.htm>. In 2007-2008, residential and industrial sector were willing to pay high prices, whereas the power sector was reluctant. International Energy Agency, "Natural Gas in China: Market Evolution and Strategy," June 2009, [http://www.europeanenergyreview.eu/data/docs/natural%20gas%20in%20china%20\(market%20evolution%20&%20strategy\).pdf](http://www.europeanenergyreview.eu/data/docs/natural%20gas%20in%20china%20(market%20evolution%20&%20strategy).pdf).

¹⁷ Danneman, Gene, Xcel Energy, "Baseload Unit Cycling Costs," Presentation before the Utility Wind Integration Group Workshop on Wind Integration Studies: Models and Methods, June 25, 2010.

¹⁸ "How Less Became More: Wind, Power and Unintended Consequences in the Colorado Energy Market," Bentek Energy, April 2010, available at <http://www.wind-watch.org/documents/wp-content/uploads/BENTEK-How-Less-Became-More.pdf>; "The impact of wind generated electricity on fossil fuel consumption," C. le Pair & K. de Groot, April 2010, available at <http://www.clepair.net/windefficiency.html>.

¹⁹ Puga, J. Nicolas, "The Importance of Combined Cycle Generating Plants in Integrating Large Levels of Wind Power Generation," *Electricity Journal*, Vol. 23, Issue 7, Aug/Sept 2010.

By contrast, modern combined-cycle natural gas plants can ramp quickly and frequently, without affecting the economics of the plants, and retrofit modifications can be made to increase the operational flexibility of older combined-cycle plants.²⁰

Obstacles remain to natural gas-fired generation in China. Even with new estimates of China's unconventional reserves bulging domestic supply figures, China's share of global reserves is still very limited. Other obstacles are easier to address. Plant construction costs, for example, are not prohibitively higher than coal plant costs – average capital costs are actually 26% lower than coal, but larger 300 MW to 390 MW-sized plants are 14% more expensive – and costs are coming down.²¹ What is not known is how a concerted effort to develop the domestic capability to build high efficiency natural gas-fired power plants can drive the capital cost down as China has done for other sources of generation.

One economic disadvantage that can be overcome deserves special attention here: China's generation pricing practice. China issues generation prices based on a combined energy-and-capacity scheme that assumes 5,000 or so annual operating hours – the typical hours of a baseload coal plant. This encourages investment in such facilities, but discourages investment in peaking or cycling generation that would be expected to operate only during peak hours or when needed to firm up wind. That is because if a generator does not operate the 5,000 or so hours over the course of the year, it will not fully recover its capital costs.

This pricing scheme has also proven a hurdle in implementing China's innovative dispatch policies that prioritize renewable energy and other clean generation – known as renewable priority dispatch and environment dispatch policies. Under these dispatch rules, dirty coal plants may be operated less than 5,000 hours, and so require some mechanism to be compensated for their capital costs. Relatively straightforward pricing reform, which would separate the recovery of energy and capacity costs, could remove the disincentive for flexible generation like natural gas, and help address these other related problems as well.

²⁰ Id.

²¹ National Development and Reform Commission, No. 2155 [2007].