

Natural Gas in the Energy Futures of China and India

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The Program on Energy and Sustainable Development at Stanford University is an interdisciplinary research program focused on the economic and environmental consequences of global energy consumption. Its studies examine the development of global natural gas markets, reform of electric power markets, international climate policy, and how the availability of modern energy services, such as electricity, can affect the process of economic growth in the world's poorest regions.

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About the PESD Study: Natural Gas in the Energy Futures of China and India

The role of natural gas in Chinese and Indian economies is of critical import both domestically and for global energy and environmental issues. The competition between coal and natural gas in these two markets has tremendous implications for local air pollution and for climate change. Rising demand for imported gas in China and India will also shape the LNG market in the Pacific Basin and could lead to the construction of major international pipeline projects to monetize gas supplies in Russia and the Middle East. PESD has partnered with leading regional research centers in both China and India to construct detailed assessments of the key drivers for future gas demand in both countries.

In China, PESD has partnered with research institutes in Beijing, Shanghai and Guangdong to build detailed bottom-up models of future energy demand in each of these regions. Each research team is using a MARKAL model to study the competition between fuels and technologies to meet energy demand growth. Scenarios test the implications of key drivers such as local air pollution controls, capital market reforms, and gas availability. PESD modeling partners are Tsinghua University, Jiaotong University, and the Guangdong Development and Technoeconomic Research Centre.

In India, PESD has partnered with research partners to identify how national-level reforms in the electricity, fertilizer, and industrial sectors could affect natural gas consumption patterns throughout the country. By studying these major off-taking industries, PESD developed a series of plausible storylines for the natural gas market might develop under a range of scenarios. PESD has collaborated with the Indian Institute of Management, Integrated Research and Action for Development, and A.T. Kearney.

Disclaimer

This paper was written by a researcher (or researchers) who participated in the PESD study *Natural Gas in the Energy Futures of China and India*. Where feasible, this paper has been reviewed prior to release. However, the research and the views expressed within are those of the individual researcher(s), and do not necessarily represent the views of Stanford University.

I. Introduction

The world's natural gas market is rapidly globalizing. Traditionally, gas supplies have been delivered entirely within regional markets—usually with little geographical distance between the source of gas and its ultimate combustion. However, a significant and growing fraction of world gas is traded longer distances via pipeline and, increasingly, as LNG. The rising role of LNG is interconnecting gas markets such that a single global market, with a single mechanism for price formation, is emerging.¹

Within this increasingly integrated gas market, the roles of China and India remain highly uncertain. Natural gas has historically been consumed primarily in the major industrialized countries in Europe, North America, and East Asia, but many projections to the future expect a greater role for developing countries – China and India being the major drivers of this growth. However, today, China and India's share of the global gas market is tiny – the Chinese natural gas market is smaller than California's (48 bcm compared to 62 bcm in 2005), while India is half that size.² Both countries have large populations and are growing rapidly. Demand for other energy commodities—coal and oil, notably—is expanding rapidly. With appropriate policies, gas could follow suite. Their proximity to major gas suppliers, in the Middle East, Southeast Asia, and Russia make them possibly important consumers of both piped gas and LNG. At present, however, projections of gas demand in each of these countries vary widely.

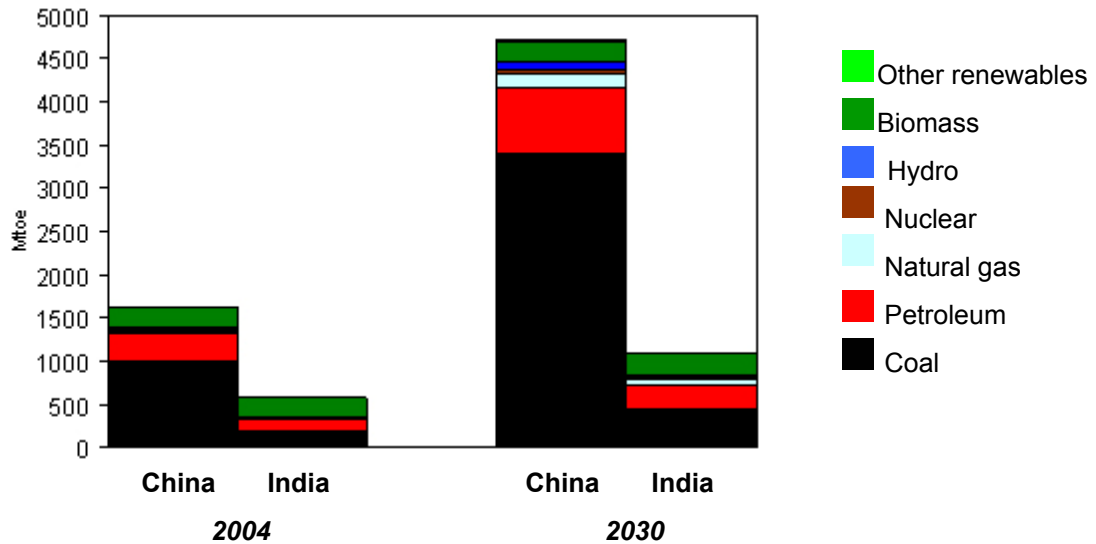
Analyzing drivers of gas demand in China and India is crucially important to understanding how this global gas market could emerge. Where gas displaces more carbon-intensive fuels, notably coal, there could be large effects on emissions of CO₂. China is projected to be the top emitter of greenhouse gases in the world by the end of 2007, while India's CO₂ emissions are also growing rapidly.³ Today, and for the foreseeable future, these countries are dominated by coal. In China, coal makes up 61% of primary energy consumption, while natural gas only 2%. Coal plays a smaller, though significant role in India, accounting for 34% of the primary energy (compared with China, India's energy mix includes a much larger role for biomass.). Natural gas' share is miniscule at 3%. Most projections envision that these relative shares will not change much in the coming decades. The International Energy Agency's (IEA) baseline scenarios envision that coal will remain dominant in both countries; in China, IEA expects that natural gas will only take up 4% of the energy mix, while it increases to 6% in India.

¹ Jensen, Jim. (2004) "The Development of a Global LNG Market." Oxford Institute for Energy Studies.

² China data from: ISI Emerging Markets, CEIC Database, (2007). Indian data from: Government of India, Ministry of Petroleum and Natural Gas (2007). "Petroleum Statistics."

³ U.S. Carbon Dioxide Information Analysis Center, U.S. Department of Energy (2007).

Figure 1: Primary Energy Consumption in China and India in 2004 and 2030



The gas demand in these two countries will also have repercussions for global geopolitics. China has been earnestly acquiring assets and building relationships in oil and gas fields abroad, and India has recently followed suit. High level negotiations have taken place between China and Russia, although no final decision has been taken to build a pipeline from the most attractive gas deposits in eastern Siberia—partly because Gazprom is attempting to assert greater authority over that field. India is engaged in discussions with four of its gas-rich neighbors for international, so-called “peace pipelines” that would bring in gas from its neighbors. The negotiations between India and Iran are most advanced, but they have also raised hackles with the United States. At the same time, the national oil and gas companies in both China and India are looking worldwide to source LNG supplies.

This study explores the factors that will affect the use of natural gas within the energy systems of China and India. Mindful of this general goal, we have adopted methods that are fine-tuned to the particular settings where gas is most likely to be utilized in China and India.

In the China study, we focus on three regions—Beijing, Shanghai and Guangdong—that together account for about half of the expected future gas market. We have focused geographically because the source of natural gas and the downstream natural gas market varies greatly by region. For example, Guangdong receives no pipeline gas and is dependent on LNG imports (at present from Australia), while Beijing and Shanghai’s gas demands, by contrast, are principally supplied by domestic pipelines. The consumption patterns of the regions are partially dictated by climatic conditions (heating needs are miniscule in Guangdong, but is the cause of much idle capacity during the summer in Beijing). The relative importance of different groups of gas consumers changes depending on the location. In Shanghai, for example, the industrial sector consumes almost all of the gas, while peaking power plants are major off-takers in Guangdong.

These geographical differences also reflect the political realities of decision-making in China. While there are national policies on energy in China, most of the key decisions that affect the usage of natural gas are taken at the provincial and local level based on the economics and consumption patterns of each region. Thus it makes little sense to analyze China's gas demand as a single national unit; rather, a regional focus is essential.

In the China study, we identified the major factors that are likely to affect future demand for gas. These include:

- availability and change in power generation technologies;
- the stringency of local and regional environmental constraints;
- financial reforms that affect the cost of capital for different types of firms that build energy infrastructures and use energy services;
- and the pricing and availability of gas.

In analyzing all these factors, we rely on three energy system (MARKAL) models—one for each region. The MARKAL model allows calculation of optimal energy systems needed to supply a certain level of energy demand.⁴ We do not believe, of course, that current or future energy systems are optimized, but this method allows for a focused and internally consistent framing of possible options and their impacts on energy markets. In particular, this method allows us to estimate the levels of natural gas demand in the future if the market within the country behaves in an economically rational way where least cost strategies would be favored.

In India, the role of central decision-making is greater and thus our study is oriented at the national level. However, decision-making varies markedly across each sector and thus we have adopted methods that vary by sector. In the power sector, where investment decisions largely reflect the relative economic merits of power generation options, we use the same MARKAL methods that have been deployed in the Chinese analysis. An energy system model such as MARKAL is especially important to utilize in this context because of the need to ensure that the analysis is consistent across the entire power sector, including the fuel supply and transport infrastructures.

In other sectors of the Indian economy we use different methods. For estimating gas demand associated with fertilizer production, an economic optimization model would not be relevant because most fertilizer production decisions are not economically rational—rather, they reflect the political imperatives of “self sufficiency” in national fertilizer and agricultural production as well as the long history of regulating farm inputs as part of a larger strategy to benefit rural farmers that account for most of India's voters. Thus, our analysis focuses on the political economy of the fertilizer sector—estimating demand by exploring how different gas pricing and fertilizer production options affect the total subsidy that government must provide and by examining how shifts in policy, such as by allowing a greater role for imported lower-cost fertilizer, could affect those subsidies. In the industrial sector we rely on surveys with industrial users to identify the potential for

⁴ Noble, Ken et. al.(2005) MARKAL Training Workshop Support Notes, The Australian Bureau of Agricultural and Resource Economics, June 30, 2005.

switching from coal and oil to natural gas. These three sectors—electric power, fertilizer and industry—account for nearly all of the current and future demand for gas.

The rest of this report summarizes these methods and the findings. This paper is accompanied by six other reports – one from each of the research collaborators – which provides a more in depth look at the modeling methodology and assumptions.

II. Demand for Natural Gas in China

1. Introduction

The story of China's ascent in the global marketplace is well-known. Rapid economic growth has been fueled by massive domestic and foreign investments in the heavy industrial and manufacturing industries. Cheap labor, raw materials, and lenient environmental regulations serve as strong incentives for businesses to build their energy intensive factories in China, mostly fueled by coal and coal-fired power plants. The government is now beginning to realize the cost that it must pay for this mode of development. Short of shifting the focus of the Chinese economy from heavy manufacturing to a service sector base, the type of technology and fuel with which the economy will be powered will be the key in determining how much energy China will consume and the consequences of that consumption. While carbon dioxide emissions are not likely to be regulated in the near future, the government has started to move in the direction of regulating local and regional pollutants such as sulfur dioxide which have undeniably taken a toll on the health and environment of most people living in the country. A third of the land mass of China is affected by acid rain, and the treatment and loss of productivity from respiratory illnesses caused by air pollution cost the economy more than 7% of GDP.⁵ Increased use of natural gas is one strategy that the government hopes will change the trajectory of its energy consumption patterns.

The natural gas sector has always been a part of the state-owned oil industry in China. PetroChina is the largest upstream player by far, producing five times more natural gas than Sinopec, and ten times more gas than CNOOC. PetroChina is also responsible for most of the pipelines that have been laid down. There is no separate company that deals exclusively in natural gas, and there is no policy that directly regulates the use of natural gas for any industry. The only mention of a unified goal for natural gas is in the 11th Five-Year Plan on Energy Development developed by the National Development and Reform Commission (NDRC) of the central government. The goal stated is to increase the share of natural gas in the primary energy to 5.3% by 2010 (currently at about 2%). There are no guidelines administered along with such a directive and thus provinces are left to grapple with the problem using local resources and knowledge. The lack of structure and support of the development of natural gas usage is partly responsible for the small part that gas plays in China's energy mix.

The final gas price is set by the NDRC based on an affordability criterion utilizing the cost-plus approach to pricing.⁶ Fees charged by gas distribution companies are approved by the local pricing bureaux. Residential users pay the highest price, followed by chemical producers, then power generators, and finally fertilizer manufacturers. As in India, prices for the chemical industry are subsidized in order to promote domestic production rather than importing finished products from the Middle East. This structure provides incentive for gas providers (PetroChina

⁵ Peng, ChaoYang et. al. (2002) "Urban Health Quality and Health in China" Urban Studies, Vol. 39, No. 12, 2283-2299.

⁶ Well-head [regulated] + pipeline mark up cost + local distribution mark up cost = sales price to customer

and Sinopec) to supply residential users in a tight gas market rather than to industrial users. There are plans to change the natural gas pricing mechanism to be 40% weighted on the international crude oil prices, 20% on international LNG prices, and 40% on international coal prices. In addition, gas prices are supposed to increase by an average of 8% annually, to balance out the increasing dependence on imports.

Demand

Across the nation, the major consumers of natural gas are in the chemical and fertilizer, industrial, power generation, and residential sectors (Figure 2). In time, IEA predicts that the power sector will be a larger off-taker by consuming 39% of the gas in 2020 compared to 11% in 1997. Residential consumption is also estimated to increase to 25% of total gas off-take in 2020 from 11%. The consumption of gas by the chemicals and fertilizer sector will fall from 43% to 16%. Although these numbers describe the national market, regional demand can look quite different.

Beijing

In Beijing, end-use consumption of gas is dominated by space heating (60%), residential use (22%), and commercial use (14%). Because space heating is such a large component of the consumption needs, one of the challenges for this system is how accommodate the seasonality of the demand. However, because Beijing is particularly motivated to rid the air pollutants such as SO₂, NO_x, and TSP before the 2008 Olympics, the government is likely to support policies which encourage the use of natural gas. Although no firm policies are set in place to do this, the Beijing government has set out consumption levels that are optimistic (natural gas accounting for 12% of end-use energy mix by 2020, the current level is at 7%).

Guangdong

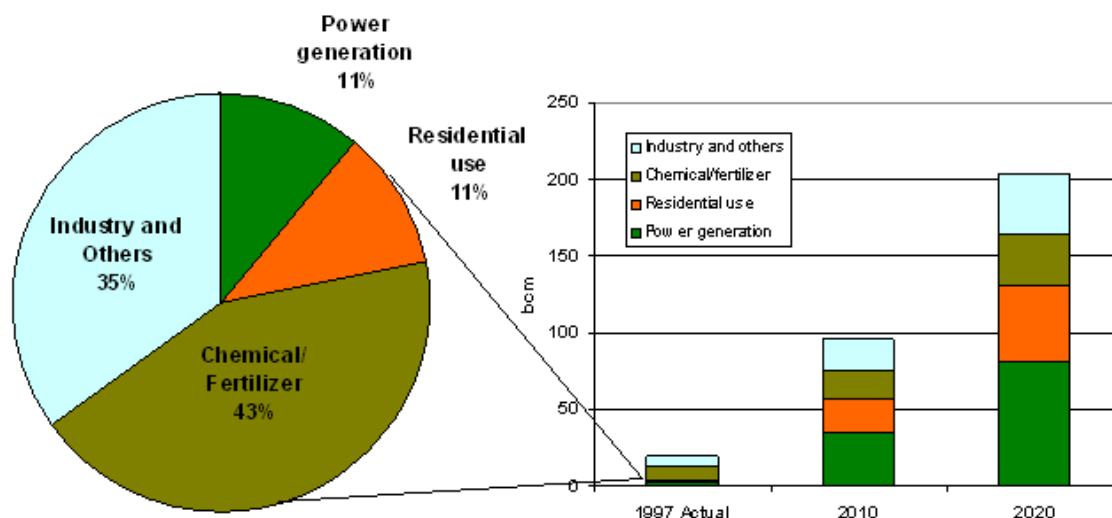
Due to scarce local coal resources, this province is well poised to be the biggest demand center in China. With the high costs and unreliability related to the transportation of coal, Guangdong faces different choices than from the other regions. In the face of high-priced conventional fuels that are often found cheaply in other locales, Guangdong is often the first to explore alternative energy supply options. China's first LNG terminal, Guangdong Dapeng, was completed in 2006. Guangdong has also initiated several nuclear power plant projects. The demand for gas in this region mostly comes from peaking power plants that would otherwise be run by expensive diesel generators. The high level of development in the region means that its residents and officials put a premium on environmental protection as well. Natural gas serves as a cleaner burning, reasonably priced alternative to other options available in this region.

Shanghai

More than half of the natural gas demand in Shanghai comes from six energy intensive industries. Industry is therefore the major off-taker in this region, rather than power plants. Shanghai experienced a rapid increase in natural gas consumption in recent years due to the fact that much of the infrastructure that is needed to bring gas to each household was already in place. This network of pipes enabled the distribution of synthetic gas (or town gas) before natural gas was available. Shanghai also has the most detailed policies in support of natural gas market development. For example, the municipal government has actively encouraged the conversion of

industrial coal boilers to natural gas boilers by offering fee-exemptions and subsidies, while fines for SO₂ emissions have been in place since 2000.

Figure 2: Natural gas consumption by sector

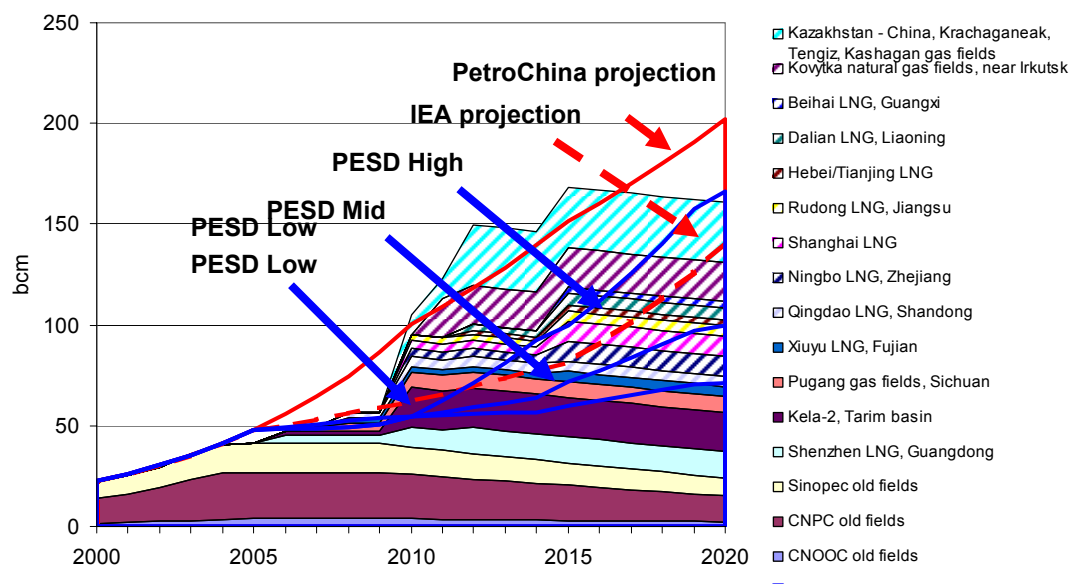


Supply

Most of the gas supplies are controlled by PetroChina, a listed subsidiary of China National Petroleum Company (CNPC). CNPC is a state-owned enterprise whose leadership has strong political ties with the government. The development of gas resources are therefore often guided by government approval as much as they are by economic gain. There is a plethora of future supply projects whose economic viability will be determined by the existence of a consistent and reliable demand for natural gas. The domestic pipeline projects will invariably be developed. By anyone's projection, these supplies are guaranteed to be consumed. In Beijing, for example, domestic supplies currently come from North China Oil Field, Shanxi-Beijing Pipeline, and the West-East pipeline. This is the supply indicated at the bottom of Figure 3. The next batch of supplies are LNG terminals, making up the middle part of Figure 3. There is one LNG terminal in operation in Guangdong currently, but seven more have been approved by the government and are likely to go forward. Two terminals are planned for Hebei and Tianjin - close to Beijing and another one planned in Shanghai. Although none of the new LNG terminals have materialized, plans have been approved by the NDRC and there is no foreseeable barrier that would halt their construction. The viability of the remainder of the potential gas supplies, however, is questionable. These supplies come from international pipelines originating in Russia and Kazakhstan. While there are other certainly other international supply options, these two suppliers seem to have made some substantive commitments toward the construction of a pipeline. These additional supplies are crucial under a high demand situation as early as 2010, but will not come into play until 2017 under the low demand projections. Therefore, in some sense, the feasibility of these pipelines is demand driven. Thus, the urgency with which China will pursue international projects will be dependent on the demand projection that the government believes is the most realistic. Similarly, it is also in China's interest to set up policies to ensure the off-take of natural gas if international projects do indeed make headway. The uncertainty in the size of the demand is considerable, the difference between the high and

low projections amount to 60 bcm, or five times the capacity of the West-East pipeline (WEP). Uncertainty in demand projections makes it challenging to guarantee a return on the massive amounts of investment on infrastructure required to bring gas in from long distances. Policies that will actively promote the natural gas market are critical in providing a less risky environment for investment.

Figure 3: Potential Natural Gas Supplies



Source: PESD estimates 2007, CNPC/Sinopec/CNOOC company reports 2007, ERI, IEA 2004

The red and blue lines in the above figure are demand projections for the entire country. The project that our study provides on lower than standard, although our highest demand exceeds predictions that of IEA's. The focus of the China study is not to attain a national figure, though we assume that the consumption of the three regions will make up around 50% of the total consumption in the country. The focus is to examine the moving parts within each region and tease out some factors that could be driving demand. We provide the figures here, however, to give an idea of what implications demand projections could have for supply options. We can see that by most projections, the international supply will become essential to satisfying demand before 2020. As mentioned before, however, the project would not be cost-effective if this projected demand somehow did now materialize once the pipeline gets built. This is the essential dilemma of developing a natural gas market. In China, most people believe that demand will be there and the challenge will be getting the political support of Gazprom and other national oil and gas companies to make these projects happen.

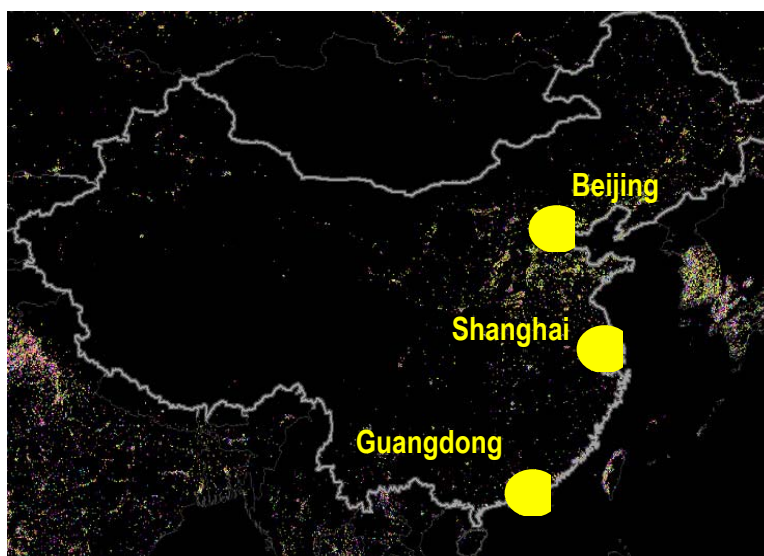
2. Study Methodology

In China, regional differences are paramount to decision-making. While the central government passes down directives, provincial governments have de facto power in implementing policies.

The same holds true for natural gas policy in China. Regional and local authorities have control over the rules that govern each project since there is such a vast disparity in the amount of gas that is consumed between different locales. This variation is the reason why it makes sense to see China not as a single unit, but rather to estimate its natural gas demand by region.

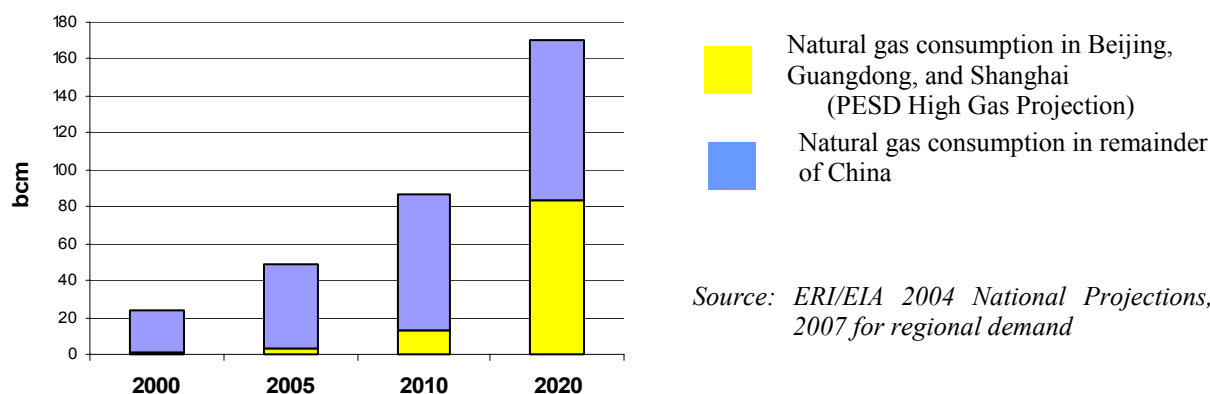
The three regions selected for this study are Beijing, Guangdong, and Shanghai. The national gas consumption by these three areas will plausibly account for about half of the national total by 2020 (Figure 5), although at present their share is much smaller. Because these regions are the fastest growing within China, their share of gas demand will eventually catch up since the other major off-takers, such as the fertilizer industry are not growing as quickly. The goal here is not to find the most accurate way to estimate the national demand for gas but rather to evaluate how economically rational decisions are made within the energy sector given different conditions. The estimate here is to give the reader an idea of how important this region is to the overall gas demand in China. The estimates for gas demand in the three regions are from a high gas demand scenario in our model.

Figure 4: Research Locations



Source: NASA photo modified by PESD.

Figure 5: Natural gas consumption in Beijing, Guangdong, and Shanghai vs National



Source: ERI/EIA 2004 National Projections, PESD 2007 for regional demand

The pivotal policy driver for each of the scenarios within the China study is the implementation of sulfur dioxide constraints upon the energy system. Because natural gas has a higher fuel cost than coal, it would be unrealistic to assume that natural gas demand would increase in China due to pure market forces. Recent growth in natural gas consumption in some regions of China, for example, has been made possible only after subsidies given to industries that convert from coal to natural gas. We believe SO₂ is a reasonable target due to local governments' concern with visible pollution which has a direct impact on its constituents. The governments of Beijing, Shanghai, and Guangdong have already voiced their commitment to controlling this pollutant. A study to estimate the outcome of possible measures could prove to be especially relevant.

In the base case scenario (R), we assume no changes are made to the status quo. From this starting point, there are two main scenario developments. Scenario P is the case in which SO₂ emissions are reduced by 40% and is defined as the “plausible” scenario. Scenario Ag is the case in which SO₂ emissions are reduced by 75% and is defined as the “aggressive” scenario and is less likely to be the future than scenario P, but not entirely out of the question. For the MoreGas scenarios, the goal is to find out how the system would react to a plausible SO₂ constraint at the same time that more piped gas (cheaper than LNG) is made available to the regions. With these scenarios, it would be possible to find out the relative effects of gas availability versus the other drivers in the model.

Figure 6: Scenario Development for MARKAL

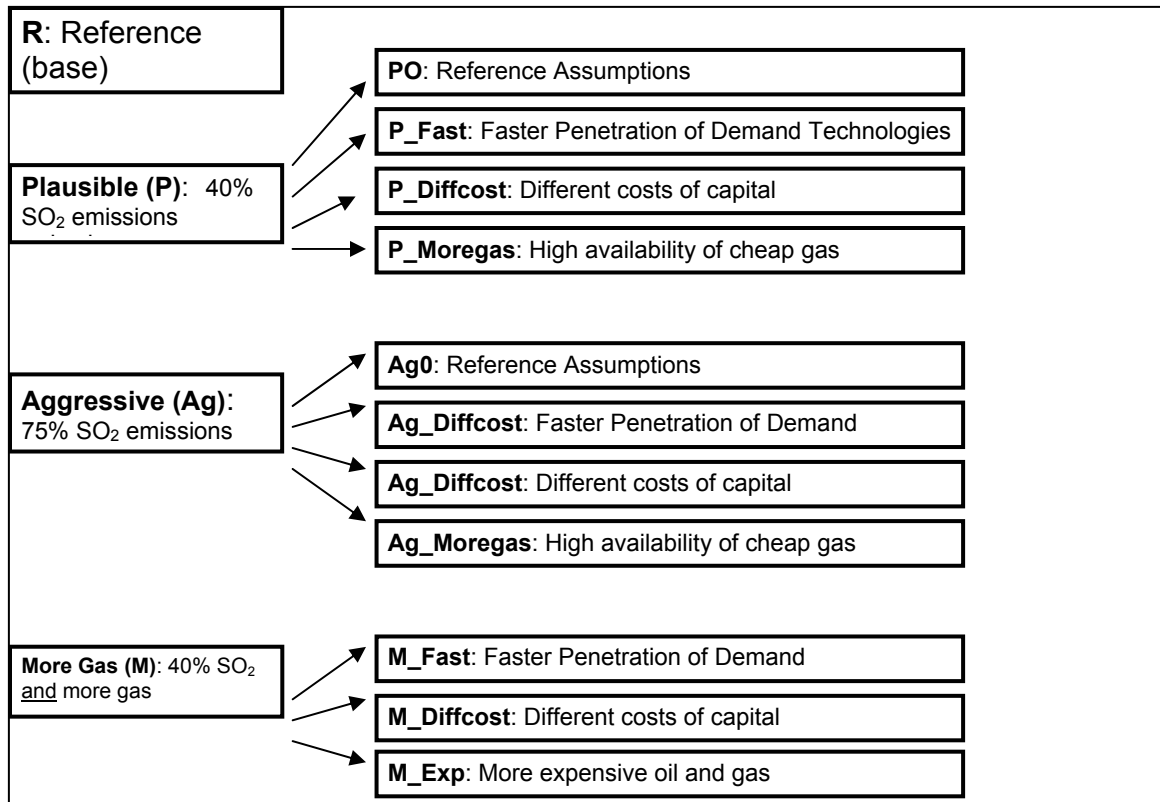


Table 1: Description of primary driver runs

Primary Runs	Driver
Reference	Status Quo
Plausible (“P” scenarios)	40% SO ₂ reduction
Aggressive (“Ag” scenarios)	75% SO ₂ reduction
Plausible w/ more gas availability (“C” scenarios)	40% SO ₂ reduction + moregas

Within each of the scenarios, we wanted to find out if there would be any variation in gas consumption if we changed the rate at which efficient, advanced technology is allowed to enter the market (the “1” scenarios). We also wanted to find out if specifying different costs of capital for each of the sectors would make an impact in consumption patterns (the “2” scenarios). The third variation we wanted to test was what happens when a lot of gas becomes available to each of the regions (the “3” scenarios).

Table 2: Description of secondary driver runs

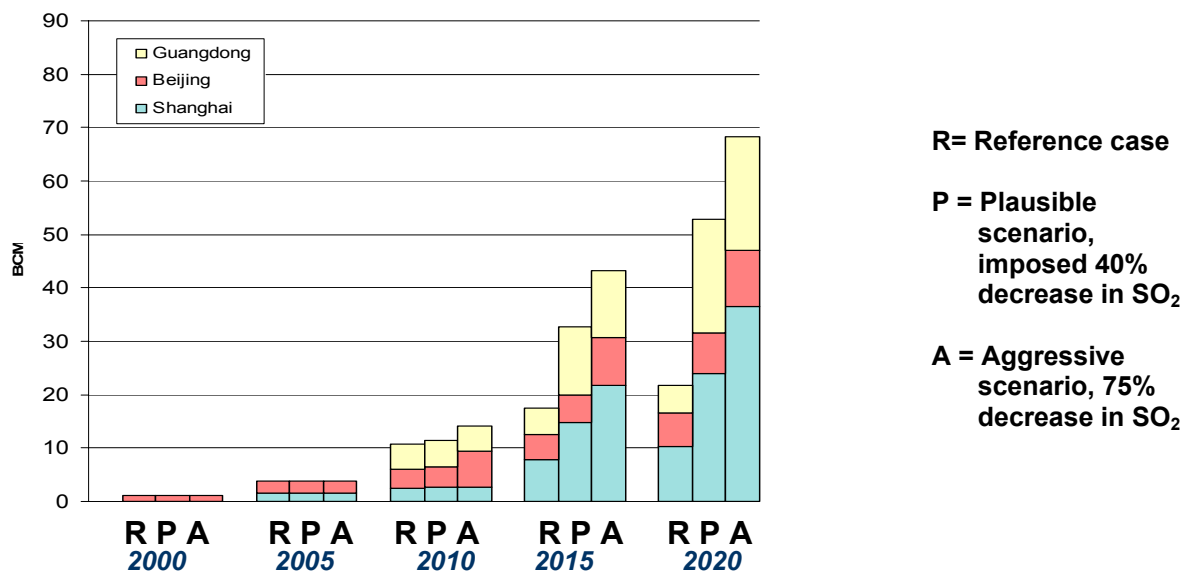
Secondary drivers	Reference case	Scenario Variation
Technological diffusion (“Fast” scenarios)	1.5% annual share growth	3%, 5% annual share growth
Cost of capital (“Diffcost” scenarios)	10% discount rate for all sectors	5.8% for power sector 10% for industrial 25% for residential and commercial
Availability of cheap gas (“Moregas” scenarios)	No gas supply from Russia (LNG availability unconstrained)	Gas supply from Russia available (LNG availability unconstrained)

3. Results

3A. Effects of varying levels of SO₂ constraints

This section will outline the effects of varying the SO₂ constraints on the energy systems (and consumption of gas) in Beijing, Guangdong, and Shanghai. Figure 7 shows gas consumption for the reference (R), plausible (P), and aggressive (A) scenarios from 2000 to 2020 in all three cities. This graph indicates two main findings. First, the total amount of gas consumed in each city varies, an obvious point. Second, the amount of gas that will be consumed should vary strongly with the stringency of the SO₂ constraint. Between the reference case and the aggressive scenario in 2020, there is a difference of about 50 bcm. Not surprisingly, a tighter SO₂ constraint leads to more gas demand. While these results shed some light on the sensitivity of the model to SO₂ policies, getting a deeper understanding of the system comes from looking at the projections within each of the three city-regions.

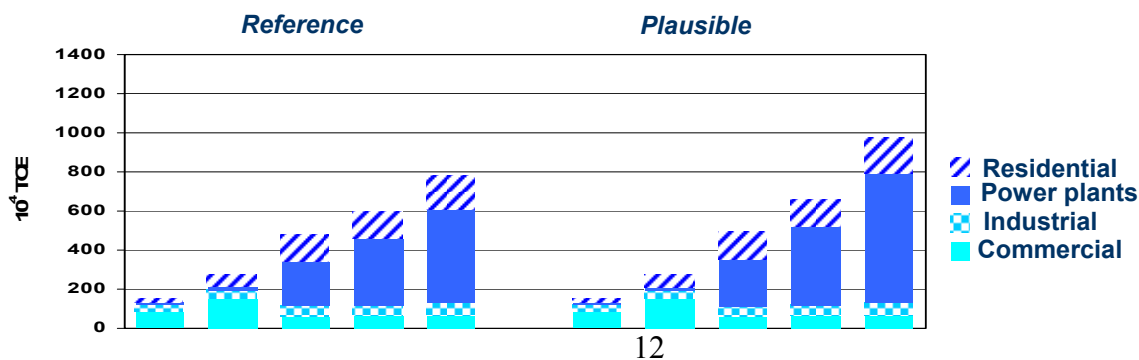
Figure 7: Natural gas consumption for all study areas: Comparison of results for reference and SO₂ constrained scenarios



Beijing

Beijing poses several challenges for natural gas consumption. Cold winters and hot summers create a highly seasonal demand for gas making it an especially challenging market for natural gas. Although there is some government support of pro-gas policies due to the upcoming 2008 Olympics that will be held in Beijing (a lot of effort has been expended on reducing the amount of local and regional pollutants such as SO₂ and NO_x emissions) there are no specific policies to promote this fuel use. Reductions in pollutants thus far have largely been accomplished by closing down coal-fired power plants and moving them to neighboring cities. Scrubbers and FGD have also been installed in coal-fired power plants. Due to such efforts, the low hanging fruit of decreasing SO₂ emissions has already been picked. It is perhaps for this reason that there is very little difference in gas consumption between the reference scenario and the plausible scenario in Beijing. However, the gas consumption does increase overall due to increased fuel use at a natural gas combined cycle co-generation facility and the Taiyanggong electric and thermal plant.

Figure 8: Natural gas consumption in Beijing for reference and plausible SO₂ constraint scenarios

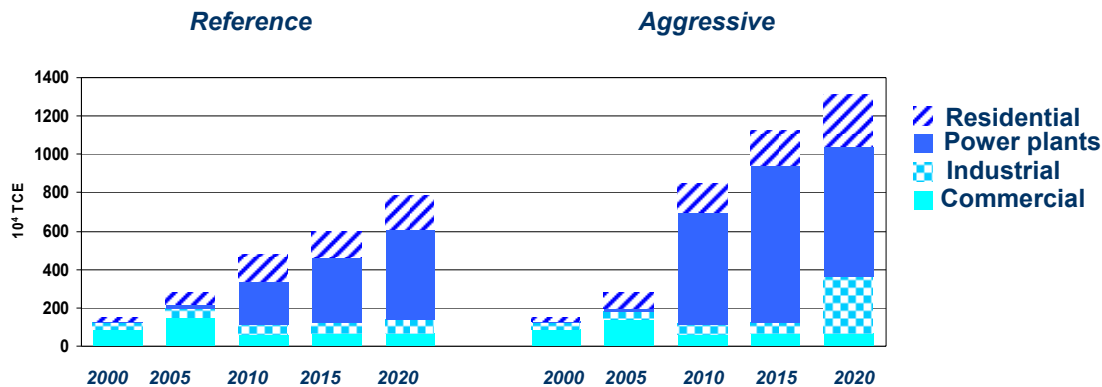


2000 2005 2010 2015 2020

2000 2005 2010 2015 2020

The system does start to change more drastically when the SO₂ constraint becomes tighter. In this scenario, power plants consume more gas starting in 2010, and the industrial sector picks up in 2020. In addition to Taiyuanong, a combined cycle natural gas plant comes online, and more gas is consumed in existing gas power plants that were already operating in the plausible scenario. In 2020, industrial coal and oil boilers get replaced by natural gas boilers. This shows that for Beijing, the most economically efficient path to decreasing SO₂ emissions is initially through the power sector rather than the industrial sector as is the case with Shanghai.

Figure 9: Natural gas consumption in Beijing for reference and aggressive SO₂ constraint scenarios



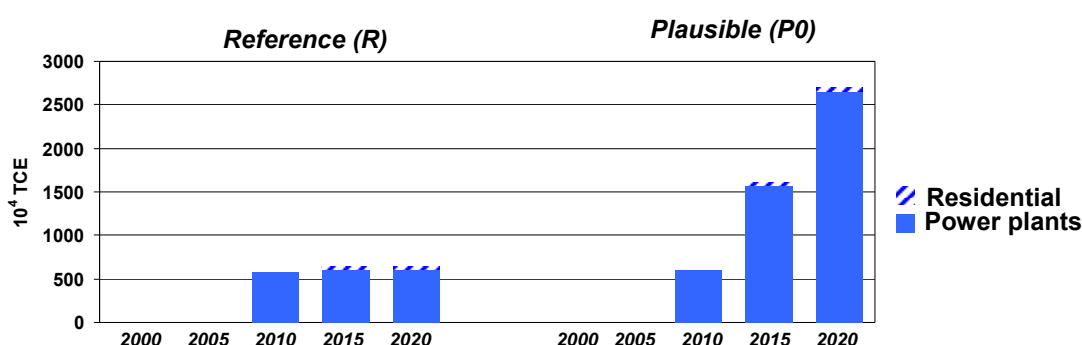
Guangdong

While all three cities are located on the eastern seaboard, Guangdong is the southernmost of the three regions. Heating is rarely needed. Its economic growth is the most rapid in China, and it emits more of all pollutants than any other region. Guangdong, unlike Beijing and Shanghai, does not have easy access to coal. There are no indigenous sources, so all coal must be imported from other regions of China or from abroad. This poses a special opportunity for the use of natural gas in this area because of the expensive coal prices this region has to pay. Guangdong also will not receive natural gas from the West-East pipeline due to geographic constraints. It is not surprising, then, that Guangdong is home to China's first LNG terminal in China.

Looking at gas consumption levels in the reference scenario, we see that the same amount of gas is consumed from 2010 onwards. Consumption is capped at the level that indicates the volume of LNG imported from Australia that is under a cheap contract (approximately \$3/mmbtu, compared with \$5 to \$7 typical of current LNG contracts). Any volume of gas above this amount would be sold at the new, higher price. Since there is no incentive for the system to spend more money than what is necessary in the reference scenario, the amount of gas consumed stops at the volume limit of the contract. Most of the gas is consumed by power plants, with residential taking a miniscule portion. When a 40% mandatory decrease in SO₂ emissions is

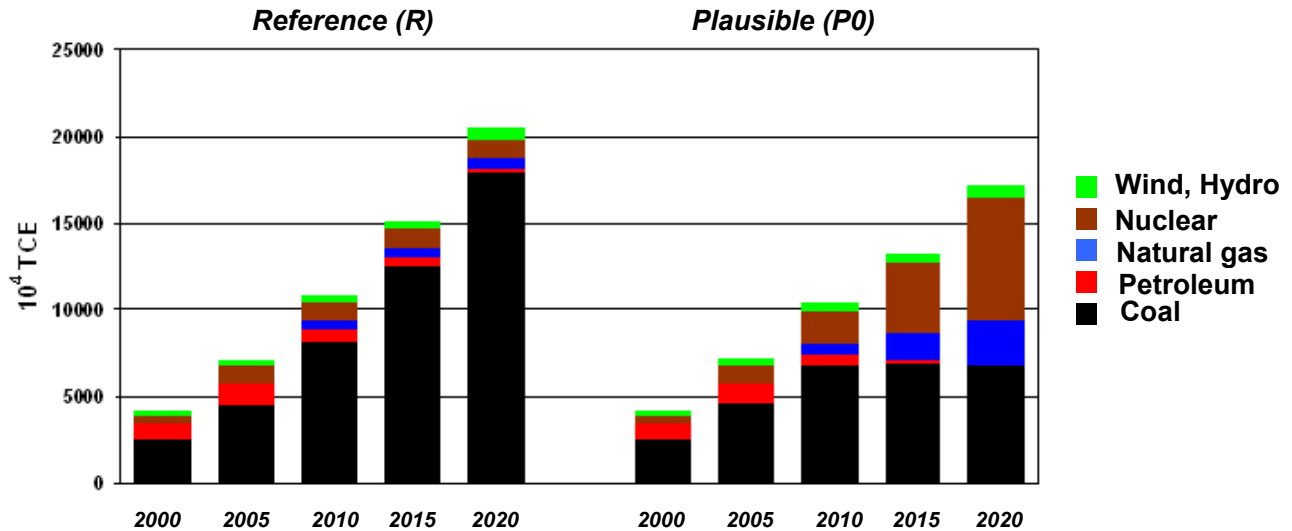
imposed on the system in the plausible scenario, the consumption of gas increases for 2015 and 2020, although there is no increase in uptake before 2015. For this plausible scenario, the amount of gas consumed is no longer constrained by the volume of LNG under the Australian contract because the system has no choice but to pay higher prices in order to meet the SO₂ constraint. All of the new increase is taken up by power plants. A deeper look into the model shows increased gas use is most economically efficient when fuel switching with oil-fired combined cycle power plants, small, inefficient peaking coal plants that are less than 135 MW, one large coal-fired power plant, and co-generation facilities. The environmental constraints also push forward the construction of an integrated gasification combined cycle (IGCC) plant.

Figure 10: Natural gas consumption in Guangdong for reference and plausible SO₂ constraint scenarios



At the same time that gas consumption is increasing, nuclear power is also on the rise. Nuclear serves as baseload, while gas is used for peaking so that there is no direct competition between the two. Nuclear increases 14 times above 2020 reference scenario levels. Nuclear power development is unique to Guangdong because there are plants that are already under construction in the area. This means that investment in this technology is cheaper here than in other regions. However, without the policy push to decrease SO₂ emissions, coal is still cheaper to build than nuclear.

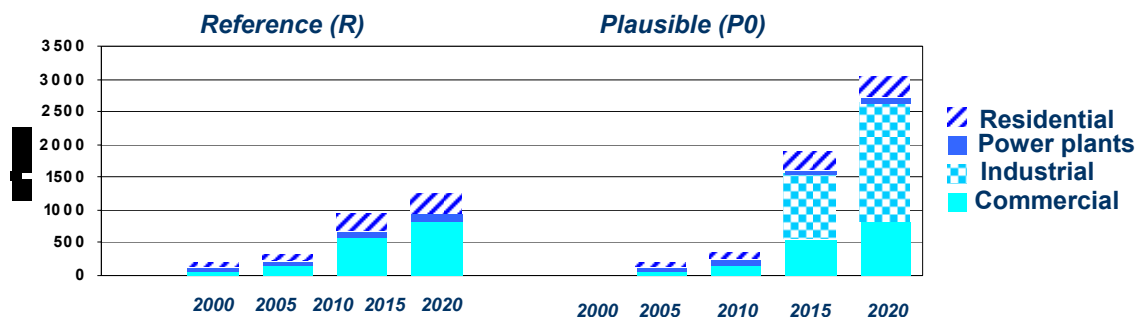
Figure 11: Fuel consumption in Guangdong Power Sector for reference and plausible SO₂ constraint scenarios



Shanghai

Shanghai's economy is dominated by energy intensive industries that thrive in and around the city. Six industries comprise 50% of the city's total energy demand—smelting/rolling of ferrous materials, oil processing, coking, nuclear fuel processing, textiles, and chemical production. In contrast to Guangdong, not much natural gas is used for power plants. This is mostly due to the fact that there is an abundant and cheap supply of coal to be used for firing baseload plants. It is much harder for gas to be competitive here with coal. When the 40% SO₂ constraint is imposed on this system, we see an increase in the consumption of natural gas appearing in 2010. Almost all of this growth can be attributed to the industrial sector. Rather than build new power plants that run on low-emission gas, it is much less costly to meet the SO₂ constraint by switching existing boilers in the industrial sector from higher sulfur heavy fuel oil and coal to essentially zero sulfur gas. Many of the coal boilers and kilns in the six energy intensive industries get switched to natural gas boilers and kilns. Many of the industrial equipment in Shanghai are also at the end of their life cycle, which means that new boilers have to be purchased anyway. This minimizes the extra cost that has to be spent on buying new natural gas boilers. Also, although may not have access to LNG until 2010, it does have access to domestic piped natural gas.

Figure 12: Natural gas consumption in Shanghai for reference and plausible SO₂ constraint scenarios



3B. Effects of the rate of technological diffusion in demand technologies

In considering the range of future scenarios, it is useful to get a sense for how the rate at which advanced, efficient demand side technologies (i.e., air conditioners and stoves) get diffused into the market can affect the outcome of what type and at what volumes different fuel types get consumed within the energy sector. For our study, we assumed the initial share of these “new” demand technologies to be 5% start in 2010. These technologies have longer life cycles and more expensive to purchase, such as industrial equipment and mass transportation infrastructure. A 7% initial share of market was allocated for demand technology in the commercial and residential sectors, such as air conditioners and stoves. We created a different scenario by changing the annual share growth percentage of this initial share, or how quickly the share of the market dominated by new technologies will grow. After consulting a range of sources⁷ for this study, a 1.5% annual share growth starting in 2010 seemed reasonable for the reference case. For the scenario in which a faster rate of technological diffusion is expected, then, we used a 5% annual share growth. A 3% annual share growth was also tested to approximate the sensitivity of the model but there were no significant changes in fuel consumption in any of the regions. The table below lists the name of runs that will be discussed in this section.

Table 3: Technological Diffusion Scenario

Name of run	Annual share growth
P0	1.5% (Reference)
P_Fast	5%
Ag0	1.5%
Ag_Fast	5%

⁷ U.S. National Energy Modeling System database (NEMS), A joint study between the Energy Foundation and China National Institute of Standardization (EF/CNIS), A joint study between Guan Fu Min in Qingdao, China and Lawrence Berkeley Laboratory (Guan/LBL)

Beijing

Under modest environmental constraints (P0, P_Fast), Final energy coal consumption decreases by 6%, while natural gas consumption decreases by about 57% by 2020. The explanation for this activity is found within the residential sector. In the status quo, natural gas is used for cooking and heating water and space heating. In this new scenario, these functions get taken up by newer technologies that do not utilize natural gas. The newer technologies that are not fueled by natural gas, such as a heating network for cooking and heating water and LPG cooking and heating units will be introduced in 2010 according to MARKAL. Because no newer available technologies for natural gas are introduced in the system, the model finds new technologies which do not emit much pollution that are not run on gas as demand increases. In addition, the imported electricity consumption and heat both increase. This means that even though emissions within Beijing are not increasing, the increased importation of these secondary energy products are simply shifting the pollution to somewhere else, not fundamentally solving the problem. Thus the availability of efficient technologies which are not run on natural gas is detrimental for gas demand and possibly also for the net volume of pollutants emitted outside of Beijing. Further analysis is needed to explain why the commercial sector was not equally as effected by this scenario since both are exposed to changes of the demand technologies

Guangdong

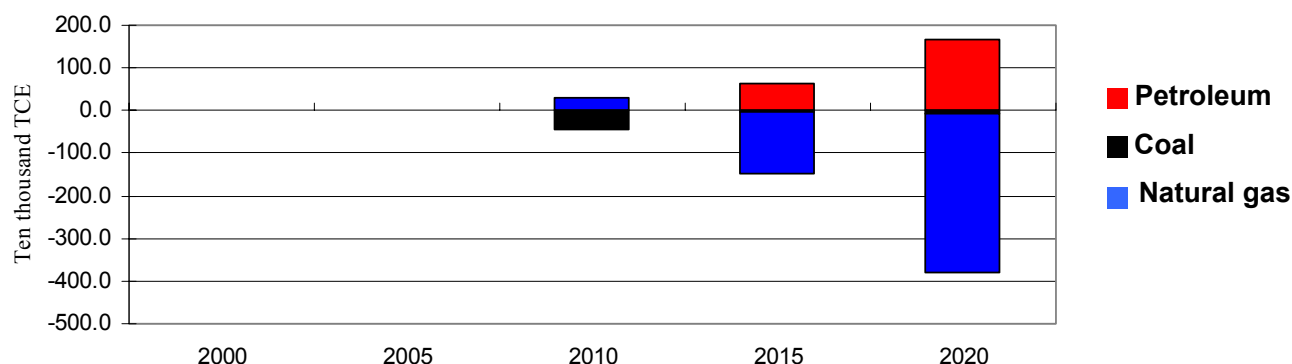
Under modest environmental constraints (P0, P_Fast), coal consumption increases when the rate of technology penetration is increased. Much of this is provoked by not only the replacement of old equipment with more advanced commercial coal stoves and boilers but also increased consumption through these technologies. In the industrial sector, new coal boilers and kilns replace older versions and also contribute to the increased consumption of coal. Oil consumption decreases slightly as improved LPG stoves and heaters in the residential sector replace older models. Electricity and natural gas consumption do not change much between the reference scenario (A0) and the high technology penetration rate (A1-5). These trends are further magnified when the system is placed under a stringent environmental constraint.

Shanghai

Starting in 2010, there is a small decrease in the consumption of coal within the residential sector. As more technology becomes available, it is plausible to assume that the cheapest and easiest way to decrease SO₂ emissions is through getting rid of old, inefficient coal-consuming technologies such as coal burning cooking and heating equipment. In 2015, we see natural gas consumption decrease, once again within the residential sector. This decreased gas consumption seems to be balanced by an increase in petroleum consumption. The same trend on a greater magnitude occurs in 2020. One possible explanation for this trend is that new oil consuming technology is cheaper than natural gas technology, so when more of this equipment becomes available to consumers, oil takes over as the main fuel for cooking and heating. Although oil is more expensive than gas, refined oil products are made available to the domestic market at a subsidized cost supported by the central government, which could explain the system's overall reliance on oil in the residential sector. Although the following figure conveys that there is a difference in fuel consumption between the P0 (plausible scenario with 1.5% default rate of

technology diffusion) and P_Fast (5% annual market share growth), it is useful to keep in mind that the total change here is only about 2.5% of the total amount of energy consumed with the system, so it is not a significant factor in determining fuel consumption patterns.

Figure 13: Differences in Primary Energy Consumption in Shanghai (P0 vs. P_FAST)



Source: Yu, 2007, Shanghai Jiaotong University/PESD study

Encouraging the rate of technological diffusion within the energy sector allows more efficient hardware to come into existence for these regions. The predictable outcome of increased efficiency might be that overall primary energy consumption decreases since the same amount of energy can be created with less fuel. For the most part natural gas consumption is not affected by this scenario since gas technology, unlike coal technology, is relatively new within China so that further improvements may not be make a big difference in improved performance.

3C. Effects of Differing Costs of Capital across Sectors

An important aspect of financing for capital intensive energy projects is the lending rate at which loans can be attained. In China, the cost of capital for building state-owned power plants is much lower than it is for private projects and business. The China Development Bank provides capital at a rate of 5.8%⁸. The power sector is viewed as a “pillar” industry by the government which garners the industry special treatment such as indirect subsidies and given access to political figures. An often overlooked aspect of the Chinese energy system, however, is that different sectors receive different lending rates and not all industries receive the special treatment that the power sector enjoys. To simulate such a situation, we have assigned different costs of capital to each sector in MARKAL. The industrial sector is allowed rates at 10%, while the residential and commercial sectors receive 25% interest rates.⁹ Many of the large industrial players are also state-owned enterprises and play a significant part in employing large numbers of people. The manufacturing companies within the industrial sector have also been the driving force behind China’s economic development. The government therefore has a stake in

⁸ Discussions with Pan Jiehua (CASS), Kejun Jiang (ERI), and Tao Wang (BP), November 2006

⁹ Discussions with Pan Jiehua (CASS), Kejun Jiang (ERI), and Tao Wang (BP), November 2006

maintaining the financial health of this important sector. The residential and commercial sectors are exposed to the full brunt of market forces by paying for up to 25% for the cost of capital. This 3-tiered cost of capital system is representative of the strategy that the Chinese government has employed since making a transition from a planned to market economy: “Let go of small enterprises and engage with large enterprises¹⁰” where smaller players in the market are always allowed to privatize first while larger entities are carefully guarded by government subsidies and regulations.

Table 4: Different costs of capital by sectors

Sector/Industry	Cost of capital
Power plants and other public service entities	5.8%
Industrial sector	10%
Residential	25%
Commerical	25%

This aspect of the Chinese energy system is often overlooked, especially in energy models. However, it turns out that reforms within the financial sector, having nothing to do with energy sector reforms, could have an effect on the energy consumption patterns. This opens up the possibility of utilizing a more effective policy to change the way energy is used.

Beijing

Coal consumption in the modest environmental constraints scenario increases in the case of differentiated costs of capital between sectors. There is increasing consumption of coal and decreasing consumption of natural gas in the power sector. This makes intuitive sense--gas-fired power plants have low fixed costs and high O&M costs and coal-fired power plants require high fixed investments and low O&M costs (See Table 5).

Table 5: Investment Costs for Various Types of Power Plants in China

\$/kW (300MW)	Beijing	Guangdong	Shanghai
Pulverized coal-fired power plant	600-676	600-676	600-676
PC w/ FGD	623-704	709-1090	709-1090
Combined cycle natural gas	522 – 576	499-550	522-575
Ultra supercritical	1089	1089	1089
IGCC	1044-1305	1044-1144	1043-1305

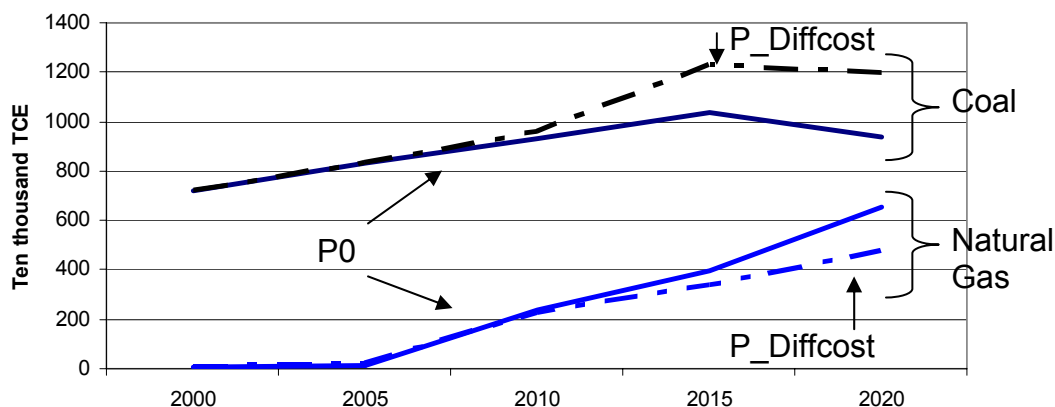
Source: PESD China collaborators, 2007

In a scenario where cost of capital for power plants is cheap, more capital intense projects such as coal-fired power plants would be favored. Since fuel cost is also lower for coal than it is for gas, there is an upshot of coal projects rather than natural gas in the power sector. This can be

¹⁰ Zhang, Jin. (2006) Catch-up and Competitiveness in China: The Case of Large Firms in the Oil Industry. Routledge-Curzon Studies on the Chinese Economy

seen in Figure 14. Coal consumption increases by about 17%, while natural gas consumption decreases by the same percentage. The same story holds true when environmental controls are set tighter for Ag0 and Ag_Diffcost scenarios. The SO₂ constraints are not sufficient to induce fuel switching in favor of natural gas because cheap capital means makes advanced coal technology, such as FGD economical (prices for FGD is already low in China).

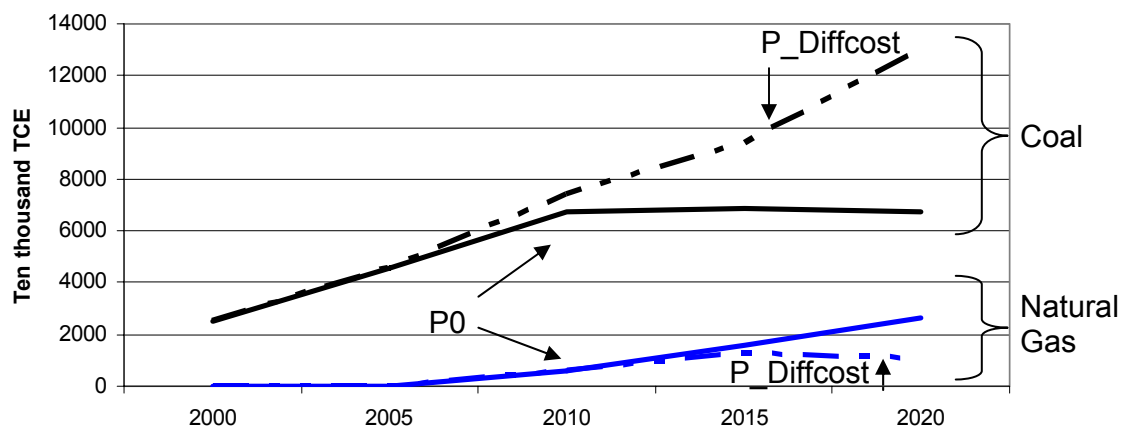
Figure 14: Coal and Natural Gas Consumption in the Beijing (Power Sector)



Guangdong

A similar story plays out in Guangdong. Coal consumption increases as differentiated costs of capital are applied to the system. At the expense of LNG-fired power plants, advanced coal plants (FGD, ESP) come in massively. These are economical choices due to the fact that investment costs are relatively low compared to gas-fired power plant investment costs. In Guangdong, the increase in coal consumption is even more dramatic at 88%, while natural gas consumption decreases by about 40%.

Figure 15: Coal and Natural Gas Consumption in the Guangdong (Power Sector)



Shanghai

There was little change in the amount of coal consumed in the scenario of differentiated costs of capital (A2, B2). The trend seen in the other two locales of massive build outs of coal projects is not seen and it is less responsive to differing costs of capitals between sectors. This could potentially be explained by the fact that the vast majority of natural gas consumed is within the industrial sector. The cost of capital for the industrial sector between the reference case and the Diffcost runs do not change (at 10%). Change is therefore not expected in this scenario.

3D. Effects of gas availability

This part of the study is focused on finding the impact of natural gas supply availability on demand. Obviously, gas cannot be consumed unless it is available, but a subtler point is that the consumers of gas change depending on how much gas supply is around. In Figure 3, we saw that part of the potential sources came from international pipelines. While China and Russia have signed an agreement in March 2006 to develop potential pipelines between China National Petroleum Company (CNPC) and Gazprom¹¹ and similar plans with Kazakhstan and Turkmenistan, it is not clear whether these plans will actually materialize. International projects such as natural gas piped from the Kovytko field in Eastern Siberia are inherently challenging to complete because they are rarely motivated purely by economics and are sensitive to political moods and relationships between the relevant governments.¹² China also has a plethora of LNG terminal projects in the works, seven of which has been approved. There is a smaller possibility that some of these may never get built, but until they get built there is always a chance that project might be stalled due to construction delays and changes in government policy. In the following scenarios, we explore gas consumption patterns in a world where international gas does not get piped to China and one in which there is additional international gas supply available.

Table 6: Gas Availability Scenario

Name of run	Gas supply
Ag0	Only domestic pipeline and LNG terminal in Guangdong
Ag_Moregas	Domestic pipeline, international pipeline, LNG terminal in Guangdong

Beijing

Beijing is not sensitive to the availability of gas in either the plausible or aggressive scenarios. This presumably indicates that the use of natural gas is not hindered by the availability of the supply. Indeed, because there is a domestic pipeline that supplies the city, and also because Beijing is the capital, it will get preferential treatment when gas is allocated. The relatively low demand for natural gas in this area, as indicated by Figure 7, is also relatively easy to satisfy.

¹¹ Interfax, 5/24/06

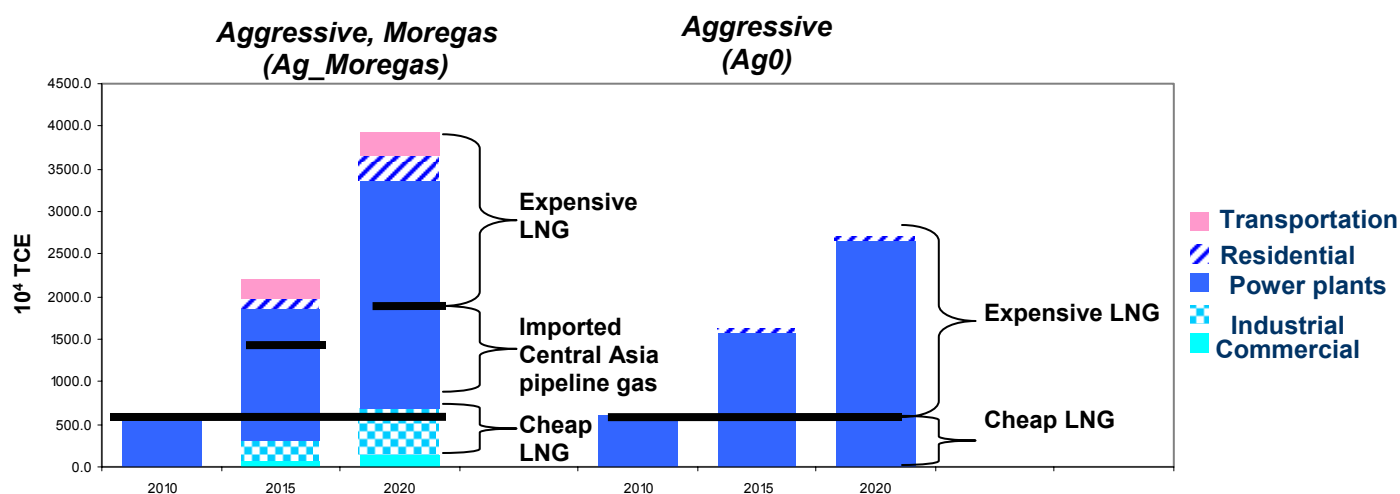
¹² Andrews-Speed, Phillips, 2002

Supply shortages will be less of an issue than for Guangdong, for example, where most of its gas supply is dependent on imports and where demand is huge.

Guangdong

Guangdong is more responsive to the availability of gas. Figure 16 shows the major consumers of natural gas by sector in both the Ag0 and Ag_Moregas scenarios (there is no movement for this scenario under the plausible SO₂ constraint conditions). Along with this, the black bars also indicate bounds for different types of supplies available to Guangdong. The main difference between Ag0 and Ag_Moregas is that for Ag_Moregas, an additional source of piped gas becomes available to Guangdong at a cheaper price than expensive LNG (\$5.50/MMBtu vs. \$7/MMBtu in 2020). Even though the amount of expensive LNG that is consumed does not decrease in Ag_Moregas, the major consumers of gas change in this scenario. What we see here is that the additional cheaper supply of gas allows major off-takers outside of the power sector to consume gas. The transportation, residential, industrial, and commercial sector all get to take a bite out of natural gas supply. When cheap gas supplies are limited, almost all of the gas was funneled into power generation in order to meet the requirements of the SO₂ emission constraints.

Figure 16: Gas Supply Options for Guangdong and Natural Gas Demand by Sector



Source: Gas volume estimates, Hayes, 2007

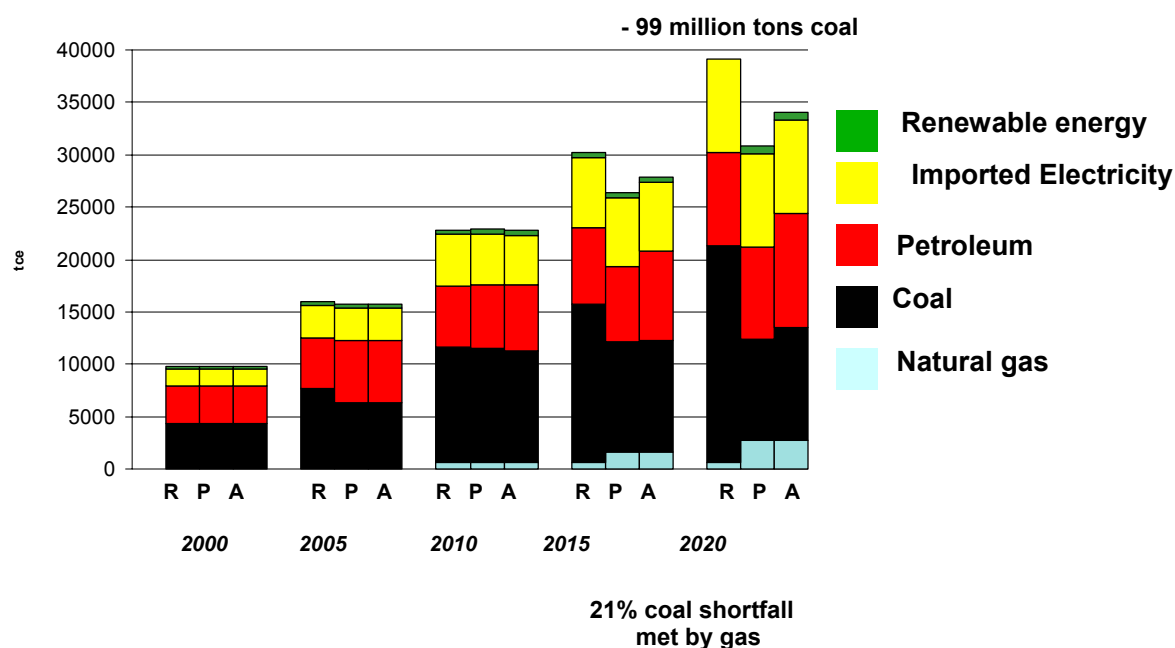
Shanghai

In Shanghai, availability of gas increases the demand for gas by a negligible amount (<0.1%) in the industrial sector, with no other major change in consumption patterns. This makes sense given the importance of industry as a major off-taker in Shanghai's economy; however it does not provide an adequate justification of why such a change would occur. In addition, given Shanghai's abundant domestic gas supply (Shanghai, like Beijing has access to gas from the West-East pipeline), it is not likely that supply constraints would drive scenarios in this situation.

4. Implications for CO₂

One of the interesting outcomes from this study is that we find indirect policies which target SO₂ reductions may have a significant impact on CO₂ emissions. While this trend is true for all regions, Guangdong has the most absolute amount of CO₂ emissions. If we take the case of the aggressive scenario in 2020, close to 99 million less tons of coals will be used than in the reference case. About 21% of this coal shortfall will be met by natural gas. In Shanghai, for another example, 85% of the shortfall is met by gas.

Figure 17: CO₂ Emissions from Guangdong from Reference, Plausible, and Aggressive Scenarios

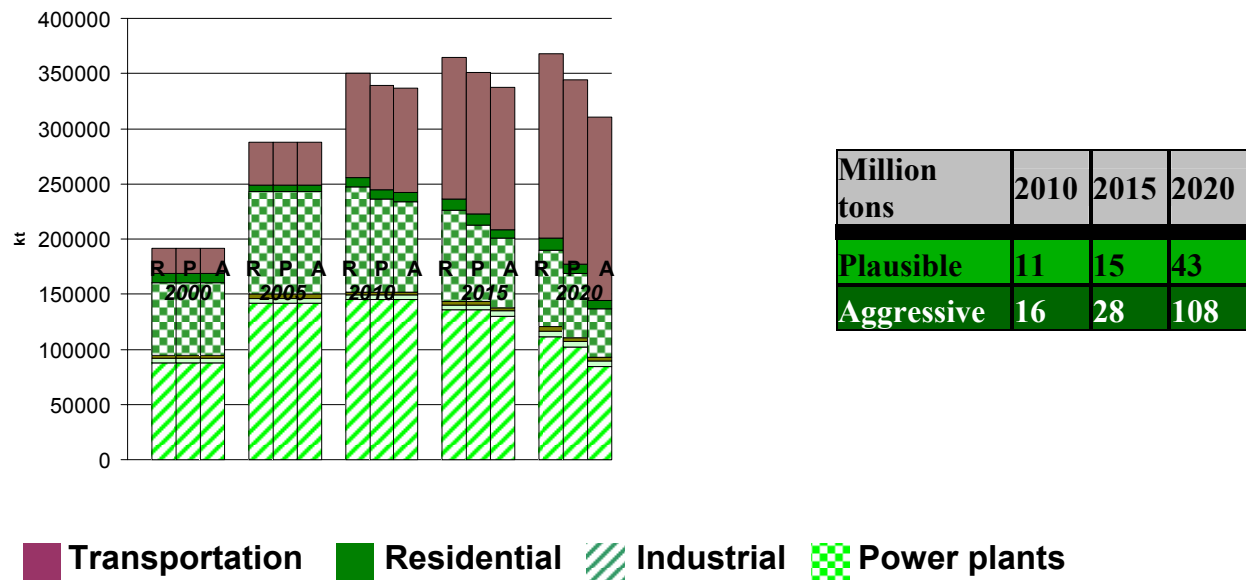


What are the carbon consequences to this switching? (See Figure 18) In Guangdong, about 100 million tons of carbon dioxide emissions can be prevented by imposing a 75% emissions cap on SO₂ emissions. 100 million tons of carbon is about 20 million tons more CO₂ saved than the entire stock of Clean Development Mechanisms (CDM) projects in China in 2006.¹³ It is also half of Europe's Kyoto commitment.¹⁴ While in terms of absolute numbers these savings are not able to change the trajectory of climate change in the status quo, it does open up the possibility of thinking about the climate issue in another light, especially when trying to bring developing countries to the table. It is more likely that countries like China and India engage in discussions that pertain to immediate environmental, regional pollutants rather than global emissions with unseen consequences. Perhaps a stringent SO₂ policy with important caveats for CO₂ could be a more acceptable offer than addressing CO₂ emissions directly.

¹³ DOE, 2006

¹⁴ DOE, 2005

Figure 18: CO₂ Emissions from Guangdong in the Reference, Plausible, and Aggressive Scenarios



Million tons	2010	2015	2020
Plausible	11	15	43
Aggressive	16	28	108

III. Demand for Natural Gas in India

1. Introduction

The Indian natural gas market is in the midst of a major shift from a centrally managed system to one operating on a greater role for market forces. Since the first major gas supplies began flowing in the mid-1980s, gas has been produced entirely by the national oil company, Oil and Natural Gas Corporation (ONGC), and transported and marketed by the state-owned Gas Authority India Limited (GAIL).¹⁵ This gas was sold at low prices set by the central government that, at the time, had large quantities of gas that it needed consumption. Along the major pipeline that GAIL constructed to link the gas producing fields in the west with interior Delhi, the government ordered construction of large fertilizer plants and other gas-consuming industries to ensure that the full volumes of gas production were consumed.

In this state-controlled system, gas was allocated through a political process to priority users in the fertilizer and electric power sectors. Low prices encouraged excessive consumption however, and soon demand for gas outstripped supply. Other potential gas consumers, especially those in industry, received the remaining gas after the priority consumers had used their allocation. Although cheap, these gas supplies were unreliable and frequently cut off without compensation, causing many consumers to build plants capable of running on multiple fuels.

Low delivered prices encouraged consumption but hindered investment in new natural gas supplies. ONGC was, first and foremost, an oil company that had little interest in gas, and private oil and gas companies had little access to the Indian market. A gas shortage quickly emerged and, by the end of the 1990s, by some estimates, nearly half of India's gas demand was unmet.¹⁶ In response to this supply shortfall, the Indian government passed a series of broad reforms designed to increase the production and availability of gas. Most prominent among these was the enactment of the New Exploration Licensing Policy (NELP), which allowed private companies to bid for oil and gas exploration blocks, and to construct liquefied natural gas (LNG) import terminals. These private investors were guaranteed attractive tax rules and the freedom to sell their gas at whatever price the market would bear.¹⁷

These reforms have yielded fruit. In 2002, Reliance Industries Limited (hereafter "Reliance") announced a 14 trillion cubic foot (Tcf) gas field, off the east coast of India, increasing India's available gas reserves by nearly 50%. Similarly huge fields have since been announced by the

¹⁵ Small quantities of natural gas are produced in the northeastern state of Assam by another national oil company, Oil India Limited. However, these supplies are isolated from the major gas market and relatively small, and have been excluded from the discussion and analysis in this paper.

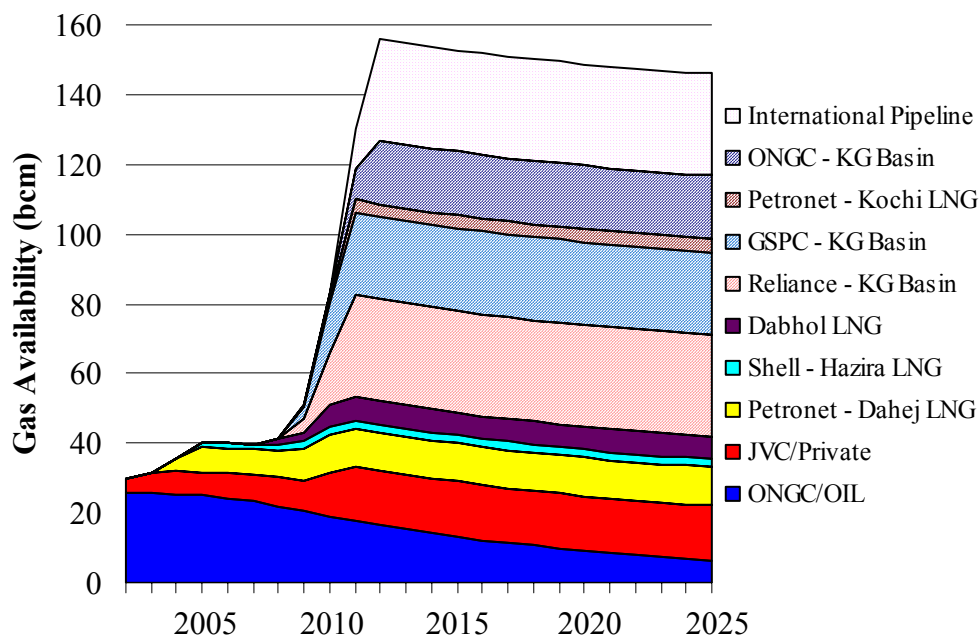
¹⁶ Government of India (2000). "Hydrocarbon Vision, 2025."

¹⁷ For more detail on India's private gas market, see Jackson, Mike (2005). "Natural Gas Sector Reform in India: Case Study of a Hybrid Market Design."

Available at: <http://iis-db.stanford.edu/pubs/20931/WP43.pdf>

Gujarat State Petroleum Corporation (GSPC)¹⁸ and ONGC respectively.¹⁹ In 2004, India's first LNG facility began operations, with a second opening in 2005. Figure 19 stacks the expected supplies from these projects, in addition to the existing (declining) fields currently in production. The assured supplies are shown at the bottom; more speculative supplies (e.g., a presently nonexistent international pipeline, such as from Iran) are at the top of the stack.

Figure 19: Projected Natural Gas Supplies by Supplier



Source: Author's estimates based on official government data and company statements..

These new gas supplies are being sold at prices well above those previously seen in India. While ONGC gas was delivered at state-regulated prices around \$2.50/mmbtu, new private supplies cost upwards of \$5/mmbtu. Some supplies have sold for even higher – in 2006, many observers were shocked when India purchased a spot cargo of LNG from Algeria a price of \$9.28/mmbtu.²⁰ Despite these high prices, private suppliers have found eager buyers because, for many users, expensive gas is more desirable than no gas at all.

In this new private market, the main consumers of expensive gas have been those unable to secure subsidized supplies from ONGC – mostly industrial consumers who have a particularly acute interest in reliable gas supplies because they must keep their factories running reliably. Fertilizer producers, by contrast, have reliably secured access to low-cost gas. In effect, the

¹⁸ GSPC is India's only state-government owned oil and natural gas company – with 95% equity held by the government of the state of Gujarat.

¹⁹ As none of these fields have begun producing and selling gas into India, the exact size of these fields is a subject of intense debate and speculation in India. No attempt was made in this study to resolve this question – researchers simply assumed official company statements about field sizes and production capacity to be accurate.

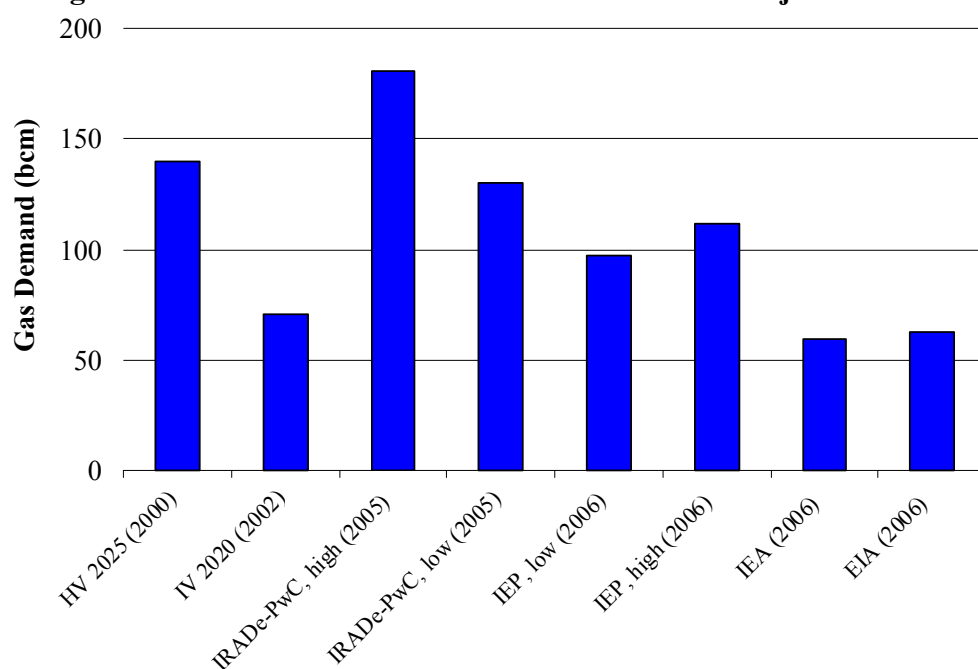
²⁰ The Hindu Business Line. "GAIL Sells Entire Quantity of LNG Spot Cargo Bought from Algeria." June 3, 2006. Available at: <http://www.thehindubusinessline.com/2006/06/03/stories/2006060303990200.htm>

market has bifurcated. Politically connected users, notably fertilizer producers and some power plants, still obtain their gas at low government-regulated prices. Other users get their gas from private suppliers at market prices. As the low-price supplies become scarcer and less reliable, a larger number of users are forced to shift from the public to the private market.

2. Study Methodology

This dual pricing and supply regime for gas, as well as the possibility of significant new supplies in the near future, have made it extremely difficult to project future demand for gas. Figure 20 summarizes all the major projections published recently for the year 2020. As the figure shows, these projections have varied widely – about threefold from 60 bcm to nearly 180 bcm. This wide range in projections is driven by different expectations of future economic growth, natural gas pricing and availability, and varying modeling methodologies.

Figure 20: Review of Indian Natural Gas Demand Projections for 2020



Sources: HV 2025 – Government of India (2000). “Hydrocarbon Vision – 2025.”

IV 2020 – Government of India (2002). “India Vision 2020.”

IRADe-PwC – Integrated Research and Action for Development and PriceWaterhouse Coopers (2005). “Fueling India’s Growth – Vision 2030.”

IEP – Government of India (2006). “Integrated Energy Policy – Report of the Expert Committee.”

IEA – International Energy Agency (2006). “World Energy Outlook, 2006.”

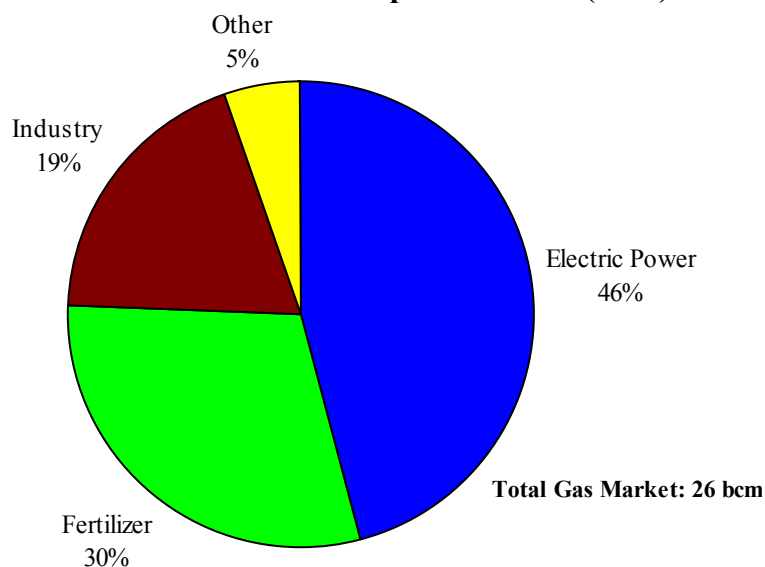
EIA – Energy Information Administration (2006). “Annual Energy Outlook, 2006.”

The PESD Indian gas market study aims to understand the major drivers of natural gas demand, and explain how the Indian gas market might develop under a range of different scenarios.

Unlike the China market analysis, which focuses on major geographical regions as the unit of analysis, the India study examines three key consuming sectors for the country as a whole:

electricity generators, nitrogenous fertilizer producers, and industrial consumers.²¹ As shown in Figure 21, these three consumers account for approximately 95% of demand. Our study excludes attention to users such as CNG for transportation – such as used widely in New Delhi under court order to help clean the air – because they play a minor current (and likely future) role in the total market.

Figure 21: Natural Gas Consumption in India (2006)²²



We focus on major consuming classes, rather than geography, as the unit of analysis, because natural gas pricing and allocation decisions are made at the national level in India. The most important variations are across consuming industries – in particular, the policies that concern supply of low-cost price-regulated gas. In addition, the most important policy reforms relevant to gas demand in these industries are the product mainly of national political choices. While there are regional differences in gas transmission infrastructure – at present, the Indian gas transmission infrastructure serves only the northern corridor of the country, between the offshore fields on the western coast, through the state of Gujarat and into Delhi – over the next 15 years a rudimentary infrastructure is likely to emerge in much of the rest of the country, at least in the major industrial regions that are the most attractive candidates for gas supply.

PESD worked with three research partners in India to analyze these three primary consuming sectors. However, within each of these sectors, it is clear that range of different policy and market developments could significantly affect demand for gas. Within each consuming sector study, we have modeled variation in these demand drivers through scenarios. The results of these scenarios help to frame an analysis of possible futures for gas demand and the factors of greatest importance. Table 7 below summarizes the major drivers modeled in the analysis, and more details on methodology can be found in the sections to follow and in the individual sector analysis papers.

²¹ Industrial consumers in this figure includes natural gas used both as a chemical feedstock and as a fuel for process heat. More details will be discussed later in the paper.

²² Ministry of Petroleum and Natural Gas, Government of India (2007). “Petroleum Statistics.” Available at: <http://petroleum.nic.in/petstat.pdf>.

Table 7: Summary of Natural Gas Study Sector Scenarios

Demand Driver	Current Value	Plausible Future Variations
Electricity		
Natural gas pricing	Some plants have access to cheap government-regulated gas	Gas supply curve allows plants to exhaust available low-cost supplies and forces them to purchase market-priced gas
Environmental controls	Piecemeal regulation of regional air pollutants in some cities	Tighter limits of sulfur emissions
Coal pricing and reform	Coal is state-controlled industry with low prices and infrastructure imposed cap on available supplies	Reforms allow much greater use of pit-head coal plants ("coal by wire"), imported coal, and raise coal prices towards international levels
Fertilizer		
Import controls	India is nearly 100% self-sufficient in nitrogenous fertilizer	Allowance of 5% and 30% dependence on imported fertilizer
Price and availability of gas	Most plants have access to cheap government-regulated gas	Cheap gas supplies decline and gas prices move to market levels
Farm gate urea prices	Prices to farmers have increased slowly and remain below international levels	Farm gate prices increase more rapidly towards international levels
Industrial		
Availability of gas	Many industrial consumers lack political access to gas supplies, and consume other fuels	Significant gas supplies are available to consumers willing to pay international prices
Economic growth	Economic growth is strong in India	Economic growth could accelerate, decelerate, or remain the same

3. Electricity Sector Demand

PESD worked with the Indian Institute of Management – Ahmedabad (hereafter “IIM”) to analyze the Indian electricity sector. IIM used a bottom-up energy-economic model, MARKAL, to analyze the electricity sector—the same modeling framework that is used in the China study. Inputs to the model are demand for energy services, conversion and end-use technology performance (power plants and boilers), and supply curves for primary energy resources (coal, oil, and natural gas). The model then determines the economically optimal arrangement of primary fuels and conversion technologies.²³

To explore the issues outlined in Table 7, we developed a reference projection that offered a most plausible “business as usual” projection. That reference projection also allowed examination of factors such as the gas supply curve and competition between the power sector and other sectors of the economy for scarce gas supplies. We then examined a number of reform scenarios, two of which are summarized here. One examines policies that affect the price and supply of coal (the main rival to gas for generating power). The other explores the consequences of a possible tightening of environmental controls.²⁴

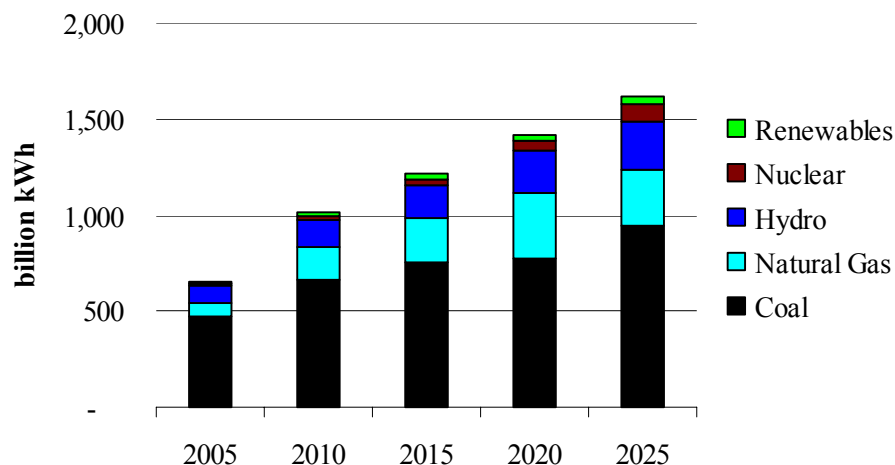
Reference Projections

Our initial run on the electricity sector is summarized in Figure 22 below. The model assumes no dramatic increases in nuclear power over the next two decades, and modest growth in hydroelectric generation. Despite the large increase in hydro in our reference scenario, our figures are considerably below even more bullish projections from the Indian government. The role of nuclear power might expand if India had greater access to fuel and technology, but we do not explore that possibility in further detail in this study.

²³ Rather than a prediction of exact natural gas demand in each scenario, MARKAL indicates the least cost solution to realize the energy mix. In some cases, it is necessary to constrain technological penetration to reduce knife-edge effects where an entire electricity grid might switch to an advanced technology IGCC the minute it becomes cheaper. The results thus provide an indication more of how energy demand could be met most cheaply, rather than the most likely outcome.

²⁴ For a more in depth description and analysis of the electricity sector study, see Shukla, P.R. and Subash Dhar (2007). “Natural Gas in the Indian Energy System: An Assessment of Demand from the Power Sector.”

Figure 22: Projected Electricity Generation Mix, 2005-2025



As the projections indicate, coal is expected to maintain its dominant position in the Indian electricity mix (69% in 2005, 58% in 2025). Cheap domestic coal, as well as imports, makes it very difficult for alternatives like natural gas to compete with coal in this market. The share of natural gas does increase from 11% to 18% of the electricity market – much of this fueled by the new gas supplies projected to come online by 2010 from Reliance and other private supplies. Natural gas assumes a large role in being used for peaking power, as the model expects that the Indian load curve will shift from baseload-dominated power of today to a load curve with greater daily variability.

Over the modeling time period, cheap government gas declines in availability (which reflects the decline of the major ONGC fields and increased consumption from the politically better-connected fertilizer sector), with the result that gas prices increase sharply after 2020. As in the China study, tests of the model’s sensitivity to higher economic growth scenarios suggest that gas consumption in the power sector will *decrease* as the economy booms.²⁵ This finding reflects the expectation that high economic growth leads to high demand from industrial consumers, who outbid power generators for available gas supplies. As gas becomes more costly, coal is increasingly favored in the power sector, reflected in the decline in gas’ share of power generation between 2020 and 2025.

The model projects a modest degree of technological change in power generation. Supercritical coal plants dramatically outcompete subcritical plants – nearly all incremental coal-fired capacity uses supercritical technology, which burns coal more efficiently without incurring a dramatically higher capital cost. While our model is likely optimistic in its expectations of supercritical deployment, construction of significant new supercritical capacity is being discussed in India today through the construction of several 4 GW coal plants called the ultra-mega power projects (a more complete discussion of the ultra-mega power projects is in the “Coal Reforms” section of the paper).

²⁵ See page 39 of Shukla, P.R. and Subash Dhar (2007). “Natural Gas in the Indian Energy System: An Assessment of Demand from the Power Sector.”

Reform Scenarios

Our study evaluated a series of scenarios that are expected significantly impact demand for natural gas in the Indian electricity sector. Some of these major reforms are discussed in the sections that follow.²⁶

Coal Sector Reforms

The Indian coal sector has historically been run entirely through Coal India Limited (CIL), the national government-owned coal company of India. CIL has been widely criticized for years as an inefficient behemoth incapable of expanding production capacity to meet India's growing coal demand. This can largely be explained by CIL's inability to charge market clearing prices for coal, as these have been set by the central government and kept low to encourage consumption on the theory that higher consumption of primary energy would boost economic growth and employment.

The domestic coal industry is also plagued by infrastructure bottlenecks – most visibly on the Indian railway system that offers irregular delivery of coal to consumers. Given that India's major coal resources are located in the eastern part of the country where energy demand is low, and must be transported to the south and northwest, where demand is high, these railway constraints have restricted growth in coal and electricity production in India.

In general, Indian coal has very high ash content (often 40%) and the country has made inadequate investment in coal washing and other techniques that could upgrade coal quality. This has exacerbated the problems with railroad infrastructure (since a large fraction of the material transported is not actually combustible) and has also forced India to import some high quality coking coal in recent years.

Catalyzed by these woes, the Indian coal sector is undergoing a serious overhaul that could revitalize the sector. The central government has taken steps to open mining to private and foreign companies. So far, these openings have been restricted to investors that establish pithead power plants, but there are indications that even these restrictions could be lifted. In 2005, CIL began selling some of its coal via competitive auction rather than through a government-managed "linkages" allocation process. The auctions are yielding considerably higher prices and revenue for CIL as well as more efficient allocation of coal resources. There are even indications that the Indian railways are improving, although railroad reform is difficult because the problems are endemic and interlocking and because passenger transport is a highly visible and politically volatile aspect of the country's rail system.²⁷

²⁶ The complete modeling results, including other policy scenarios and sensitivity analysis, are described in Shukla, P.R. and Subash Dhar (2007). "Natural Gas in the Indian Energy System: An Assessment of Demand from the Power Sector."

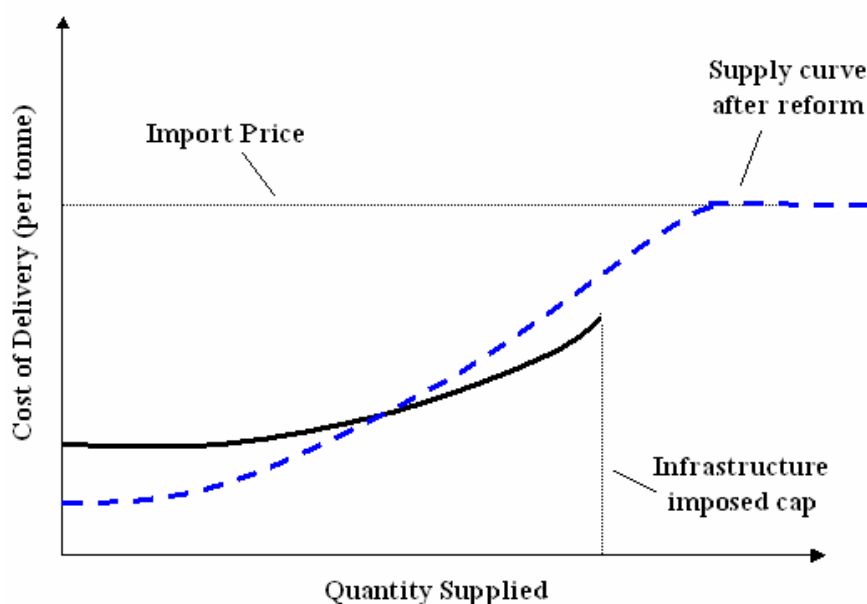
²⁷ For more discussion on Indian coal sector reforms see Ministry of Coal, Government of India (2005). "Report of the Expert Committee on Road Map for Coal Sector Reforms."
Available at: <http://www.coal.nic.in/expertreport.pdf>

The government has also significantly reduced duties on imported steam coal, to be used in power production. Between 2003 and 2004, import duties on steam coal were reduced from 31% to only 5%, in response to the coal shortages facing India during that time. These coal imports could help link Indian coal prices to the world market, and we predict would raise prices in India towards international parity.

These reforms to the coal sector are most visible through the Indian government's role in promoting nine 4 GW coal plants, called the Ultra-Mega Power Projects. Some of these projects would be constructed at the pit-head in the eastern regions of the country, while others would be located on the coasts and fueled by imported coal. The first two projects, one coastal and one pithead, were auctioned to private domestic companies in 2007, with the hopes of beginning operations by 2012.

Figure 23 provides a conceptual supply curve to show how these reforms are projected to impact the pricing and availability of coal in India. At present, before significant reforms are implemented, the black supply curve illustrates that coal prices are low but the volume that can be delivered is constrained by a soft cap due to inadequate investment in infrastructure (which, itself, is a function of low prices for delivered coal).

Figure 23: Impact of Indian Coal Sector Reform

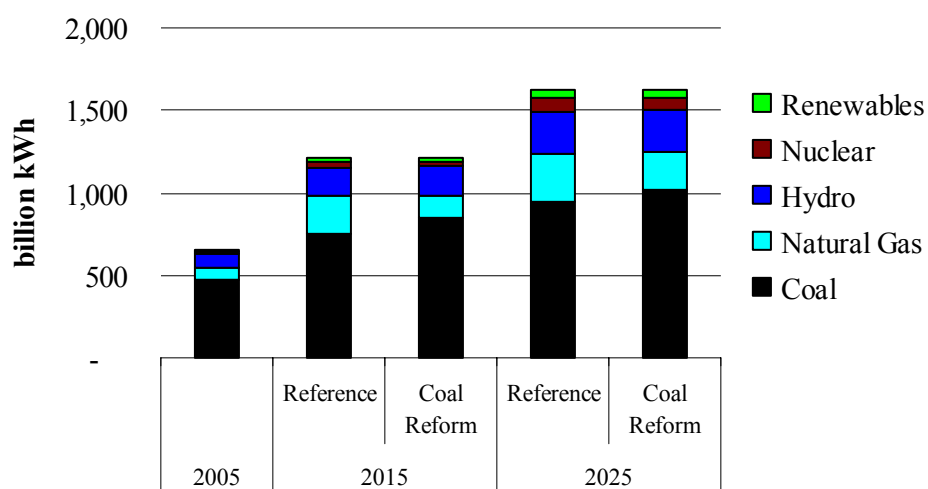


As the figure indicates (dotted blue line), coal reforms are likely to reduce the cost of some supplies (mainly from pit-head generation applications) while, at the same time, increasing the volume of coal that can be delivered at higher prices that eventually equilibrate with international levels due to a larger role for imported coal. In effect, the marginal price of coal will rise but so will volumes.

A comparison of the coal reforms scenario with the reference scenario is provided in Figure 24 below. As the figure indicates, the reform scenario creates a shift towards coal, owing to the

increased availability of domestic coal resources. However, that shift is modest because over the time horizon that is relevant here, the infrastructure cap is a “soft” one—it has some impact on constraining supplies but not a dramatic one. This is largely due to the fact that some reforms (notably restrictions on coal imports) have already been enacted and are included in the reference scenario.

Figure 24: Comparison of Electricity Mix Between Reference Scenario and Coal Sector Reform Scenario



Stringent Environmental Reforms

Another modeling scenario varied the controls on environmental pollutants – our study focused on sulfur dioxide (SO₂), which is of acute concern to Indian policymakers and also allows comparison of results in India with China, where our models adopted similar controls. Regional air pollutant controls are already in place in the most polluted and sensitive areas of the country – such as Delhi, Mumbai, and Agra – and more are likely in the future.

We modeled a stringent environmental scenario by constraining SO₂ emissions to 40% below the reference scenario projections. The Chinese study adopted the same limit, as well as additional scenarios with even tighter limits. The model results indicate the least cost solutions to meet these sulfur constraints on the power sector.

As Figure 25 indicates, natural gas plays a much more prominent role in the electricity mix under this scenario, nearly doubling in capacity. Natural gas demand under this scenario is nearly double demand seen in the reference scenario. In addition (not pictured), nearly half of the coal capacity under this scenario is equipped with flue-gas desulfurization in order to comply with the sulfur restrictions.

Figure 25: Comparison of Electricity Mix between Reference and Stringent Sulfur Scenarios

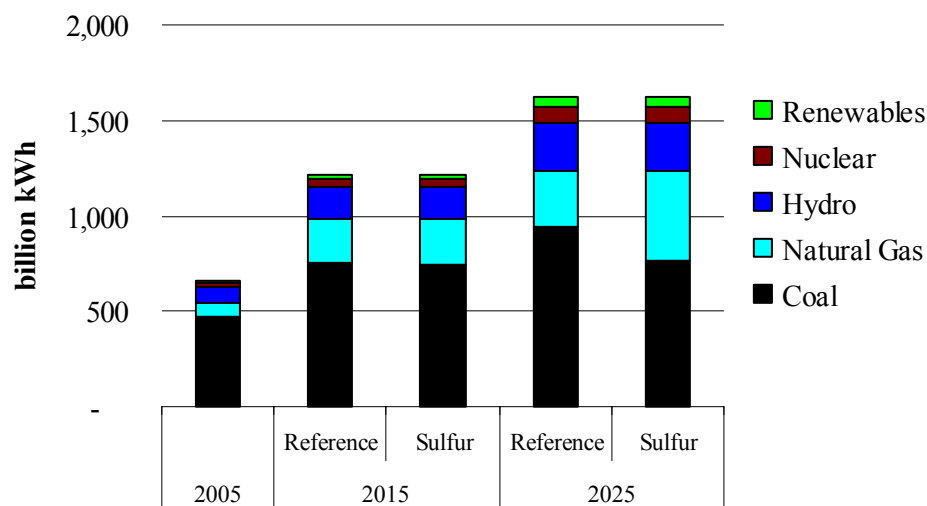
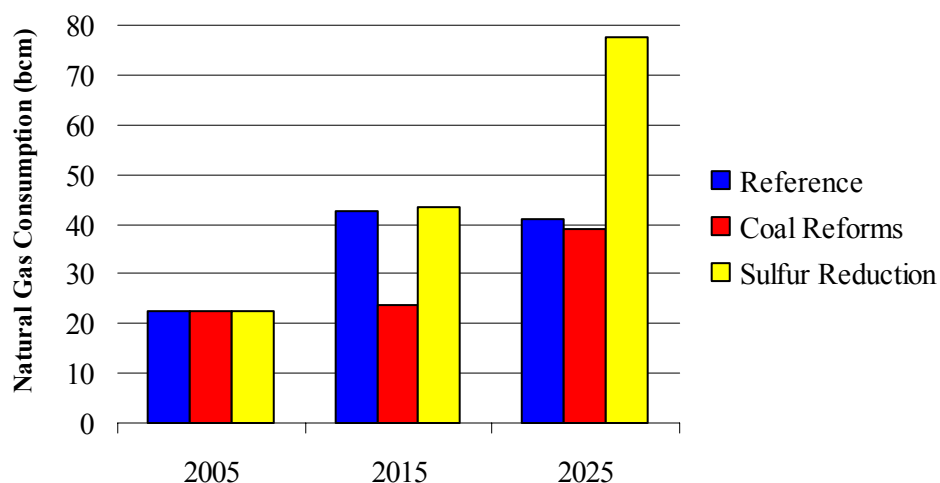


Figure 26 summarizes natural gas consumption under these scenarios. The coal reform scenario results in significantly less gas being consumed through 2020 as reforms relieve the infrastructure constraints on coal availability, indicated in the figure by very low gas consumption in 2015. The differences between the coal reform scenario and reference scenario lessen by 2025 as it is assumed that infrastructure constraints on coal delivery are relieved even in the reference scenario, largely through increased imports of coal.

Figure 26: Natural Gas Consumption Across Major Modeling Runs



The sulfur reduction scenario provides a much brighter future for natural gas – nearly double the demand of the reference scenario by 2025. While half of the sulfur reductions occur from the installation of flue-gas desulfurization on the new coal plants, about 40% of the reductions are realized by the large switch from coal to natural gas.

Issues for Further Analysis

As is normal, modeling tools require simplifications that can limit the analyst's ability to examine the full range of issues. We note one, in particular, that merits further analysis as it could dramatically affect the role of gas in the power sector. Due to perennial insolvency and politicization of electric power in India, the country's supply system is fragmenting. Politically connected users relying on the grid, often with low tariffs, but the most lucrative industrial customers are leaving the grid system and relying increasingly on "captive" power systems. Reforms in 2003 have, in part, accelerated this tendency, which some analysts welcome because it offers the prospect of competition for the grid system. Where gas is available, these captive customers have often relied on gas because it is clean and flexible and less costly than oil. Many captive suppliers also use biomass – especially in the agricultural sector – and coal.

More analysis is needed that looks to the future for captive power. On the one hand, continued economic troubles in the power sector along with wider availability of gas distribution infrastructures could accelerate the use of gas for captive power. On the other hand, efforts already under way to raise electricity prices and depoliticize the sector through more insulated central electricity regulatory bodies could encourage new centralized generation while reducing power consumption. By bringing solvency and increased reliability to the sector, captive generation could actually be reduced.

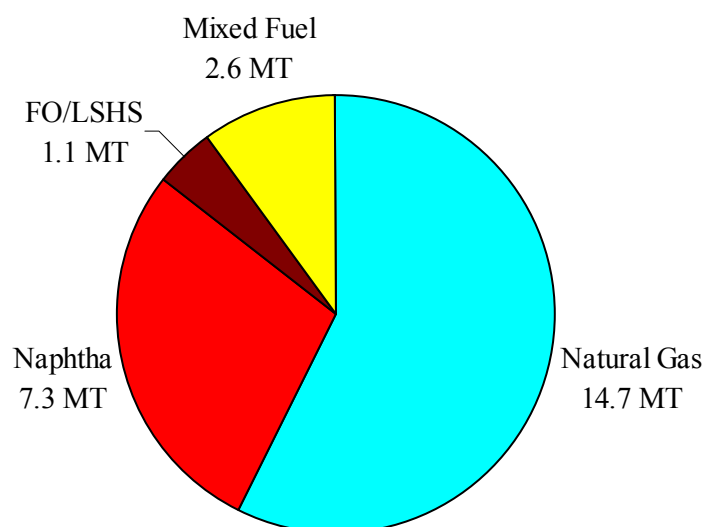
4. Fertilizer Sector Demand

The highly political nature of the Indian fertilizer sector renders an economic optimization model, like the one used in the electricity sector, essentially useless. Approximately two-thirds of India's 1.1 billion people derive their livelihood from farming, and these highly vocal masses have created a populist governing regime for the agricultural sector in India, resulting in governance based less on economic efficiency than on meeting the short-term needs of the masses. Essentially all ruling coalitions must orient their agriculture-related policies to this simple electoral math.

Nitrogenous fertilizers are no exception.²⁸ Since the 1970s, India has maintained a cost-plus pricing regime for domestic fertilizer producers, guaranteeing them an attractive rate-of-return over their production costs. Through the 1980s and early 1990s, Indian policymakers encouraged construction of fertilizer plants along the HVJ pipeline that connects gas fields in the west with the major consuming centers in the interior to Delhi, and provided these plants with extremely inexpensive natural gas. As a result, India has been able to achieve 100% self-sufficiency in nitrogenous fertilizer production. However, due to frequent shortages of gas in pipeline, much of India's fertilizer production was built with the flexibility to utilize gas (when available) or oil-derived naphtha (which, as a liquid, is easier to transport and store on site). Figure 27 summarizes Indian production capacity by fuel.

²⁸ Unless otherwise noted, the term "fertilizer" in this paper refers to nitrogenous fertilizers.

Figure 27: Fertilizer Production Capacity by Feedstock²⁹



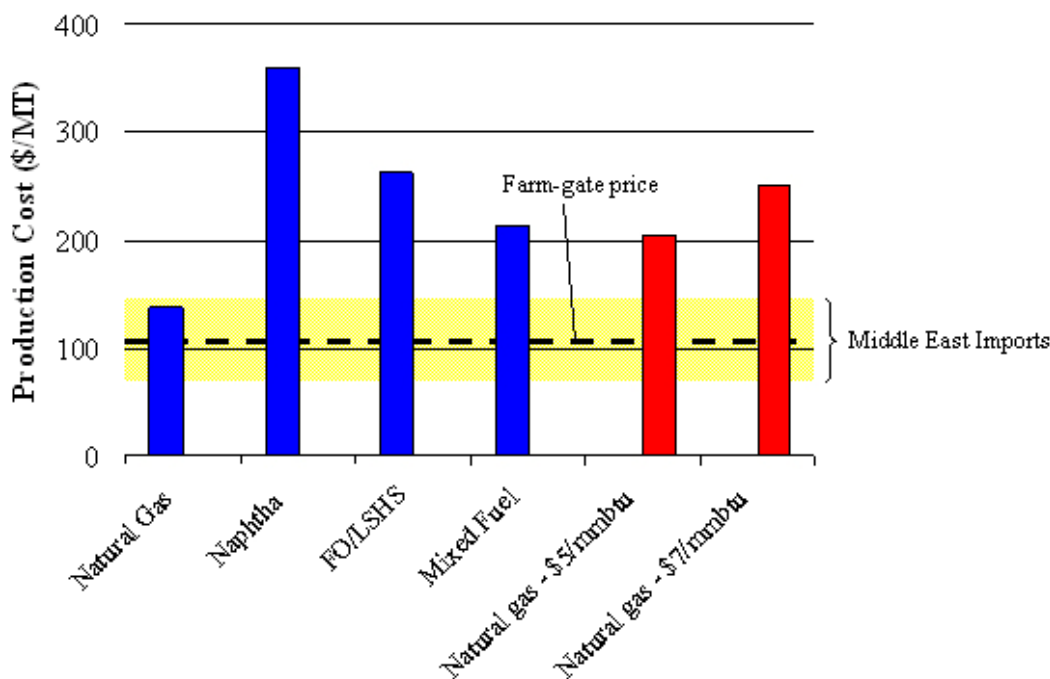
At the same time, farm-gate prices for nitrogen fertilizers have been maintained well below the cost of production, with the difference between production costs and farm-gate prices paid by the central government as a subsidy. As the quantity of this subsidy increased through the 1990s to over \$2 billion, Indian policymakers have sought greater fiscal probity, and the central government has sought ways to reduce this burden.³⁰

Figure 28 summarizes the average production cost of fertilizer based on feedstock in India, along with the farm-gate price and import parity. As indicated by the figures, there is a wide range in fertilizer productions costs based on fuel, and nearly all Indian fertilizer is more expensive to produce than current world standards for new plants.

²⁹ See Integrated Research and Action for Development (2007). “Demand for Natural Gas in the Indian Fertilizer Sector.”

³⁰ Department of Fertilizers (2005). “Annual Report, 2004-05.”

Figure 28: Fertilizer Production Cost by Feedstock



Source: Natural gas, naphtha, FO/LSHS, and Mixed Fuel costs from Government of India, Planning Commission (2006).
 Natural gas at \$5 and \$7/mmbtu from IRADe (2007). "Demand for Natural gas in the Indian Fertilizer Sector."
 Middle East Imports based on delivered prices from an Indian project to import fertilizer from Oman, which commenced operations in 2005.
 Farm-gate price is Rs. 4,850/tonne.

The main driver of the production cost differences is the cost of hydrocarbon feedstocks to the fertilizer plant. In India, pricing of many petroleum products, including naphtha and fuel oil, have been decontrolled by the central government and are at parity with international prices – with prices in the range of \$12-15/mmbtu. However, because the central government continues to pay the difference between production costs and farm-gate prices, naphtha-based plants have little incentive to switch to natural gas – at subsidized or even private market prices.

As Figure 28 indicates, fertilizer sourced from the Middle East would be the cheapest option for India. One such plant, has been set up in Oman as a joint venture between the Oman Oil Company and two Indian fertilizer cooperatives, and commenced operations in 2005. The plant sources gas at a price below \$1.00/mmbtu, and plans to sell fertilizer to India on a long term contract at a price between \$80-150/tonne. Despite the cost advantages of this strategy, the political realities in India, anchored in a strong desire for food security and self-sufficiency, suggests that domestic production will continue to be favored over these international ones.

Study Design and Reference Projections

Because domestic fertilizer production is so heavily dependent on a protectionist import policy, fertilizer production in India in the future can be estimated by using a simple engineering model to determine how much natural gas would be necessary to meet projected fertilizer demand.

PESD worked with Integrated Research and Action for Development (IRADe), an economic policy think tank in Delhi, to construct this model, and determine demand for gas and allocation of subsidy under a range of proposed policy reforms.

In the next few years, private domestic production from Reliance and others are likely to increase the availability of gas to the fertilizer sector. As a result, the Department of Fertilizers has mandated that in the near future, all plants must operate on natural gas. Given the obvious cost savings – private gas supplies are cheaper than naphtha and fuel oil – we find it hard to see how this policy would fail to be enacted, and therefore include a switch to a fully natural gas fueled fertilizer market in all of our scenarios.

The reference projections assume a 95% self-sufficiency requirement, a mix between government supplied cheap gas and private gas, and slowly increasing farm gate fertilizer prices. Comparisons between assumptions used in the reference projections and two other projections described in this paper are provided in Table 8 below.³¹

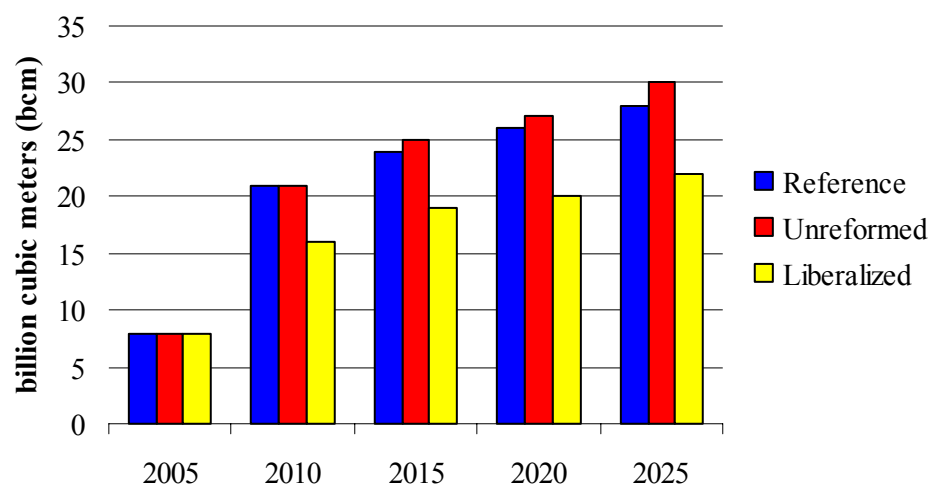
Table 8: Summary of Major Fertilizer Demand Scenarios

	<i>Self-sufficiency requirement</i>	<i>Farm Gate Prices</i>	<i>Natural Gas Pricing and Availability</i>
<i>Reference</i>	95%	Increasing by 10%	Mix of cheap government gas and private
<i>Unreformed</i>	95%	Remain constant	Unlimited cheap government gas
<i>Highly Reformed</i>	70%	Increasing by 10%	Mix of cheap government gas and private

The results for natural gas demand are provided in Figure 29 below. As expected, we found that the strongest driver of natural gas demand in India is likely to be the fertilizer import policy, because imports are expected to outcompete domestic production to the extent they are allowed into the market. Our model found that rising farm-gate prices decreased demand for fertilizer only marginally. The large jump in gas demand observed between 2005 and 2010 is driven by the switch of all plants to natural gas by 2010.

³¹ Other variables were modeled in the study, all of which can be seen in Integrated Research and Action for Development (2007). “Demand for Natural Gas in the Indian Fertilizer Sector.”

Figure 29: Gas Demand from Fertilizer Sector Under Different Scenarios



PESD is continuing to work with collaborators at IRADe to calculate the quantity and distribution of subsidy paid by the central government under each of the scenarios. Because imports can be sourced more cheaply than domestic production, we expect to find that the liberalized scenario entails the lowest subsidy burden on the central government, while the unreformed scenario is only possible at very high cost to the government.

In conclusion, we find that gas demand from the Indian fertilizer sector will be driven by two main factors. The first is the willingness of the central government to allow imports of fertilizer. The Oman project – being located in a foreign country, but partially owned by Indian companies – offers a compromise between the desire for self-sufficiency and a need to reduce the cost of production. Should this model prove politically tenable on a larger scale, gas demand growth from the fertilizer sector could be significantly reduced. If the current political fashion towards self-sufficiency remains, then the Indian fertilizer sector could consume very large quantities of gas into the future.

The cost of these scenarios to the central government could help drive the political outcomes. Massive subsidy burdens have forced liberalization throughout the Indian economy over the past fifteen years, and it could be that India simply cannot afford to follow the unreformed path as demand for fertilizer doubles over the next twenty years. In such a scenario, gas demand from the fertilizer sector would likely decline as farm-gate fertilizer prices increase or cheap imports gain market share.

4. Industrial Gas Demand

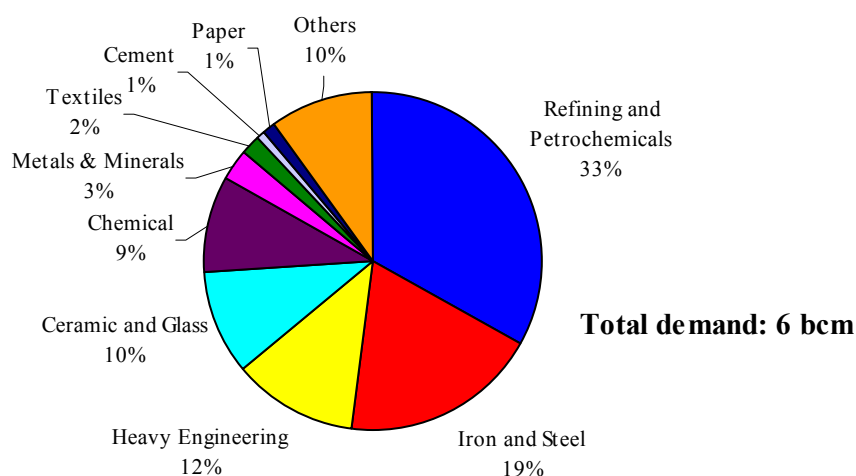
Industrial consumers that are connected to gas supply infrastructures (and thus have access to gas) could potentially emerge as a major consumer of natural gas in the future. These consumers, historically, have had difficulty securing reliable supplies of natural gas, but with the increased availability of gas in the near future, industrial consumers will have the option to purchase gas from private suppliers (who source gas from domestic fields or LNG) at higher prices than those that prevail in today's government-regulated supply system. In India today, the major consumers

of LNG cargoes thus far have been these industrial consumers, who have been willing to pay for expensive gas rather than be left with no gas at all.

PESD worked with analysts from A.T. Kearney in India to determine the economic viability of natural gas for industrial consumers in 2025. Researchers projected industrial demand for hydrocarbons to 2025, and then, through interviews with nine major industries, determined what demand could be met economically by natural gas, incorporating conversion cost, fuel cost, gas infrastructure constraints, and other relevant variables.³²

Figure 30 below summarizes the major natural gas consuming industries in 2006. As the figure indicates, the refining and petrochemicals industry consumes the most gas in 2006, followed by iron and steel. We will reexamine these two industries in our analysis of the modeling results.

Figure 30: Distribution of Industrial Gas Demand, 2006

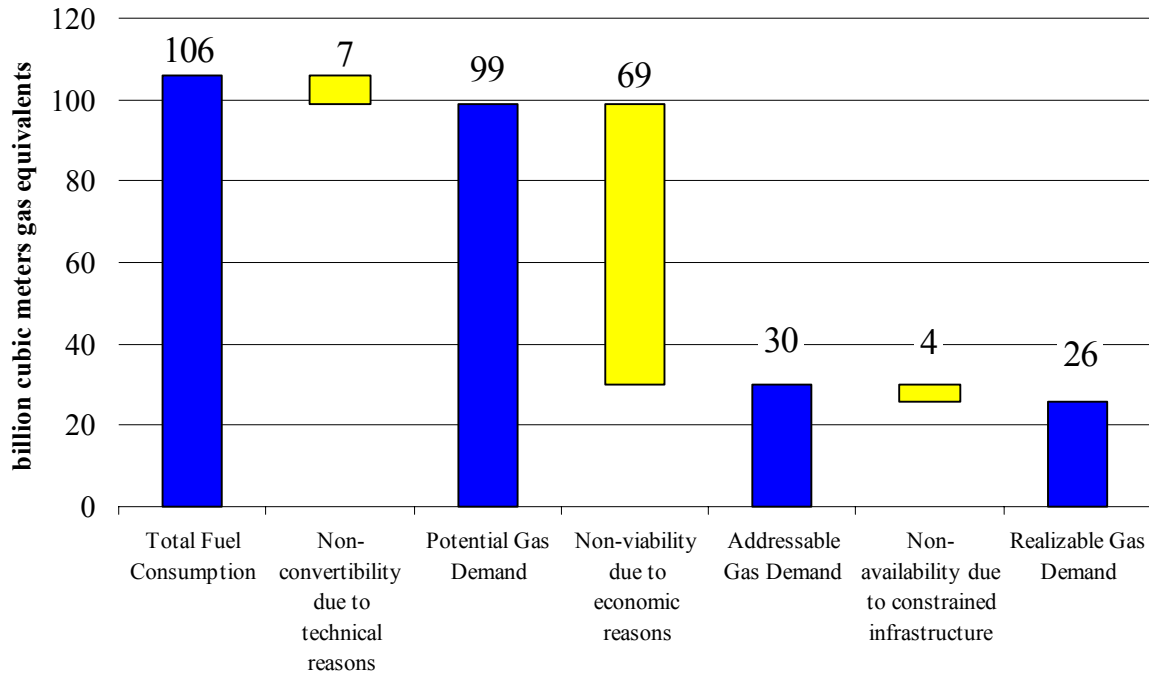


Modeling Results

Through focused interviews with these nine major industries, the A.T. Kearney study projected total demand for industrial fuels in 2025, and calculated the amount of this demand that could be met economically by natural gas. Figure 31 summarizes these results.

³² For a more detailed discussion of the modeling framework and results, see A.T. Kearney (2007). “Demand for Natural Gas in the Indian Industrial Sector.”

Figure 31: Projected Realizable Industrial Natural Gas Demand, 2025

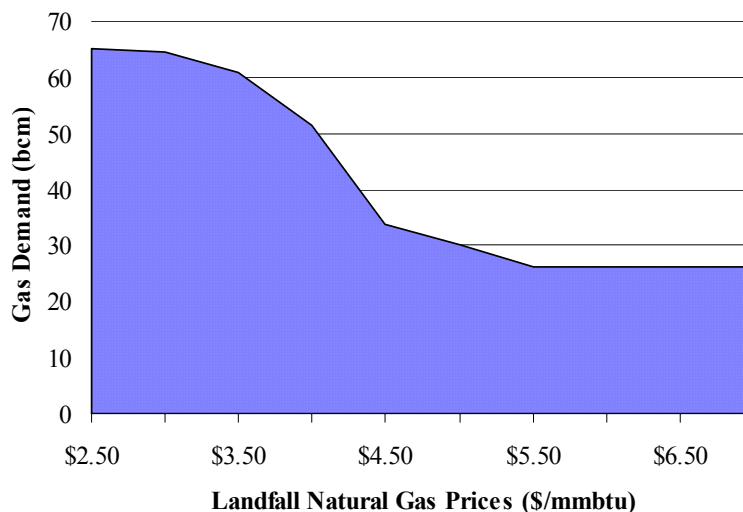


Note: Assumes a delivered natural gas price of \$5.50/mmbtu.

As Figure 32 makes clear, natural gas is technically capable of meeting all but a small amount of industrial energy demand (coking coal in the iron and steel industry, for example, cannot be switched to natural gas). The major constraint on natural gas use is the high price of natural gas relative to the alternative, cheap coal. The major opportunity for growth in natural gas demand is in displacing petroleum use, where gas prices paid in the private market are a bargain for consumers currently paying prices over \$10/mmbtu for oil.

These results are reflected in Figure 32, which projects a demand curve for natural gas in 2025.

Figure 32: Industrial Natural Gas Demand Curve, 2025



The demand curve for industrial gas suggests two important findings. First, significant additional natural gas could be consumed by the industrial sector if gas prices were low enough that gas could compete directly with coal. That scenario would require gas prices much lower than those seen in India today, which is implausible since industrial consumers do not have the political clout to obtain government-regulated gas. However, if tight environmental controls were applied to coal-based industrial boilers then gas might find itself in a much more competitive position relative to coal in the industrial sector. We haven't explicitly modeled a more stringent environmental control scenario for industrial consumers, but are exploring that possibility for future study.

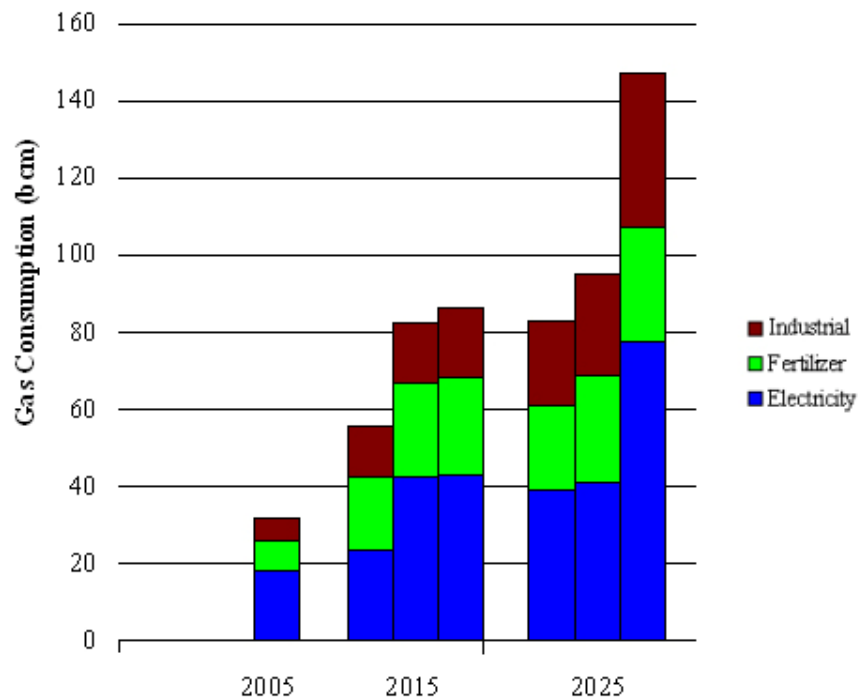
Second, second is that demand for natural gas is highly inelastic at prices above about \$5.00/mmbtu. This is largely because in this price range, most switching is from oil to natural gas; even at very high natural gas prices, gas is more economic than oil. This supports the finding that most of the growth in gas consumption comes from refining and petrochemicals, where coal use is low. Conversely, steel and iron producers share of the industrial gas demand declines to 2025, because most of their consumption continues to be met by cheap eastern coal. This would suggest that Indian industry should not be constrained on price in accessing LNG from overseas because they are able to pay prices seen around the world today. Furthermore, it explains why Indian LNG importers have been able to import and sell gas at very expensive prices on the spot market, such as seen with the recent high-cost purchase of LNG from Algeria.

5. Implications for Indian Gas Demand

Because natural gas pricing and allocation is segmented by consumer in India, adding up the projected consumption of gas from each major consumer provides a close approximation of the projected size of the overall gas market in the future. We assume fertilizer producers will be able to access as much gas as they can consume (though some runs assumed higher prices). We then removed this consumption from the available gas to the power sector to construct a gas supply curve exclusively for the power sector. And because industrial consumers operate in a market connected largely to global LNG markets, we assume that LNG supplies are likely available if industrial consumers pay prevailing global market prices.

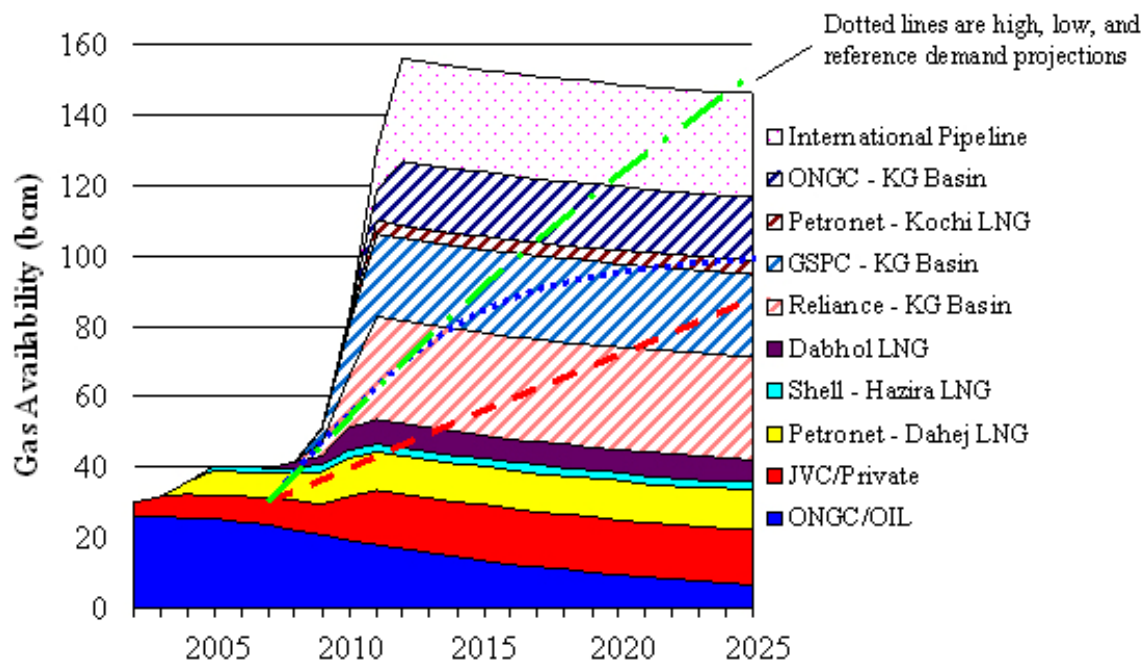
Figure 33 stacks our projections for gas demand under our reference, high, and low scenarios. These projections are meant to provide bounds on our projections of Indian gas demand. For example, the High Gas scenario assumes stringent sulfur constraints in the power sector, protectionist constraints on fertilizer imports, and high economic growth driving industrial gas use. The Low Gas scenario assumes vigorous coal sector reforms, liberalized fertilizer imports, and low economic growth slowing industrial gas demand. Clearly, these High and Low Gas scenarios are provided largely for illustrative purposes – different combinations of High and Low Gas demands from each consumer are plausible ways in which the gas market might develop.

Figure 33: Projected Natural Gas Demand (2005-2025)



In Figure 34, we have plotted these demand projections onto the likely available supplies of natural gas over the next twenty years from Figure 19.

Figure 34: Indian Gas Supply and Demand Projections



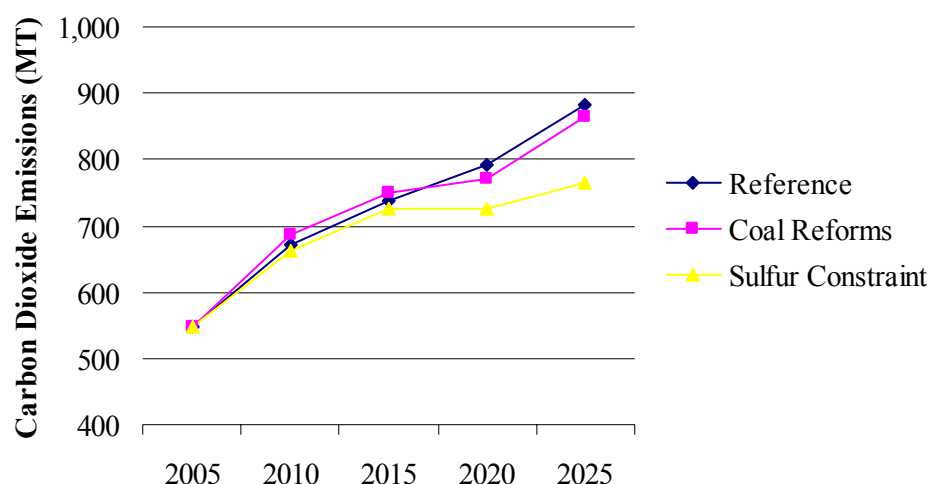
As Figure 34 indicates, the supply projects being developed in India today will be sufficient to supply India's gas demand under all but the most aggressive growth scenarios. A proposed international pipeline – from Iran, Turkmenistan, Bangladesh, or Myanmar – appears to be a

risky endeavor, not only because of security of supply concerns, but because it is unclear whether India can reliably guarantee consumption of the gas. With such highly uncertain demand for imports – due to uncertainty in both the domestic demand and supply – smaller LNG terminals, constructed when excess demand is assured, appear to be a more rational supply strategy for India.

5. Implications for Climate

Although we did not model an explicit CO₂ abatement scenario, the MARKAL model reported CO₂ emissions from the power sector for each run. Figure 35 summarizes CO₂ emissions under the three electricity scenarios reported in this paper, and finds that emissions vary across the modeling runs. Of particular note is a 115 million tonne CO₂ reduction between the sulfur constraint and reference scenarios. In the context of emissions reduction strategies discussed around the world today, this is a quite significant. For example, it is approximately triple the reductions already monetized in India through the Clean Development Mechanism of the Kyoto Protocol.

Figure 35: Carbon Dioxide Emissions under Electricity Scenarios



IV. Conclusions

The study suggests a number of key findings on the role of China and India in the global gas market, and offer insights into the competitiveness of natural gas in these two countries over the next two decades.

1) Demand size and uncertainty influences supply infrastructure

Growth in gas demand in both countries, particularly China, could force these countries to import significant quantities of natural gas. In the case of China, it appears that demand is likely to far outstrip domestic supplies, and in the absence of significant imports – either a large international pipeline from Russia or Kazakhstan or several LNG regasification terminals – gas consumption will be constrained by available domestic supplies.

In India, the role of imports is much less certain. While three new huge gas fields are expected to begin production in the coming few years, the actual flow of gas from these fields is unknown. If these new fields produce at the levels publicly announced thus far, India could produce nearly all the gas it consumes, with imports restricted to marginal LNG supplies. However, should these fields underperform today's expectations and gas demand remain robust, there could be a market for a large pipeline from one of India's gas-rich neighbors.

Previous studies by researchers at PESD found that many gas supply projects in the past were disrupted not because of the supplier withholding gas to extort a higher price, but because the offtaking country's demand didn't materialize as expected.³³ Because of the highly uncertain import requirement from India, we find it highly unlikely that a major international pipeline could be economically feasible. Instead, we see LNG as the more logical supply option because each project is much smaller and can be built modularly as demand becomes certain.

2) Gas demand is highly dependent on policies outside the energy sector

In China, financial reforms that lead to extremely low costs of capital for the power sector make the construction of capital intensive coal plants even more attractive. In Guangdong, for example, coal consumption within the power sector can increase by up to 88% if assumptions of cheap cost of capital are used.

In the case of India, we find, for example, that fertilizer import policy could have a large impact on overall gas demand in India – a fully plausible liberalized import regime could reduce nationwide gas demand in India by 10%.

3) The industrial sector generally most attractive for switching to natural gas

In both China and India, large parts of the industrial sector are fired by fuels that can be switched cheaply to natural gas. In the case of Shanghai for example, when sulfur constraints are modeled

³³ Victor, David, Mark Hayes, and Amy M Jaffe (2006), ed. "Natural Gas and Geopolitics."

in the city, a switch from coal to gas for industrial customers appears more cost effective than the power sector. Replacing an inefficient coal boiler is much less expensive than converting a power plant to switch from burning coal to natural gas, especially when there are enough boilers in the industrial sector to make a difference in SO₂ emissions.

In India, a large percentage of industrial demand in India today is met by oil because industrial consumers have been largely denied politically allocated gas supplies. Because prices of oil products in India are at international levels – above \$10/mmbtu – this demand can easily be switched to even expensive gas (e.g., \$7/mmbtu) gas at a cost savings.

4) The electricity mix in both countries is unlikely to change dramatically

Our models solved for the least-cost solution to meeting China and India's demand for energy services. In both cases, it is very difficult to foresee a scenario in which coal does not remain the dominant part of the electricity mix. Coal is simply too cheap and abundant in both countries to leave unused (China has the world's third largest coal reserves, India the fourth). Aggressive sulfur reductions do shift the electricity mix to a greater role for natural gas, but sulfur reductions can often be met more cheaply through fuel shifts in the industrial sector and by installing end-of-pipe solutions to coal plants.

5) Coal sector reform may be very dangerous for climate

When available, coal outcompetes natural gas in the power sector and industrial use. The experience in India through the 1990s and early 2000s suggests that potential coal use could be constrained because of lack of investment into new production capacity or transportation bottlenecks. In this world, natural gas could play a much larger role.

But coal sector reforms in both countries are likely to dramatically improve the availability of coal. In India, liberalization of the coal sector is expected to introduce new mining technology, stimulate more efficient operations from CIL, and bypass transportation bottlenecks (through coal-by-wire and imports). While coal prices will increase as a result, they are not expected to increase high enough to allow natural gas to outcompete coal as a fuel for baseload power.

6) Non-climate policies could have a large impact of carbon emissions

While China and India are unlikely to accept binding carbon dioxide emissions reductions targets in the near future, very large CO₂ reductions might be realized as a side benefit from other policies enacted for reasons aside from climate concerns. For example, in the case of China, a cap on SO₂ emissions could have significant implications for CO₂ reductions by promoting the use of cleaner burning fuels and more advanced technology. A SO₂ policy may be more palatable to the Chinese government, however, because it addresses immediate and local concerns about air quality and health which directly relates to their constituents. This is much more likely to get traction and make real change even though we are only seeing changes on the order of 100 million tons of CO₂ saved, which is about equal to the amount that is being saved by the entire stock of Clean Development Mechanism (CDM) projects in China today.

In the case of India, a more national sulfur reduction policy could have similarly huge implications for carbon emissions. The coal to gas switch observed in the power sector given a 40% reduction in sulfur would result in about 115 million tonnes of reduced CO₂ emissions.

While these reductions are a far cry from solving the global climate problem, they could play a significant role in addressing climate change. For example, the 250 million tonne CO₂ abatement described above is five times the reductions called for in California's aggressive climate programs, and about the size of the entire Clean Development Mechanism reductions to date. In the context of Socolow and Pacala's famous carbon stabilization wedges, these carbon reductions represent roughly 15% of one wedge to 2025, or 2% of the reduction necessary to stabilize atmospheric CO₂ concentrations by the end of the century.³⁴ While small amounts in themselves, most every climate policy that has been envisioned has, by itself, a small impact. What's interesting about these policies is that they yield reductions in countries that have been most reluctant to adopt binding limits on emissions and yet are essential participants if there is to be success in cutting global concentrations of CO₂.

³⁴ Pacala, S. and P. Socolow (2004). "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies."