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Expanding Natural Gas Use in China

A Joint Sino-U.S. Research Report

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FOREWORD

(U.S. Sponsor)

I am pleased to introduce this study, which addresses an important opportunity for environmental protection in China and for U.S.-China environmental cooperation. Natural gas burns cleaner than coal and oil and thus helps to minimize harmful emissions of sulfur dioxide, particulates, nitrogen oxides and other air pollutants. It also produces lower levels of carbon dioxide—the most important anthropogenic greenhouse gas (GHG) —relative to other fossil fuels. In China's case, replacing highly polluting coal use with more extensive use of domestically produced and imported natural gas could have enormous benefits in cleaner air, reduced public health damage and reduced GHG emissions. The United States and China have strong common interests in working together to achieve these goals. This was recognized in one of ten Statements of Intent (SOI) on environmental cooperation signed by the Administrator of the U.S. Environmental Protection Agency with the Chairman of China's State Development Planning Commission in April 1999. This SOI initiated a cooperative expert study on opportunities to expand use of natural gas in China and the environmental benefits this could produce.

The State Development Planning Commission designated the University of Petroleum-Beijing to coordinate China's research contribution, working with the Pacific Northwest National Laboratory in the the United States. After two years of intense effort, the authors have succeeded in producing a high quality summary report which documents the potential for and environmental benefits of expanded natural gas use in China, identifies key barriers restraining rapid development of China's gas sector, and identifies opportunities for further U.S.-China collaboration toward that goal.

Market reforms and technology development have helped expand the use of natural gas in many regions of the world over the past decade. Several countries have developed competitive wholesale and retail natural gas markets that result in lower costs and greater convenience for consumers. They have also learned a great deal about the careful crafting of policies governing these reforms. Technological advances in areas such as seismic imaging, drilling, and high-temperature gas turbines have helped to increase the availability and affordability of natural gas. Other technologies, such as fuel cells and gas-to-liquids conversion, are under development and promise to further expand the potential uses of natural gas.

Because natural gas until recently played a minor role in national energy policy, many of these international developments have not yet been replicated in China. As late as 1997, natural gas accounted for only two percent of the country's energy demand mix, far below the world average of 25 percent. China's interest in expanding natural gas usage has grown over the past few years as air quality continued to deteriorate, especially in urban areas. More ambitious plans are now on the drawing board to make natural gas a significant source of new energy in China over the next 20 years. To make this vision a reality, however, new measures will be needed to encourage exploration and development, transportation, distribution, and, perhaps most importantly, market

demand for natural gas. There are significant opportunities for drawing on the advanced technologies and policy experience available from the U.S. and other countries to support these developments in China. This document aims to inform policymakers of the important issues related to expanding natural gas use in China and to outline collaborative opportunities that could help overcome some of the obstacles. I believe that the report makes a significant contribution in this regard, and represents a major constructive step in the ongoing cooperation between China and the U.S. to promote cleaner energy and a cleaner environment.

Paul Stolpman
Director, Office of Atmospheric Programs
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FOREWORD

(Chinese Sponsor)

The State Development Planning Commission was pleased to cooperate with the U.S. Environmental Protection Agency on ways to boost natural gas use in China. This study outlines key measures to accelerate development of China's natural gas industry and suggests future steps the U.S. and China can take together to help improve development of the sector.

China's natural gas sector is now receiving great attention. The Chinese government is stimulating the industry by developing new policies to push forward natural gas use. This study adds to the measures to develop clean energy sources such as natural gas, and clarifies future opportunities for cooperation between China and the U.S.

Experts from the University of Petroleum-Beijing and Pacific Northwest National Laboratory worked hard to produce study results that are helpful to governmental decision-makers in the natural gas industry. Also, this project has helped build confidence in cooperating with the U.S. on energy and environmental issues. China will continue conducting market reforms and developing technology to drive the use of natural gas in China. We will make greater use of international human resources to train Chinese personnel in the natural gas sector. China will also need to attract more foreign investment to transfer advanced technologies to drive the development of the gas industry.

China plans to make natural gas a significant source of new energy over the next 20 years. To make this vision a reality, however, new measures will be needed to encourage exploration and development, transportation, distribution, and market demand for natural gas. This document helps to inform policymakers of the important issues related to expanding natural gas use in China and to outline collaborative opportunities that could help to overcome some of the obstacles.

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EXECUTIVE SUMMARY

Trends and Overview

China's long dormant natural gas sector looks set to begin a period of rapid growth. Expanded use of natural gas as a substitute for dirtier fuels could help address many of the country's severe air pollution problems, including greenhouse gas emissions. While important policy changes have occurred over the past few years, a number of obstacles could constrain development of the natural gas market. This study identifies these obstacles and describes ideas for U.S.-China collaboration to overcome them.

China has demonstrated its intention to boost natural gas as a substitute for coal and oil. The misconception that natural gas exists in insignificant quantities in China is diminishing. Within the last year, China has announced large gas discoveries in Xinjiang and Inner Mongolia, adding to other relatively abundant reserves identified during the 1990s. Infrastructure for natural gas—including the West to East natural gas pipeline—is being developed to transport gas from remote locations to population centers. Plans for China's first liquefied natural gas terminal in Guangdong are progressing and the terminal could be operating by 2005. And China's major oil and gas companies are being commercialized and encouraged to cut staff, focus on profits, and improve management. These changes could transform the natural gas industry into a dynamic sector capable of fueling cleaner economic growth, but additional measures will be required.

Chinese planners are promoting natural gas mainly for its relative environmental benefits. A heavy reliance on coal over the past five decades has made China one of the most polluted countries in terms of air emissions. Environmental pollution is now widely acknowledged to cost the economy billions of yuan in losses each year due to impacts on human health, agricultural productivity, and human-built infrastructure. The move to natural gas is a step to reverse the environmental damage, and would also have a significant impact on greenhouse gas emissions. Other benefits of expanding the use of gas include:

- Balancing energy supply and demand centers,
- Improving the nation's energy security, particularly with respect to rapidly rising oil imports, and
- Removing bottlenecks in the already strained freight transport sector.

Despite the positive signals in development of a natural gas value chain, stronger government support is needed if China is to maximize the benefit of natural gas. Developing the natural gas system from exploration to end-use requires enormous investment and strong coordination between economic planning agencies, municipalities, environmental protection bureaus, and energy companies. The weakest link in the chain can arrest development of the entire system. As China is transitioning from a planned to market economy, the government needs to establish a more transparent, comprehensive framework in which market-oriented companies can succeed.

Economic reforms in China are beginning to have a noticeable impact on state-owned industrial enterprises, including oil and gas companies. Consolidation and closure of industrial enterprises have improved economies of scale and efficiency. State owned enterprises are facing firmer budget constraints and receiving fewer policy loans from Chinese banks. Many are beginning to focus on profits rather than just output and have begun raising significant sources of finance on domestic and international stock markets. Still, conflicts between central and local authorities often slow efforts to reform as do the rising number of unemployed workers that threaten social stability.

This study outlines important trends in China's natural gas sector and identifies opportunities where China, the United States, and possibly other organizations can collaborate to overcome barriers that prevent rapid development of the industry. It is a relatively modest effort and will require earnest follow-on work to catalyze significant change.

Section 1 provides a brief overview of recent trends in China's energy sector, placing the natural gas sector in proper context. The environmental impacts of expanding natural gas use—including estimated reductions in local and global pollutants— are considered in Section 2. Section 3 describes recent changes in administering and guiding China's gas sector. In Sections 4 and 5, the authors focus on key issues and challenges in the supply, transport and distribution of natural gas. Downstream, or end-use demand, for natural gas is discussed in Section 6. The final section summarizes potential areas of collaboration between China, the U.S., and potentially other international organizations to overcome obstacles to developing the gas sector more rapidly.

Key Issues

Summarized below are the key findings identified in each section of the study.

Environmental: Natural gas has the highest environmental and health value in displacing coal use in the residential sector, but markets are more likely to first develop in the power generation and industrial sectors. For every 20 billion cubic meters of natural gas used in place of coal, sulfur and carbon dioxide emissions would decline by 650 thousand tons (kt-SO_2) and 14 million tons (Mt-C), respectively. Natural gas is already competitive in regions where coal is relatively expensive and a clear winner when environmental costs are included. Greater enforcement of existing environmental regulations would help create market demand for natural gas.

Administration and Policy Development: Important new measures have been enacted to boost gas use including pipeline construction, liquefied natural gas development plans, and generic economic reforms aimed at commercializing state-owned enterprises. Trends are underway to advance market-based pricing of natural gas, and all new gas supply projects are to allocate gas according to market demand. A comprehensive natural gas development framework, however,

has yet to emerge. Communicating clear policy priorities, clarifying lines of authority, and enforcing existing laws would promote development of the gas sector by lowering risk and optimizing resource use. Domestic bond and stockmarket offerings are now playing a larger role in financing natural gas exploration, development, transport, and distribution activities. Foreign investment in onshore activities has been meager, but could grow rapidly if new measures are taken to improve transparency, promote the rule of law, and expand market reforms. Foreign investment can help transfer the technologies needed to make gas use more affordable. Continuing market reforms can help lower the cost of bringing natural gas supplies to end users.

Upstream: China has more domestic gas than once thought, although most resources are located far from centers of demand. Recent discoveries of large fields in Xinjiang and Inner Mongolia have added to the growing resources identified during the 1990s and supported construction of the West-East natural gas pipeline project. Development of China's first liquefied natural gas terminal in Guangdong is proceeding, although China is likely to enter the LNG market cautiously. Progress on importing gas from Russia and other Central Asian countries has been slower. New drilling and imaging technologies can improve the success of finding gas resources economically and Chinese gas companies would benefit from using them on a wider scale.

Midstream: Construction of a cross-country pipeline linking gas supplies in western China with users in the east has been the most significant development in China's gas sector. The project has driven new reforms and opened the sector further to foreign investment. If gas is to play a significant role in China's overall energy strategy, tens of billions of dollars will be needed to build additional transport and distribution infrastructure. Total costs will depend heavily on the policies China enacts and how successfully they are enacted. Chinese companies and municipalities would benefit by training experts in the latest methods of planning, regulating, and operating safe, efficient natural gas pipelines. Furthermore, the difference between wellhead natural gas prices and those paid by end-users is currently high and can be reduced by streamlining government authority and making distribution companies more efficient.

Downstream: Ensuring market demand for the newly available natural gas supplies is now the most important hurdle facing project developers. Wellhead prices for natural gas "within the plan" are currently set artificially low. "Out of plan" prices are far higher due to market distortions, inefficiencies, and, to some extent, difficult geology. The environmental benefits of natural gas should be included in energy pricing mechanisms in order to level the playing field among existing energy options. More research and development is needed to bring end-use technologies such as gas turbines, gas-to-liquids conversion, and fuel cells to market.

Recommendations for Further Collaboration

There are several promising areas for further collaboration between China, the United States, and other participants to overcome barriers in the natural gas sector. As in any successful

collaboration, stakeholders need to be flexible and each must contribute something of value. The most promising opportunities are outlined below.

Business and Finance Training: China will need to train thousands of specialists over the coming decade if it is to boost natural gas use significantly. Especially valuable skills are those related to market-oriented management, finance, and regulation. Chinese natural gas specialists are often well equipped with analytical and technical skills, but lack skills in business planning and finance that help create successful business models.

The U.S. government could assist in the development of a training center in China that focuses on building market-oriented business and regulatory skills. A modest investment could lead to the creation of a permanent training center that becomes self-supporting after several years of operation. Chinese nationals who received training from international experts would staff the training center. Trainees would pay a modest fee to participate.

In addition to offering training in business skills, the training center could also build capacity in other areas to help accelerate development of China's natural gas sector. Three such topics include natural gas safety, pipeline operation and maintenance, and policy development. Chinese regulators will need to establish safety protocols to prevent accidents in newly built gas infrastructure from improper digging and end-use activities. The U.S. also has extensive experience it could share with China in planning, operating, and maintaining natural gas pipelines. Chinese specialists could be invited to visit facilities in the U.S. focusing in these important functions, but a more sustainable effort at the training center could leverage more powerful benefits. Finally, training could help high-level government officials develop a more comprehensive policy framework to ensure more rapid, coordinated action.

Technology Transfer: Chinese gas companies and end-users could lower costs by making greater use of new technologies. New developments in three and four-dimensional seismic imaging, data processing, and drilling techniques have increased the chances of finding exploitable gas supplies. In the United States, specialized service companies carry out many of these activities, but Chinese companies have yet to fully employ their benefits. End-use technologies including gas turbines, fuel cells, and gas-to-liquids (GTL) are of great interest to Chinese researchers, but need more attention if they are to play a significant role in the future economy.

Probably the most promising means of transferring these "hard" technologies to China is through joint venture or licensing agreements with foreign companies. The U.S. government would probably not assist in these maters directly as it cannot order private companies to transfer technology, and is not likely to buy the rights to the technologies so that they can be transferred. The U.S. could help bridge the gap, however, by helping identify barriers to the formation of such joint ventures and licensing agreements. It could also offer expanded scholarly exchange

opportunities such as the International Visitors Program or Humphrey Fellowships to bring more employees from China's natural gas sector to the U.S. for advanced training.

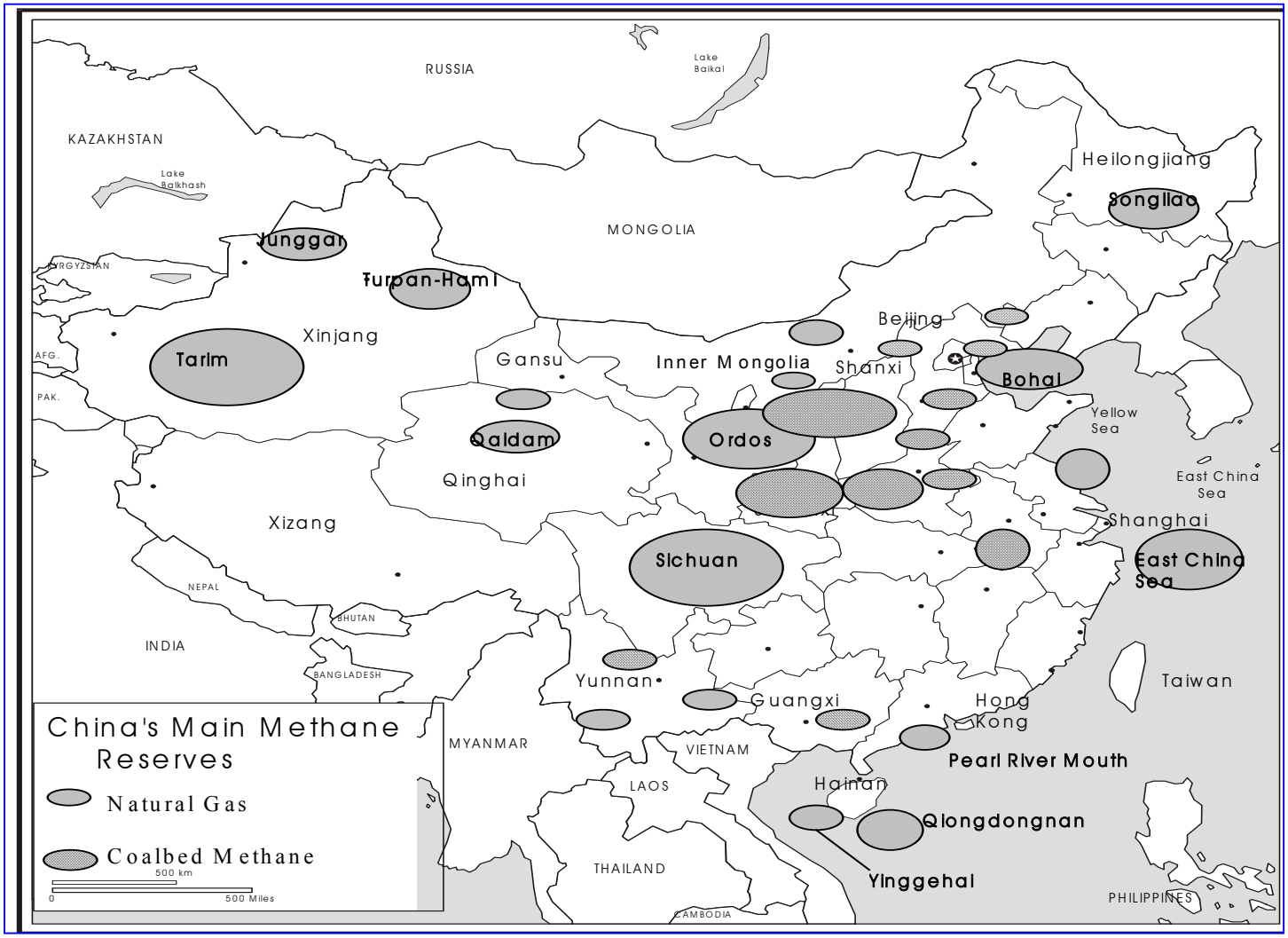
Boosting Foreign Investment: Many foreign oil and gas companies would like to expand their business operations in China but have been constrained by both real and perceived barriers. Most of these companies have been encouraged by recent changes in China's gas sector, but claim that they could do much more if given the opportunity. Greater inflows of foreign investment would help China solve shortcomings in technology, finance, and management, although not without benefits for the investors.

Some barriers preventing greater inflow of foreign investment are generic to all foreign companies, like the claim that transparency is poor. Others are specific to the gas sector, such as the feeling among some companies that only very risky or poor quality development parcels are offered for exploration.

One of the most direct ways of boosting foreign investment would be to offer more exploration blocks and production sharing contracts, especially onshore, to foreign companies. Another would be to officially expand foreign investment and ownership in all pipeline and downstream projects. A final relatively direct method would be to allow more gas to be sold at market prices and loosen the allocation of gas to particular industries.

Other methods of boosting foreign investment are less direct and associated more with generic economic reforms. Enforcing laws according to contracts, publishing information on who holds final decision-making authority, and clarifying policy priorities would all help to lower the market risks perceived by potential foreign investors. The U.S. could help China create policies or institutions to accelerate the spread of these practices.

Policy and Regulatory Development: Chinese planners have experimented with a huge variety of reforms since beginning the move to a market economy. The U.S. could assist China in additional policy reforms related to expansion of the natural gas sector, but acknowledges that it is not in a position to tell China how to reform. If China chooses to further market reforms, U.S. specialists might be able to advise on issues related to policy, institutional, and regulatory development. The existing U.S.-China Oil and Gas Industry Forum has already considered some of these issues and may be capable of recommending advisors.

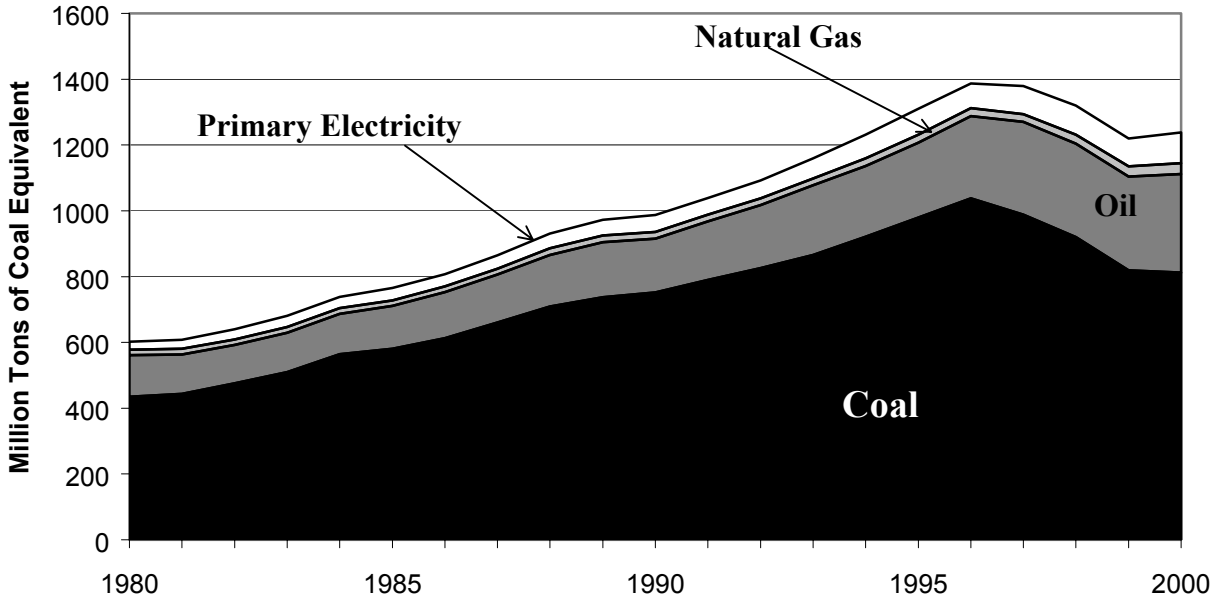


Map of China's Primary Natural Gas and Coalbed Methane Reserves

I. China's Energy Sector in Context

China's energy sector has undergone dramatic change over the past few years. Some changes have been driven by reforms associated with the move from a centrally planned to a market-driven economy. Others were the result of more specific measures aimed at meeting new energy and environmental objectives. In the year 2000, reported coal consumption accounted for approximately 65 percent of China's total energy demand, down sharply from over 75 percent in 1996. (See Figure 1-1.) Petroleum, natural gas, and primary electricity (hydroelectric and nuclear) provided the remaining 24, 3, and 8 percent, respectively. While the quality of recent energy statistics are under review, it does appear that China has lowered overall coal consumption from the peak in 1996.

Figure 1.1 – Reported Primary Commercial Energy Consumption in China



Source: China Statistical Abstract, 2000. Values for 2000 are estimated using preliminary data from the State Statistical Bureau.

Coal: Reviving Production and Use

Reported use of coal in China dropped by approximately 20 percent between 1996 and 2000, despite an expansion in official gross domestic product of 35 percent. Reasons for the dramatic reversal in coal use are poorly understood due to limited data, but closure of small, inefficient factories and improvements in coal quality could explain much of the drop. Unreported production and consumption of coal is also occurring, however, as at least some of the tens of thousands of recently closed coalmines have illegally reopened. Other factors such as structural

change in the economy may also play a role. While Chinese coalmines are moving toward greater mechanization and economies of scale, they also employ millions of rural workers. Policymakers want to control migration from rural to urban areas, which may slow further reforms in the coal sector. Emissions of sulfur dioxide, particulates, carbon dioxide and other harmful pollutants have declined roughly in parallel with reported coal use. Preliminary data for 2001 indicate that growth in coal use has returned.

Petroleum: Surging Imports

Imported crude oil accounted for nearly one-third of China's petroleum demand in 2000, up from essential nothing in 1996. Average oil production grew by 1.9 percent annually between 1995 and 2000 while demand rose by over 5.3 percent each year. China reformed the regulatory and administrative functions of its oil sector in 1998. Many of China's existing domestic oil production sites are aging, yet promising new resources in western China have yet to be developed. To improve energy security, China began investing in overseas oil production ventures in the early 1990s and hopes to transport 15-25 million tons from these fields back to China by 2005. China's major oil companies succeeded in raising over $7 billion in investments on the Hong Kong and New York stock exchanges in 2000 and 2001, and foreign direct investment has also been strong. Domestic equity markets are also providing a new source of capital for many petroleum companies within China. Together, these investments could help to encourage greater efficiency and transparency among Chinese state-owned oil companies.

Electric Power: Rapid Growth Returns

China's power sector continues to grow rapidly despite lagging reform. Installed capacity in early 2001 reached 320 gigawatts, approximately 40 percent as much as in the United States, but per capita power consumption remained low. A power glut—associated with the overall economic slowdown—appeared in some parts of the country beginning in 1997 and 1998. Rapid growth in power consumption returned in 2000, averaging nearly 10 percent, although some regions remain oversupplied. Coal supplies over three-quarters of all electricity, with hydroelectric accounting for most of the remainder. Plans to rapidly expand the nuclear power sector have slowed due to high costs and financing difficulties. Besides the massive Three Gorges Project, China is also building or planning many other large hydroelectric plants. Over the next few years China will continue to experiment with competition in electricity generation in some regions, but efforts have slowed due to difficulties in establishing functioning markets both inside China and in other places such as California.

Natural Gas: Growing supply, Uncertain Demand

China's natural gas sector has gone from being largely ignored to one of the centerpieces of the country's energy strategy, largely for environmental reasons. Planners hope that gas will account for at least 10 percent of all commercial energy demand by 2020, up from the current three percent. Significant market reform, policy development, and investment are needed, however, to identify promising gas resources, build transport and distribution infrastructure, and—perhaps

most importantly—create markets for gas utilization. Major gas discoveries have occurred over the past few years in western China and in offshore regions. These new finds have helped justify the construction of a cross-country pipeline from Xinjiang to Shanghai, slated to begin in 2002. Other pipelines have recently been completed that transmit gas to Beijing and Shanghai. China has also expressed an interest in importing natural gas from Russia and Central Asia, although regional issues need to be addressed to develop financing for the pipelines. China is also moving along with plans to build its first liquefied natural gas import terminal in Guangdong. Most of China's natural gas value chain is now open to foreign investment.

Energy Conservation and Efficiency

China has achieved unprecedented success in saving energy. Unlike most developing countries, China's post-reform economy has grown faster than its energy use. Measures to conserve energy have avoided the need to combust hundreds of millions of tons of coal and thereby prevented further environmental degradation. China's Tenth-Five Year Plan continues to rank energy efficiency as vital to the nation's energy interests. The accelerating shift to a market economy is providing new opportunities to save energy, particularly with profit-driven energy service companies.

Renewable Energy

China has vast potential for wind, solar, and small hydroelectric energy use. Overall development to date has been constrained by relatively high prices and market distortions. Some regions can expect accelerated growth in the near future, but renewable energy will likely remain a relatively limited supply option without dramatic reforms or technological breakthroughs.

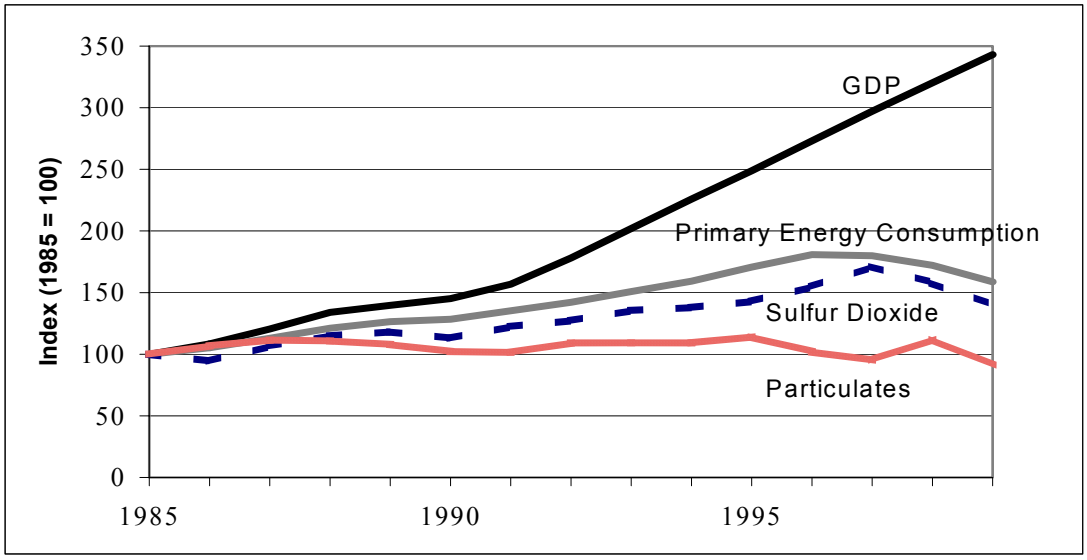
II. Natural Gas and China's Environment

This section addresses the question "How would greater use of natural gas as a substitute for coal impact China's environment"? It begins with a brief summary of recent environmental problems, focusing mainly on atmospheric pollution. It also considers environmental economics in power generation.

A. Economy and Emissions

China has made progress in tackling energy-related environmental problems since the mid-1990s, yet huge challenges remain in the 21st century. Coal combustion is largely responsible for the two most damaging air pollutants: particulates and sulfur dioxide. Particulate emissions, especially damaging to human health, have declined from earlier peaks, mainly due to greater use of end-of-pipe control equipment. (See Figure 2-1.) Sulfur dioxide emissions have also declined in recent years, but this reduction appears to be linked to the overall drop in coal use rather than adaptation of specific policies or technologies. Other pollutants, such as nitrogen oxides, hydrocarbons, and carbon monoxide will likely become more problematic as the number of vehicles on Chinese roads continues to grow. Finally, China is the world's second largest emitter of carbon dioxide behind the U. S.[1] While per capita emissions remain low, a return to rapid growth in coal use could make China the largest emitter by 2040 or 2050.

Figure 2-1 China's Economy, Energy, and Emissions of Selected Pollutants, 1985-1999



Source: (SSB, 2000), (Sinton, 1996), (Nygard, 2000).

[1] According to data from China Statistical Abstract 2000, CO_2 emissions in 1999 had declined to 725 MtC due to falling coal use. For comparison, U.S. emissions of CO_2 were estimated at 1517 MtC in 1999 (EIA, 2000). It is likely, however, that actual CO_2 emissions in China could be 800 MtC per year or higher due to unreported coal use.

China has paid more attention to addressing local and regional air pollution problems in recent years as social and economic repercussions have grown. Over 30 percent of China's land area is now affected by acid deposition and China's State Environmental Protection Agency estimates that sulfur emissions alone erase nearly 2 percent of GDP by reducing crop productivity, eroding exposed infrastructure, and damaging human health. (SEPA, 1998.)

Poor urban and indoor air quality is widely acknowledged to contribute to a number of pulmonary diseases in China although the causation cannot always be defined precisely. In a 1997 report, the World Bank estimated that nearly 300,000 deaths could be avoided each year if China met its own Class II standards for ambient pollution. (World Bank, 1997.) The same report estimated that environmental damage could have been responsible for roughly $54 billion in economic losses in 1995, or roughly 8 percent of the gross domestic product. Other studies estimate an even higher loss. (Smil, 1997.)

Energy users in China consume a large portion of their coal directly, with minimal or no environmental controls. Many industrial boilers, for example, are small and lack both dust collection systems and sulfur control. These boilers contribute to poor local environmental quality and are responsible for over one-third of all sulfur dioxide emissions in the most degraded areas. (See Table 2-1.) A relatively large percentage of households also still rely on direct coal combustion for cooking and heating, although many municipalities now have fuel-switching programs in place. China has also established successful programs to introduce coal briquetting and efficient stoves in rural areas. Use of coal in residential settings is perhaps most damaging to human health since pollution control equipment is rare and users are in direct and frequent contact with the emissions. Fortunately, the practice of using coal directly in small industrial and residential applications is beginning to change.

Table 2-1 Shares of SO_2 Emissions by Source in China's SO_2 Control Regions, 1998

Source	Percentage of Total Emissions
Utility Boilers	35
Industrial Boilers	34
Industrial Kilns	11
Household Stoves	12
Other	8

Source: SEPA, 1999.

More coal is now used for energy transformation than direct end-use. In 1980, 64 percent of China's coal was used directly by industries and residents. By 1999, however, this trend had completely reversed itself and 64 percent of the nation's coal was used in energy transformation such as generating electric power, creating municipal coal gas, heating, and coking. (Sinton and Fridley, 2000.)

China has enacting new air pollution control strategies and is experimenting with innovative market policies to control acid rain. Acid control regions have been established that limit or prohibit the use of high-sulfur coal and mandate the use of control technologies in some cases. China has also revised its pollution levy system and raised the fees polluters pay when exceeding emission limits. (Wang, 2000.) Whether the new reforms will also result in greater enforcement—a chronic problem—remains to be seen. Finally, China is experimenting with an SO_2 trading program with assistance from the U.S. Environmental Protection Agency. This type of market-based program can dramatically lower the costs of achieving environmental objectives.

The environmental benefits of natural gas over other fossil fuels are clear. Efficient combustion of natural gas emits virtually no sulfur dioxide or particulates. Nitrogen oxide emissions, which contribute to urban smog and other environmental problems, are typically half as much as those from coal combustion, although specific technological measures can affect this ratio greatly. Finally, natural gas combustion emits only 60 percent as much carbon dioxide per unit of energy released as coal. In the power sector, carbon dioxide emissions from gas-fired plants are 40 percent as much as from equivalent coal plants due to the higher efficiency of combined-cycle power plants. (See Table 2-2.)

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

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

a – Assumes 1.2 percent sulfur content in coal.

b – For coal based boilers, assumes fly ash removal efficiency of 99 percent and solid waste of 74 grams/kWh.

Note: TSP = total suspended particulates;

Source: Derived by PNNL.

Industrial boilers, furnaces, and kilns all operate more efficiently and produce less pollution using gas instead of coal. Converting or replacing even a fraction of China's half million coal-fired boilers to use natural gas could dramatically reduce harmful emissions and reduce energy consumption due to the higher efficiencies.[2]

[2] Typical coal boilers in China are 15 percent less efficient than those found in industrialized countries. Large gas boilers operate about 5-10 percent more efficiently than coal units, but smaller units can be 25 percent or more efficient. (BECon, 1995, p.4)

In residential applications, coal-burning stoves and heaters produce dangerous mixtures of particulate, carbon monoxide, and toxic emissions, causing extensive damage to human health. Traditional coal burning stoves have efficiencies of only 10-15 percent, and improved versions only 30 percent. Converting the stoves to use natural gas, as with industrial boilers, would lower harmful emissions and also cut energy consumption due to their higher efficiencies. Typically, the smaller the application, the greater the environmental benefit of switching from coal to gas.

Greater use of natural gas does not come without environmental and safety drawbacks, however. First, at natural gas fields, hydrogen sulfide emissions could pose environmental problems if gas output expands significantly. Leaks from drilling rigs and pipelines are also a concern, not just for safety reasons, but because they contribute to overall methane emissions. Methane has roughly 20 times the climate effect of carbon dioxide. Finally, storage of compressed natural gas could become a public safety issue without proper precautions. As more and more households switch over to natural gas, China may need to develop more rigorous safety measures and standards to prevent accidents.

B. Environmental Impacts of Expanding Gas Utilization

If China champions greater use of natural gas through successful reforms, gas could account for at least 10 percent of the country's energy mix by 2020. Estimates of future fossil fuel use are projected from the year 2000 based on growth rates from individual fuels as given in the Sino-U.S. China Climate Change Country Study (1999) as shown in Table 2-3. These values assume that, unlike the trend beginning in 1997, growth in coal consumption will return to a moderately fast level. If consumption of natural gas reaches 200 billion cubic meters (BCM) by 2020, it would account for about 12 percent of total energy demand. Greater gas use would significantly lower emissions of sulfur and nitrogen oxides, carbon monoxide, particulates, and carbon dioxide by replacing dirtier coal combustion.

Table 2-3 Reported and Projected Fossil Fuel Use in China

Year	Total Primary Energy (MTCE)	Coal (MTCE) (%)	Gas (BCM) (%)	Oil (MT) (%)
1985	767	581 (76)	11 (2)	87 (17)
1990	987	752 (76)	14 (2)	111 (17)
1995	1312	979 (75)	16 (2)	156 (18)
2000	1230	805 (65)	33 (3)	203 (24)
2010	1783	1103 (62)	100 (7)	295 (24)
2020	2273	1345 (59)	200 (12)	367 (24)

Figures in parenthesis are percentage of total commercial energy use. Data for 2000 are estimated based on preliminary information. Forecasts for 2010 and 2020 are derived using growth rates as provided in CCCS (1999).
Source: SSB, 2000.

Fuel switching from coal to natural gas will affect Chinese and global environmental quality depending on where it takes place. Gas has the highest priority use in the residential sector, where coal combustion causes the most health and environmental damage, but a majority of early gas supplies will probably be consumed in the power sector since generators are the best initial target markets.

Table 2-5 shows the reduction in emissions associated with the use of 60 BCM of natural gas (half in power generation with the remainder split evenly between the industrial and residential sectors) in place of coal. This quantity is roughly the difference between a successful gas development program and one that follows a "business as usual" forecast. Table 2-4 provides the efficiency assumptions used in the calculations.

Table 2-4 Efficiency Assumptions Used in the Emissions Calculations (percent)

Sector	Average Gas Efficiency	Average Coal Efficiency
Power	55	37
Industrial	90	80
Residential	50	35

Source: Feng, 1993; BECon, 1995.

The reduction in particulate, sulfur dioxide, and carbon emissions amounts to 1, 2, and 41 million tons, respectively, for each 60 BCM of gas that replaces coal. Over 124 million tons of coal combustion would be avoided and an additional 25 million tons of solid waste would be prevented. These calculations use relatively conservative assumptions so even greater reductions could result.

Table 2-5 Environmental Impact of Using 60 BCM Natural Gas in Place of Coal

Sector	Gas Used in place of coal (BCM)	Coal Displaced (Mt)	SO_2 reduction (kt SO_2)	TSP Reduction (kt)	Solid Waste Reduction (Mt)	CO_2 Reduction (MtC)
Power	30	53.8	862	14	18.8	16.7
Industry	15	31.0	496	465	4.3	8.6
Residential	15	39.4	709	551	2.2	16.1
Total	60	124.2	2,067	1020	25.3	41.4

Note: Coal sulfur content is estimated at 1 percent. Particulate capture is estimated at 99.5, 70, and 30 percent, respectively for power, industry, and residential applications. Coal ash assumed to be 25 percent, except for residential applications where it is 10 percent. Bottom ash assumed to be 80 percent and fly ash 20 percent.

Box 2.1

Expanding Natural Gas Use in Shanghai:
Summary of Pollution Reduction and Health Benefits

The U.S. Environmental Protection Agency has been collaborating with the Shanghai Academy of Environmental Sciences and the Shanghai Medical University to characterize the impacts of greater natural gas use in Shanghai. Studies have focused primarily on the pollution reduction and health benefits associated with switching from coal to natural gas. Analysts used the MARKAL model—a technology based model tailored to the Shanghai economy—to simulate changes in emissions resulting from greater gas use. The emission changes were translated into changes in pollution concentrations within the city. Concentration-response functions were then applied to estimate the health benefits associated with air quality changes.

Modelers first conducted a base case scenario that assumed natural gas use would remain constant through 2020. They then ran scenarios that simulated gas use rising from the current 425 million cubic meters to roughly 10 billion cubic meters per year in 2020 in the high use scenario. The health impacts of this high scenario are summarized in the table below.

Health Benefits of Expanding Natural Gas Use in 2020 (avoided cases)

Premature Deaths	3,680
Chronic Bronchitis	7,454
Acute Bronchitis	278,200

Economic Benefits of Avoided Health Damage in 2020 (million US$)

Premature Deaths	644
Chronic Bronchitis	238

The economic benefits in this study are calculated using a "willingness to pay" methodology. An alternative, based on the human capital approach, is often used in such studies and results in significantly lower values for avoided deaths. While estimating the value of health is controversial, these methodologies are gaining increased acceptance around the globe in establishing environmental policies.

Source: "Benefits of Expanded Use of Natural Gas for Pollutant Reduction and Health Benefits in Shanghai," Preliminary draft, 2001. Chen Changhong, Q. Fu, M. Chen, B. Chen, H. Kan, and C. Green. For more information, please contact Collin Green at collin_green@nrel.gov.

Chinese municipalities like Beijing, Shanghai, and Guangzhou promote the use of natural gas vehicles as a way to improve local environmental conditions. China's rapidly growing transportation sector could account for a significant amount of natural gas consumption over the

coming decades. Currently, the transport sector consumes roughly 500 MCM of natural gas each year, about 2 percent of the country's total gas usage. The environmental benefits of natural gas vehicles over those using traditional petroleum are considerable: gas-fueled vehicles are basically free of sulfides, have 90 percent less carbon monoxide, 70 percent less hydrocarbons, and 40 percent less nitrogen oxides.[3] The speed at which gas consumption grows in this sector will depend on factors such as the cost of retrofit systems, fuel availability, safety perceptions, and reliability of the NGV technology. Development of a market for fuel cell vehicles in China could also impact the development of natural gas infrastructure.

Methane Emissions from Natural Gas Use

Greater use of natural gas will likely lead to more methane emissions. While development of natural gas pipelines will result in less gas flaring in the field, it will lead to more incidental leakage from pipelines, valves, and storage depots. Methane emissions associated with increased natural gas usage will likely offset at least some of the carbon dioxide benefits natural gas enjoys over coal. However, even if China's gas infrastructure suffers losses greater than typical in most countries (2 percent vs. less than 1 percent), increased methane emissions will offset only about one-tenth of the carbon benefit associated with the switch from coal to gas. Fortunately, China will be building most of its natural gas infrastructure from scratch so leakage can be minimized with proper planning and use of modern technologies.

C. Energy and Environmental Economics of Power Generation

Power generation options in China vary greatly according to technology, fuel choice, and location. A simple qualitative chart summarizes components of different costs, including environmental impacts. (See Table 2-6.)

Table 2-6 Electric Power Options in China

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

Notes: Technical costs refer to initial construction costs. Clean Coal refers to integrated gasification combined cycle or pressurized fluidized bed combustion.

Source: Modified from Battelle, 1998, p. 81

[3] Lan, Q. and Paik, K.W., 1997. "China Natural Gas Report," Xinhua News Agency and The Royal Institute of International Affairs, London, p. 50.

A more qualitative comparison between coal and gas-fired plants is also instructive. Figure 2-2 compares the economics of the two types of plants as a function of fuel costs. The diagonal lines indicate where the levelized cost of power from a typical combined-cycle power plant[4] equals that of a coal-fired plant. For a given natural gas price, if coal is more expensive than the value at which the dashed horizontal line touches the vertical axis, then gas-fired power is cheaper. It should be noted that China does not yet have the capacity to manufacture the gas turbines used in modern combined-cycle systems, and would need to rely on imported units until it could produce them domestically.

For example, if natural gas cost $3.50 per gigajoule (RMB 1.1/m^3) or more in a certain region of China, it would only be cheaper to use coal if that fuel cost $37 per ton or less. (See "Standard Pulverized Coal" line). For coal plants using flue gas desulfurization, gas-fired power would be cheaper if the price of coal exceeded $26 per ton. (See "FGD" line) In another example, if an estimate of some of the environmental externalities (the damage to human health, agriculture, and infrastructure that is normally ignored) is included in the cost of power, coal prices would need to be $27 or less further for it to be more economic than gas. In this case, we use estimates of $500 per each ton for sulfur dioxide, nitrogen oxides, and particulates.[5] (See Environmental Externality "EE" line.) Coal is often more expensive than this in many of the heavily populated regions of China.

Developing China's natural gas sector to improve local environmental quality makes sense independent of carbon dioxide mitigation. Greater investment in China's gas sector could result, however, if international negotiations can develop a system for crediting carbon mitigation. China has expressed interest in attracting foreign investment for carbon mitigation. Investors and host countries would need to agree on a way to define baseline emissions and share carbon credits.

Two examples of carbon trading prices are also included in Figure 2-2. For a carbon permit valued at $20 per ton (tC), the break-even point for coal and gas declines from $37 per ton to $29 per ton of coal. (See "$20/ton-C line".) A carbon credit valued at $40 per ton of carbon would lower the break-even point to $18/ton of coal. It should be remembered that these values assume a natural gas price of $3.50 per GJ; clearly, prices in China will vary according to region. Carbon permits in this range would probably be attractive to potential international investors, but other transaction costs within China might also raise the actual price paid. For reference, each $20/ton-C increase in permit prices would increase the price of electricity generation by approximately $0.005 per kilowatt-hour.

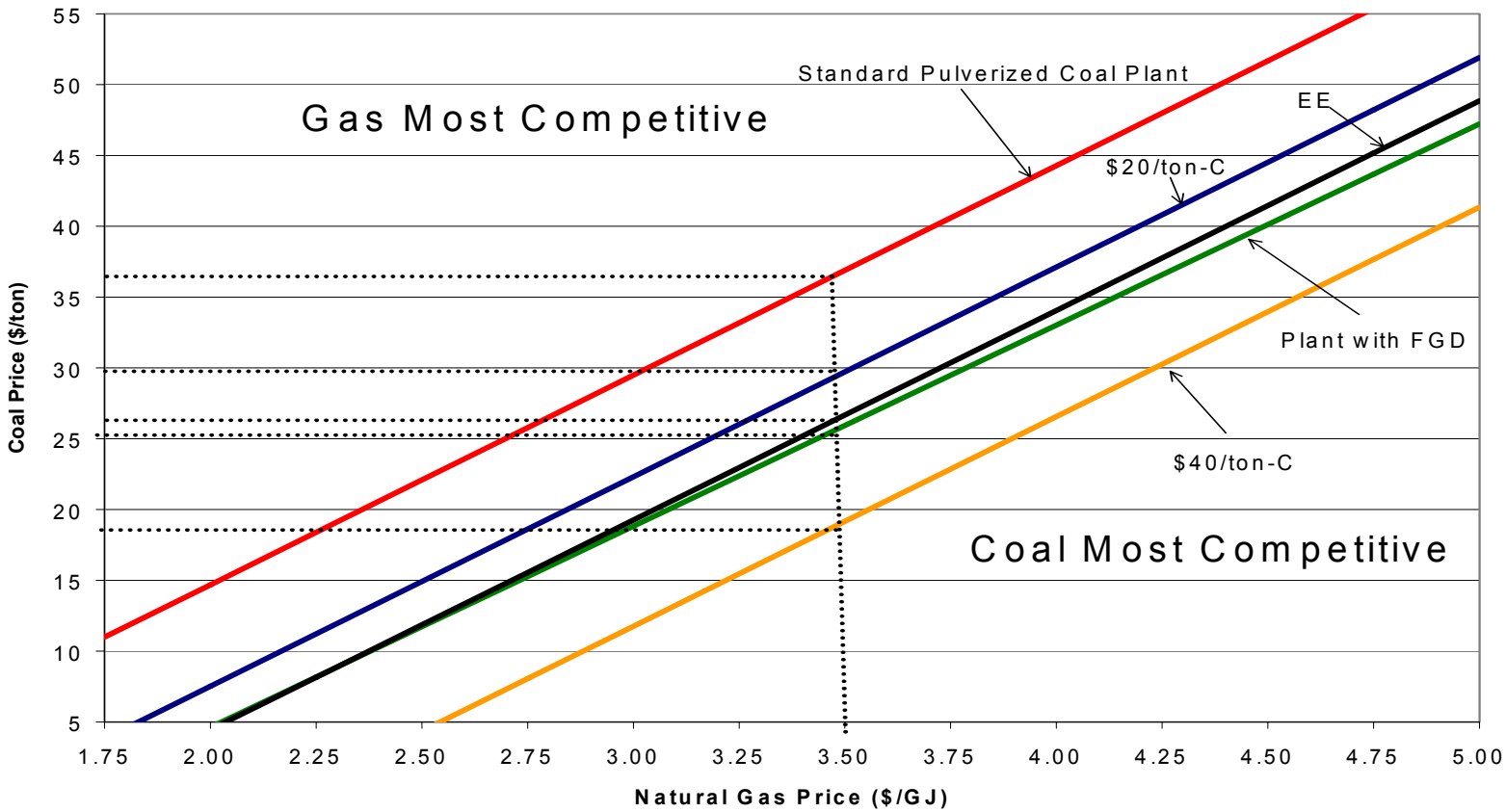
[4] A combined-cycle plant uses both gas and steam turbines to maximize efficiency, while a standard coal plant uses only the latter.

[5] For more information on estimating environmental externalities in China's power sector, see Zhou, et. al. (2000).

Summary of Key Environmental Issues

- Natural gas can dramatically lower emissions of harmful local pollutants when substituted for coal and oil combustion. It can also cut net greenhouse gas emissions significantly, even if methane emissions from leaky pipes increase.
- Natural gas is already economically attractive in regions where coal is expensive. When health and environmental benefits are taken into account, natural gas is often the cheapest form of power generation.
- Stronger safety protocols and regulations are needed to minimize the risk of explosions and leaks as gas use expands.
- Greater enforcement of existing environmental regulations and new approaches can help level the playing field between natural gas and other energy alternatives.
- International investors will be interested in fuel switching projects in China if carbon mitigation becomes a commercial reality.

Figure 2-2 Economics of coal and gas-field power generation in China with other options (1999)



To use this graph: Given a price for natural gas ($3.50/GJ), move vertically to the diagonal line. Then move horizontally to the associated coal price ($37/ton). If the actual price of coal is higher (lower) than this, then natural gas provides power at a lower (higher) levelized cost than coal.

Assumptions: Coal plant has high-efficiency electrostatic precipitators and an efficiency of 37 percent. Combined-cycle gas turbine plant efficiency is 55 percent. Capital costs are $500/kW and $700/kW for gas and coal plants, respectively. Environmental externalities for sulfur dioxide, nitrogen oxide, and particulate emissions are $500 per metric ton each. Note: FGD means flue gas desulfurization or wet scrubbers. EE means environmental externalities. $x/ton-C refers to the net price of a hypothetical carbon permits in China. Other transaction costs could significantly alter these costs.

III. Administering China's Natural Gas System

This section describes recent changes in governing China's natural gas system. These changes include restructuring of both regulatory agencies and the state-owned oil and gas companies. Reform of natural gas pricing, a key issue for both exploration and developing companies and end-users, is also discussed. The authors also consider investment and financing policies governing domestic and foreign companies.

A. Structure and Regulation

Two Chinese government agencies have primary responsibility for guiding the direction of natural gas development: the State Development Planning Commission (SDPC), and the State Economic and Trade Commission (SETC), both under the State Council. The State Council, China's cabinet, supervises the industry and sets high-level goals and standards. The SDPC is responsible for long-term economic planning and development, while the SETC manages more of the project-related standards and responsibility. In practice, the SDPC carries the most responsibility since it formulates exploration and development plans, coordinates efforts among gas organizations, allocates gas among industrial users, and sets prices.

Other organizations that affect China's natural gas sector include the National People's Congress, the State Environmental Protection Agency (SEPA), and the Ministry of Science and Technology (MOST). These organizations play a less direct role than the three mentioned above, although the marginal effect can be powerful in some cases. The National People's Congress—China's legislature—investigates and oversees enforcement of regulations at a high level. As the transition to a market economy progresses, the number of laws and regulations in China are increasing, although enforcement has remained relatively weak. SEPA, and its local and provincial environmental protection bureaus, are responsible for drafting and enforcing regulations on emissions, greater enforcement of which could lead to stronger incentives to use natural gas. MOST helps guide development of technologies such as gas turbines, fuel cells, and gas-to-liquid conversion equipment that could expand markets for natural gas utilization.

In 1998, major reforms were announced in both the structure and regulation of China's oil and gas companies. First, the duties of ownership and regulation in China's two major state-owned oil companies, CNPC and Sinopec, were separated, allowing the companies to focus more on commercial performance, while attempting to eliminate any conflict of interest regarding regulation. The regulatory functions were allocated to bureaus within the SETC. Second, CNPC and Sinopec were reorganized to create two fully integrated companies. (See Text Box 3-1.)

Box 3.1

Recent Restructuring in China's Oil and Gas Sector

China's state-owned oil and gas companies have undergone major structural transformation over the past few years. Two vertically integrated oil and gas firms, both created from state-owned assets, dominate the landscape. Before restructuring, China National Petroleum Corporation (CNPC) had been engaged mainly in oil and gas exploration and production, while China Petroleum Corporation (Sinopec) had been engaged in refining and distribution.

In 1998, the Chinese government ordered an asset swap that transferred some exploration and production assets to Sinopec and some refining and distribution assets to CNPC. This created two regionally focused firms, with CNPC dominating the north and west, and Sinopec the south. A third company, China National Offshore Oil Corporation (CNOOC), retains control over the majority of offshore oil and gas production. A fourth state-owned oil and gas company, China National Star Petroleum Corporation, enjoyed a brief period of independence between January 1997 and November 1999, when it was acquired by Sinopec. In 1996, China United Coalbed Methane Corporation (CUCBMC) was founded and given exclusive responsibility for the independent and cooperative exploration, development and production of coalbed methane. All foreign investment in coalbed methane development must be in cooperation with CUCBMC.

The intention of the restructuring was to make these state firms more like vertically integrated corporate entities elsewhere. In connection with this process, the firms have been spinning off or eliminating many unprofitable ancillary activities like housing, health care, and education. Massive layoffs also have been undertaken, some as part of the companies' initial public offerings. These measures are intended to cut losses at state owned enterprises and prepare them for limited competition when China enters the World Trade Organization (WTO).

Source: Modified from "China Country Analysis Brief," Energy Information Administration, U.S. Department of Energy, 2001.

Legal development in China's oil and gas industry has been slow and generally lagged events. Unlike the electric power sector, there is no Natural Gas (or Petroleum) Law to help guide development of the industry. Furthermore, China does not have a clear and transparent policy framework that prioritizes development objectives.

The SDPC is responsible for creation and implementation of China's natural gas policy, although many other organizations play a role in reviewing the proposals. No single document fully details China's natural gas policy, leading some to claim that China, in effect, has no inclusive policy. Instead of a comprehensive document on natural gas policy, a number of other sources comprise the policy including laws passed by the NPC, regulations issued by the State Council, speeches given by ministers or members of the State Council, policy statements issued by the SDPC or other commissions, and regulations or policy documents issued by local government.

Clearer communication of China's natural gas policy and demarcation of lines of authority would benefit development of the overall gas system. In particular, communication of policies relating to natural gas use is lacking and conflicts between state agencies over authority are widespread. These problems create uncertainties for companies that create extra risk because huge investments are required to develop infrastructure. Without a transparent policy that prioritizes objectives and sets standards for achieving them, companies cannot maximize efficiency.

Some encouraging signs have appeared recently, however, especially for foreign investors. Foreign companies can now participate in most aspects of China's natural gas sector, at least on paper. They can now invest in and operate pipelines and distribution networks for the first time. China has also given some foreign investors greater opportunity to invest in pipeline and distribution networks over the past few years, although there is uncertainty over the extent of this new policy. Some foreign companies have also been invited to bid on onshore exploration and development activities, but the practice is not widespread.

Reform in the state-owned enterprise sector is also making Chinese energy companies more efficient. Reforms have promoted consolidation among small state-owned companies during the late 1990s. (See Table 3-1.) Consolidation allows these companies to achieve greater efficiency and access to capital. Specific data on consolidation within the natural gas sector are not yet available, although it seems likely that these companies are under similar pressure to improve performance by achieving greater economies of scale. More non-state and private companies are also emerging to play a role in gas marketing and distribution.

Table 3-1 Number of State-Owned Enterprises in China

	1995	1996	1997	1998
Small	569,069	554,876	510,417	141,672
Medium	16,591	16,862	16,751	15,850
Large	6416	7052	7199	7558

Source: China Statistical Yearbook, 1996-99.

Chinese gas transport and distribution companies will need to become more efficient if the relatively large gap between low wellhead prices and high end-use charges is to narrow. In many urban areas, for example, natural gas is priced at 0.65 yuan per cubic meter (about $2 per gigajoule), but end users pay nearly three times this amount due to fees and surcharges added by municipalities and gas transport companies. Part of this is due to the early stage of development of the sector and part to high costs of doing business in China. Many urban distribution and retailing companies will have to shed excess employees and institute stronger management to cut costs.

B. Price Management of Natural Gas

Industry observers have long claimed that low prices for natural gas have slowed development of China's natural gas system. Low prices give exploration and development companies little incentive to find and develop new resources. Ironically, while wellhead prices are generally low, prices paid by end users for new gas projects are high due to the relatively steep processing, transportation and distribution charges.

Administration of natural gas pricing is changing, at least in some markets. The SDPC and provincial pricing bureaus still have control over gas pricing, but some producers can now sell a portion of their gas at prices above the plan. Furthermore, new gas projects are now allowed to use "cost-plus" pricing to ensure a reasonable profit. Getting the price right for natural gas is critical: low prices offer little incentives for producers to find and develop new fields while high prices slow the creation of a market for gas by discouraging use. Decades of cheap coal have created a market of price-sensitive energy consumers in most regions of China.

Low gas prices have been a serious and long-term obstacle to the expansion of China's gas sector, but average prices have increased recently. Since the 1980s, there have been at least 10 adjustments to the price of natural gas allocated by the state. However, the price is still low compared to other energy options. Typical wellhead prices of 0.65 yuan per cubic meter are not high enough to encourage greater exploration and account for the environmental advantages of gas.

Sichuan is experimenting with a two-track pricing system wherein producers can sell a portion of the gas over their quota at prices above the plan price. Only about 10 percent of their total production can be sold at the higher price, and the "market" price is limited to within a narrow range of the plan price. (CERA, 2000.) While China also experimented with two-track pricing before finally freeing prices for other commodities in the 1980s and 1990s, it is unclear how quickly and how far the gas price decontrol will go.

Price control is linked to gas allocation, with most reserved for fertilizer production and oil field use. The government allocates gas at low prices to the fertilizer industry in order to offer subsidized fertilizer to hundreds of millions of farmers. However, with stronger moves to a market economy, some planners are beginning to question how the economy can make the most efficient use of natural gas. Importing cheaper fertilizer might allow the government to remove subsidies for gas and use the savings on other programs. Still, in mid-July of 2001, the Chinese government announced that natural gas prices would remain under state control even after China joined the WTO.

The U.S. has useful experience in regulating natural gas prices as outlined in Text Box 3-2, although it may be difficult to apply these lessons in the Chinese context since the two countries have fundamental differences.

Box 3-2 **Lessons from the U.S. Natural Gas Regulatory History**

Differences between the social and economic systems of China and the U.S. traditionally leave little room for comparison between the two countries. However, efficient gas transport is of particular concern to both countries because long distances separate production and consumption points in both markets. More importantly, the past experiences of the U.S. in applying the right level of regulation can provide valuable lessons as China begins to develop a natural gas transport network.

Regulatory agencies in the U.S. began controlling various aspects of natural gas transport in the 1940s, but by the 1970s shortages were common due to excessive regulation of wellhead prices. The effect of the regulations was both to deter producers from supplying the interstate market and to raise consumer demand. The government eventually recognized the inefficiencies of such over-regulation and reversed course by following a deregulation path beginning in the late 1970s. The changes introduced competitive forces to the production and supply markets as producers were granted open access to pipelines and local markets while transporters were allowed to collect open access tariffs. A further deregulatory step was to liberalize entry into gas marketing. The significance of efficient marketing is that supply and demand needs are better matched, lowering transaction costs. Furthermore, aggregation of contracts diversifies and minimizes supply and price risks.

The key lesson from the U.S. experience is that competition in each sector of the natural gas market and coordination between them increases pipeline operation efficiency. A second important point is that wholesale price liberalization increases participation in all sectors of the natural gas industry. The benefits of competition and allowing natural gas prices to reflect economic costs accrue to all industry participants. Ultimately, consumers benefit from lower real prices and increased service options.

Further liberalizations of the U.S. natural gas market that took place through the 1990s may also serve as models for China over the long run. For example, the establishment of spot markets has facilitated continuous natural gas trade at market prices. The creation of a financial gas market where futures and options contracts are traded mitigated the risk of price volatility in the spot market. Most recently, the U.S. market has enhanced its efficiency by linking marketers to all regional gas and electricity markets through an electronic trading system. Despite these advances, natural gas prices surged in late 1999 to early 2001 due to unusually cold weather, high demand, and temporarily distorted markets.

Source: Modified from Juris, Andrej. "Development of Competitive Natural Gas Markets in the United States," World

C. Investment and Financing Issues

Chinese companies and municipalities will need to raise tens of billions of dollars over the coming decades if they are to construct needed natural gas infrastructure. While domestic and foreign loans once accounted for the majority of such capital, new financing channels are appearing with China's transition to a market economy. Bonds, stockmarket offerings, and creative foreign direct investment schemes are now able to mobilize large sources of capital and will likely grow further in importance as reforms progress.

1. Financing Channels

Internal sources account for approximately 70 percent of all capital used in China's natural gas sector, with domestic loans making up most of the remainder. It goes without saying that sources of finance in China's gas sector are constrained, especially in the upstream sector, but new opportunities are appearing.

Internal Capital

Internally generated capital is convenient for Chinese companies. There is less concern over the problem of repayment so asset-liability ratios remain stable and set a good basis for further financing. It has particular disadvantages, however, in that it is unstable and prone to fairly sharp fluctuations.

International and Domestic Loans

In 1984, the government changed the budgetary appropriations for the petroleum and natural gas industry from grants into ordinary loans. Since then, China's natural gas industry began employing international and domestic loans supplied by banks, foreign governments, and global financing organizations. Over the past few years, availability of subsidized loans has become much more constrained due to ongoing reforms in the banking sector. Advantages of domestic bank loans include relative low cost, quick turn around time, and flexibility. A disadvantage, however, is that capital is often scarce for Chinese entities.

The number of overseas commercial banks entering the Chinese market is growing, especially with China's planned WTO accession. Enterprises that are transparent, efficient, and profitable will have advantages in seeking international commercial bank loans for natural gas development projects. International commercial banks have stricter lending requirements than domestic banks.

International Export Credit

When constructing natural gas pipelines and importing equipment from abroad, Chinese enterprises may opt for international export credit. Interest rates for export credit are generally lower than market interest rates and have longer payback periods. Sovereign guarantees— difficult or impossible to obtain in China— are often required as a way to ensure repayment of the loans.

Financing Through the Market

Chinese state-owned enterprises have issued shares on domestic and international stock markets since the early 1990s. Only in the past few years, however, have they begun to raise considerable sums of money on both. The run-up to listing on domestic and especially international markets requires enterprises to at least give the appearance of being efficient, transparent, and modern organizations. In reality, firms are rarely as they may appear on paper, but stock market listings have forced many Chinese enterprises to cut staff, adopt stricter accounting standards, and introduce new management methods. While these measures may be onerous, many enterprises have been able to raise significant sources of capital listing shares on stock markets.

During the 1990s, the proportion of government budgetary investment registered a steady decline. According to figures from CNPC, government allocations to exploration and development in 1997 and 1998 accounted for only 0.8 and 0.9 percent, respectively, far below the 6.4 and 8.8 percent the government invested in basic construction over the same years.

In 1999, CNPC began to restructure in order to raise capital on international stock markets. In April of 2000, PetroChina Company Ltd. (a subsidiary of CNPC) issued stock on the Hong Kong and New York markets, successfully raising $3.3 billion. Over 17.5 billion shares were offered accounting for 10 percent of PetroChina's value. Sinopec also succeeded in raising approximately $3.5 billion in its international initial public offering in November 2000. Most recently, in February 2001, CNOOC raised over $1.25 billion using a similar strategy. The apparent successes of PetroChina, Sinopec, and CNOOC offerings indicate the potential of this kind of financing.

Project Financing

Project finance is growing in importance around the world and China is no exception. The petroleum and natural gas field uses project financing frequently because of the large scale of most projects and their high up-front costs. Few enterprises possess the ability to finance such project independently so resources are often pooled.

Foreign Direct Investment

In global terms, foreign direct investment accounts for a very small portion of total investment in Chinese natural gas companies. Advantages of foreign direct investment for Chinese firms include access to financial capital, advanced technology, and management skills. Drawbacks include sometimes-difficult negotiations with foreign partners over how the investment will be operationalized and how the foreign investor will be compensated.

After CNOOC came into existence in 1982, the exploration and development of offshore oil and natural gas fields opened to foreign enterprises and began attracting foreign investment on a relatively larger scale. By the end of 1997, there were 132 petroleum and natural gas contracts or

agreements signed by CNOOC with 68 enterprises in 18 countries. Direct investment reached US$5.72 billion, accounting for over 56 percent of the total offshore exploration and development investment.

After 1985, the onshore sector also began to open to foreign oil and gas companies. The Chinese government encourages oil and gas enterprises to make use of foreign funds through a variety of methods, but only recently has capital begun to flow.

2. Preferential Policies for Foreign Companies and Joint Ventures

Since reform and opening in the late 1970s, China's petroleum and natural gas industry has made some progress in attracting foreign investment. However, the amount of funds put to use has been small. Compared with the petroleum industry, the amount of foreign capital used in the natural gas sector is very small. Foreign funds used in China's natural gas industry have focused mainly on offshore exploration and development, while mid- and downstream activities have been prohibited until recently. Onshore investments have also increased, but only for a few companies.

China has established several preferential policies for foreign gas companies, but many of these have only marginal benefit since the system is not fully open to foreign investment.

Preferential Policies for Foreign Companies and Joint Ventures

In 1994, the Chinese government created tax advantages for foreign companies engaged in oil and natural gas exploration and development, either alone or with Chinese partners. Only 10 of the current 18 taxes are imposed and preferences and special treatments on some of the taxes are provided. Foreign investors should note that Chinese joint venture partners also enjoy the benefits of tax relief, at least for the time being.

Value Added Tax - The value added tax rate on the exploration and development joint ventures for foreign companies is 5 percent. Domestic enterprises pay 17 percent for oil and 13 percent for gas.

Mineral Reserve Compensatory Tax - If oil and gas exploration and development joint ventures or foreign companies have paid mining royalties, they do not need to pay the mineral reserve compensatory tax.

Income Tax - The income tax rate is generally 33 percent while the preferential rate is 15 percent.

Other Preferential Policies - Tariffs, value added levies, and consumption duties normally applied to imported equipment for joint ventures or foreign companies engaged in exploration and development of natural gas are exempted.

Preferential Policies Concerning Coalbed Methane Development - For coalbed methane exploration and development joint ventures, the value added levy rate is 5 percent. Imported equipment and materials are exempted from tariffs and levies. The price of CBM is not controlled by the government, and can fluctuate according to market conditions.

Policies Related to the West-East Gas Transportation Pipeline Project – The Chinese government has stated that it encourages foreign investment in all aspects of the West-East gas pipeline project. Foreign companies can invest not only in exploration and development of upstream natural gas resources, but also in the construction of the pipeline, urban gas grids, and gas-consuming projects. This is the first time foreign investment in many of these areas has been allowed.

Urban gas grids will play a key role in the West-East Gas Pipeline Project. In order to speed up the construction and transformation of urban natural gas grids, the Chinese Government now permits foreign cooperation in the building of urban gas grids in cities along the pipeline.

Different forms of foreign cooperation in the project can be used. Both Chinese-foreign equity joint ventures and contractual joint ventures can be set up. In addition, foreign investors can also take dominant shares of stocks in the joint venture. The most appropriate form of cooperation, satisfying both foreign investors and their Chinese partners, will be selected through mutual negotiation.

3. Encouraging Greater Foreign Investment

Foreign gas companies could play a much larger role in China's gas development, especially in exploration and development of quality onshore gas reserves. Many have been encouraged by recent changes in the natural gas sector. In particular, they applaud the decision to allow greater investment in activities associated with the West-East pipeline project and the Guangdong LNG terminal.

Most potential foreign investors still perceive significant barriers in China's gas sector, however. The following results were drawn from an informal survey in early 2001 sent to multinational companies, primarily those headquartered in the U.S. These perceptions are widely shared by most potential foreign investors. The survey was conducted without attribution to any company.

For companies focused on upstream and pipeline development activities, the top barriers were noted as:

- Transparency is not conducive to investment,
- Only poor quality or risky exploration and development parcels are offered,
- Lack of natural gas infrastructure inhibits investment,
- Government approval for projects is difficult to obtain,
- Market demand for gas is low due to the perception that it is expensive for end-users,

- Low wellhead prices fixed by the state discourage upstream investment,
- Gas is not allocated according to market demand, and
- Environmental regulations are not enforced

For companies oriented toward downstream activities, the top perceived barriers were:

- Perception that gas is expensive for end-users
- Difficulties in project finance
- Environmental regulations are not sufficient or enforced
- Lack of infrastructure
- Low prices for upstream developers
- Transparency is not conducive
- State champion is needed to coordinate policy

Overcoming these barriers could significantly increase foreign investment in China's natural gas sector. Expanded investment from foreign companies would not only help finance exploration, development, and infrastructure construction, but also open the door to the advanced technologies and management skills needed for Chinese companies to become world class.

Summary of Key Administrative and Policy Issues

- Chinese policymakers have taken positive steps to boost development of the natural gas system. Measures include construction of new transportation and distribution infrastructure, plans for China's first LNG import terminal, and a number of measures to make state-owned oil and gas companies more commercially oriented. Stockmarket listings have been a particularly effective way of raising capital for natural gas activities, although efficiency and transparency will need to improve if this mechanism is to be sustainable.
- More transparent communication of key policies in the natural gas sector would aid both Chinese and foreign companies. Publication of a National Gas Law that outlines goals and priorities could help.
- Lines of authority are often confusing and result in uncoordinated government policy that slows development of gas projects.
- Boosting the amount of gas sold at market prices would encourage exploration and development, but efforts should be made to reduce prices paid by end-users. Ongoing market reforms should improve the efficiency of distribution and retailing companies, helping them cut costs.
- The current structure of allocating "old" gas to specific industries may not be the most efficient use of limited natural gas supplies. Chinese researchers are debating the use of onshore gas reserves for fertilizer production versus importing the fertilizer directly.
- Economic reforms aimed at commercializing state-owned oil companies have improved their ability to attract finance and investment. However, more needs to be done to improve rule of law and transparency. The degree to which China enforces contracts,

particularly take or pay provisions, will greatly impact the risk associated with future investment.

- China could rapidly increase foreign investment if it addressed perceived barriers in: transparency, gas pricing and allocation, environmental enforcement, and offering quality exploration parcels to foreign companies.

IV. Upstream - Natural Gas Supply Issues

This section considers developments and trends in China's natural gas supply. Domestic resources as well as imported liquefied natural gas and international pipeline gas are considered. The amount of gas lying within China's borders will affect how quickly infrastructure is built and decisions about importing natural gas. Estimates of natural gas reserves are provided below, but these should be considered preliminary since there have been few incentives, until recently, to find and develop natural gas resources.

A. Domestic Resources

China's total natural gas resources are estimated at just over 38 trillion cubic meters (TCM), accounting for about 9 percent of the currently know world resources.[6] Nearly 80 percent of these resources are located onshore, with the rest lying below the oceans surrounding China's extensive shoreline. Based on known geological conditions and the present level of technology in China, the ultimate proven geologic reserves of natural gas are roughly 13 TCM, one-third of the total resources.

Oil and gas assessments in China include only conventional natural gas resources. Unconventional gas, such as coalbed methane, water-soluble gas, and methane clathrates (hydrates), are excluded. Coalbed methane and water-soluble gas are both abundant in China, while hydrates are still poorly understood. Based on recent forecasts, coalbed methane resources located up to 2000 meters below the surface total 32 TCM. Water-soluble gas is potentially even more abundant, although economically recoverable resources are not well defined.

Economical recoverable reserves are, by nature, dynamic. Developments in technology, geological theory, energy policy, and economic conditions continuously influence the scope of exploitable reserves. In recent years, the level of economically recoverable reserves has been increasing. Furthermore, the price of natural gas plays a vital role in determining the amount that can be exploited economically. As prices rise, more gas fields can be rationally developed. Current economically recoverable reserves are approximately 2.1 TCM. How much economically exploitable gas lies within China's borders is hotly debated and a more accurate estimate may not be known until the full chain of incentives is in place. Despite the obstacles, proven reserves have increased dramatically over the past five years.

China can be divided into five regions to account for the country's unique geotectonic and economic characteristics. Approximately 80 percent of China's know resources are located in the central, western, and offshore regions. (See Table 4-1.)

[6] One trillion cubic meters of natural gas contains roughly 38 exajoules of energy, equal to the total commercial energy consumption in China during the late 1990s.

Table 4-1 China's Natural Gas Resource by Region

Region	Geological Reserves (TCM)	Proportion (%)
Eastern	4.36	11.5
Western	10.74	28.2
Central	11.52	30.3
Southern	3.28	8.6
Offshore	8.14	21.4
National	38.04	100

Eastern: Harbin, Jinan, Liaoning, Shandong, Shanghai, Jiangsu, Zhejiang, Fujian, Guangdong. *Western*: Xinjiang, Qinghai, Ningxia, Tibet, Gansu. *Central*: Hebei, Henan, Inner Mongolia, Shaanxi, Shanxi, Hubei, Sichuan, Anhui. *Southern*: Guangxi, Jiangxi, Hunan, Yunnan.

Most of China's known natural gas resources appear to be highly concentrated in certain regions. Among the 150 basins and regions with assessed natural gas resources, 13 of them contain natural gas resources amounting to 33.8 TCM, accounting for nearly 90 percent of the nation's total. (See Table 4-2 and Map.)

Table 4-2 China's Natural Gas Resources by Basin

Basin	Location	Geological Reserves (BCM)	Proportion (%)
Songliao	Heilongjiang	987	2.6
Bohai Bay	East of Beijing, offshore	2118	5.5
Tarim	Xinjiang	8390	21.9
Jungar	Northwest Xinjiang	1229	3.2
Qaidam	Qinghai	900	2.4
Turpan-Hami	Xinjiang	365	1.2
Ordos[7]	Juncture of Shaanxi, Ningxia and Gansu	4180	11.0
Sichuan	Sichuan	7358	19.4
Middle Yangtze Offshore	North of Shangai	651	1.7
East China Sea	East of Shanghai	2480	6.5
Qiongdongnan	Offshore Hainan	1625	4.2
Yinggehai	Offshore Hainan	2239	5.9
Pearl River Mouth	Southeastern Guangdong	1299	3.4
Subtotal		33821	88.9

Note: Subtotal may not equal sum of parts due to round-off.

Source: China Natural Gas Report, Xinhua News Agency and Royal Institute for International Affairs, 1998.

Distribution of onshore natural gas resources in China is often inversely proportional to economic development. The eastern region, which has a large population and prosperous

[7] This field is also commonly referred to as Shaan-Gan-Ning since it straddles the three provinces of Shaanxi, Gansu, and Ningxia. The Changqing gas field, which supplies natural gas to Beijing, is located in this field.

economy, has less than one-fifth of the nation's natural gas resources. Most of the central and western regions that hold rich natural gas resources are characterized by sparse population and undeveloped economies. Many of the remaining natural gas resources are distributed in regions with remote, rugged, or harsh environments.

The majority of China's natural gas resources are difficult to develop. Ranked by geology, just over 40 percent of China's onshore natural gas resources (12.5 TCM) are defined as Type 1, meaning they are relatively superior. Type 2 resources, designated with a lower degree of realization, total nearly 30 percent (8.6 TCM), while the remaining 30 percent (8.8 TCM) are located in regions with a low degree of realization.

In addition, approximately one-third of China's onshore natural gas resources are buried in stratum between 3500 and 4500 meters, while one-quarter is buried deeper than 4500 meters. Half of this deeply imbedded gas is characterized by geology with low or very low permeation.

Despite the imbalanced resource distribution and difficult geology associated with China's natural gas, there are reasons to be optimistic that significant new sources can be found and developed. In the second round of China's oil and gas assessment, only just over half of the country's sedimentary rock areas were assessed. These 150 basins or regions totaled 3.42 million square kilometers, leaving 48 percent of the sedimentary rock areas unexplored. These largely unknown regions have a great resource potential and are currently unvalued.

Sichuan and Ordos together account for half of the national gas-field gas proven reserves. Those in the Tarim Basin are increasing quickly from the current proportion of 8 percent while the Eastern region holds 70 percent of the proven reserves of soluble gas.

Sichuan: Geological surveys and exploration work has been conducted on a large scale in Sichuan since 1953. Sichuan basin is the main productive area of gas-field gas, and is home to China's largest industrial base reliant on pipeline gas. By the end of 1998, Sichuan had proven reserves of 555 BCM and annual production of 7.5 BCM, accounting for about one-third of the national total.

Ordos basin: Since the implement of the "develop oil and gas together" policy of the 1990s, significant breakthroughs have been made in the natural gas development, including verification of the largest gas fields during the 1990s—Changqing and Sulige. Ordos had geologic reserves of 313 BCM, of which recoverable reserves were 179 BCM, and annual production capacity of over 2 BCM. However, due to lack of demand, most gas wells in Changqing were not in continuous operation compared with their productive capacity during the late 1990s. Sulige was only recently discovered, but is thought to have recoverable reserves of similar size to Changqing.

Eastern region: Current production efforts in this region are focused heavily on soluble gas associated with oil production. Songliao and Bohai Bay basins are China's major production zones for petroleum, but output of soluble gas is expected to continue playing an important role in the near future. In 1997, the output of Daqing (in Songliao basin) was over 2.3 BCM while that from Liaohe (in Bohai Bay) was almost 1.6 BCM. Additional efforts are being made to develop gas-field gas in this region as well.

Western region: The current level of natural gas development in the Western region is relatively low, but this area is slated for unusual attention over the coming years. Oil production has developed fairly rapidly in some parts of the Western region and the output of soluble gas is just over 2 BCM annually, the majority of which is consumed in industry. By the end of April 1999, total proven reserves in the Tarim basin had reached 568 BCM, making it the largest gas field in China, providing the West-East pipeline project with significant energy potential.

Offshore: Natural gas exploitation has grown quickly in this area. In the Qiong-Ying basin, the construction of gas transporting pipelines from the Yacheng 13-1 gas field to Hainan and Hong Kong was completed in the 1990s and the pipelines are operating successfully. Also offshore, a new natural gas pipeline from the East China Sea to Shanghai recently started to deliver gas. In the Bohai Bay basin, the Jinzhou 20-2 gas field has entered full development, and the joint-development of other fields in the eastern, central and southern parts of the Bohai Sea are now getting under way.

Coalbed Methane Resources

China has abundant resources of coalbed methane (CBM) and is taking an active interest in its development. The Chinese government attaches high importance to CBM development, and has included CBM in the 10th Five-Year Plan for energy development. The United States, where CBM accounts for nearly 6 percent of natural gas output, sets a strong example for how this energy source could play a more important role in China.

According to 1996 figures, CBM resources buried no deeper than 2000 meters underground total approximately 32-35 TCM, close to the figure of conventional natural gas resources. China's CBM resources account for 25 percent of the world's total supply. Estimates show CBM resources shallower than 1000 meters total 11 TCM. However, assessing the prominence of CBM resources is based on coal resources and gas contents in coal seams, giving no consideration of the special requirement of exploration technology. In this case, how much and in what situation the resources can be developed among the estimated total is not well known.

CBM resources buried shallower than 2000 meters are primarily distributed in the northern, northwestern and southern regions. The northeastern region has the smallest share at less than 8 percent. (See Table 4-4.) The CBM resources with superior geological conditions and development prospects are mainly distributed in the central and eastern regions, whereas

conventional natural gas resources are relatively poor in these areas. This complementary structure is beneficial for overall development of China's natural gas industry.

Table 4-4 Distribution of China Coalbed Methane Resources Less than 2 Kilometers Deep

Region	Northeast	North	Northwest	South	Total
Resource (TCM)	2.48	20.13	5.06	4.97	32.64
Percentage (%)	7.6	61.7	15.5	15.2	100

The Qinshui basin and Hedong coal fields, situated in Shanxi province of the northern region, are abundant in CBM resources. The two sites contain one-sixth and nearly one-tenth, respectively, of the national total, setting a firm foundation for the development of a large scale and further production and consumption.

Recovery and use of CBM in China has a history of more than 50 years, but the quantity of the methane recovered to date has been small. By the end of 2000, 184 underground gas drainage systems were established in China's mining areas, and total national methane recovery reached 840 million cubic meters. Surface CBM recovery technology has been tested in China since the early 1990s and by the end of 2000, over 200 surface wells had been drilled, 30 of which had achieved commercial production.

China began utilizing CBM since the end of the 1970s. By 2000, there were a total of 60 CBM utilization projects, with a total consumption of roughly 500 million cubic meters.

Rapid progress has also been made in international cooperation on CBM development. China United Coalbed Methane Co., Ltd. signed 11 production sharing contracts with foreign companies between 1998 and 2001. Of the 11 blocks under joint exploration by Chinese and foreign companies, total resources are estimated at 2 trillion cubic meters over an area of 20,000 square kilometers.

Qinshui and Hedong in Shanxi province may be the most favorable CBM basins in China. Qinshui has probable resources of 5.5 TCM, and its predicted production scale could exceed 3 BCM annually. Hedong basin has resources of 2 TCM with a production capacity that could reach 2 BCM.

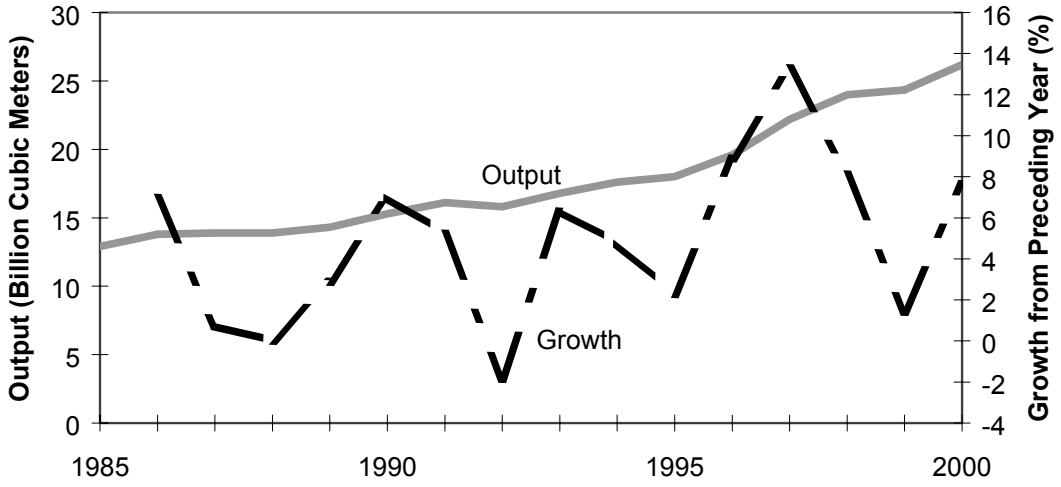
Forecasts of annual output of CBM were recently updated and expanded. By 2010, China United Coal Bed Methane Company expects to produce 10 BCM, a challenging, but achievable goal. By 2020, the estimate climbs to 15 BCM.

Natural Gas Output and Forecast

Natural gas output has grown steadily over the past 5 decades. China produced a mere 10 million cubic meters (MCM) in 1949 but had boosted output to 10 BCM by 1979. By 2000, China was

producing over 26 BCM of natural gas each year. (See Figure 4-1.) During the 1990s, natural gas output grew by 4.7 percent annually.

Figure 4-1 Output and Growth of Natural Gas in China



Source: China Statistical Yearbook 2000.

In spite of the steady growth in natural gas output, China still uses far less gas than most countries. Currently, gas output in China accounts for roughly 1 percent of the world total. Given China's large population, per capita consumption is even lower. The average per capital consumption of natural gas throughout the world is about 405 cubic meters, while the value in China is a mere 18 cubic meters.

Forecasting the output of natural gas in China is difficult due to rapid changes in economic, energy, and environmental policy, and development of new technology. Nonetheless, it seems likely that China's natural gas output can reach 110 BCM by 2020 given continuous improvements in exploration and development efforts. This level of production would require annual growth of approximately 7 percent, and would be supplemented by imported gas as well. The authors believe that output could be even higher given the proper incentives. Table 4-5 proves a breakdown of sources for possible future domestic gas output.

Table 4-5 Estimation of China's Natural Gas Output (Billion Cubic Meters)

Time	Natural Gas		Coalbed Gas	Total
	Gas-Field Gas	Soluble Gas		
2010	62	9	10	81
2020	85	10	15	110

Upstream Technology Assessment

Development of China's natural gas sector has been restricted by a variety of barriers. Most gas fields in China discovered before 1990 were small, offering little justification for development and pipeline construction. Exploration had focused primarily on limited regions identified as having abundant natural gas reserves. Conflicting authority and distorted management created inefficiencies. Use of outdated technologies has also prevented the gas system from developing as quickly as it could have. The current state of Chinese upstream technologies is assessed below.

During the 1990s, petroleum and natural gas technologies have improved dramatically resulting in cheaper, more efficient prospecting, development, drilling, and engineering. New theories and technology development, particular in cross-cutting interdisciplinary subjects, have expanded production of petroleum and natural gas throughout the world. Developments in China's natural gas industry have also progressed, but the general level of technology lags that in industrialized countries.

Exploration Technologies

Technologies used for exploration of petroleum and natural gas fall into four main categories: seismic imaging, logging, drilling, and testing.

Seismic Survey Technology

Through introduction and adoption of advanced foreign technologies, Chinese petroleum and natural gas enterprises have made progress with three-dimensional seismic imaging. This technology allows explorers to create more accurate and efficient maps of underground resources, and can suggest smarter drilling options. China can now domestically mass produce 480 channel seismographs. China imports advanced software to operate more complex seismographs. Technologies to better understand oil pool geophysics are being utilized and developed, but on the whole there is a considerable gap between the Chinese and foreign technology.

Logging Technology

To improve the economic benefits of prospecting and developing gas fields, Chinese petroleum and natural gas enterprises are importing technology related to digital control of well logs. Domestic development of image well-logging technology is an area of great interest for researchers as it is currently considered a weak link in gas exploration activity.

In terms of interpreting and processing well log data, Chinese researchers believe their technologies are more or less on par with those from abroad, but some key techniques need further development. Perforation technology is close to the international level, but lateral core technology is lagging.

Drilling Technology
Chinese companies have developed mid to long-radius horizontal well drilling technology, but the scale of use is still very small. Small bore, horizontal, and large displacement well drilling technologies are being developed and utilized. Technologies related to branch wells, geologic orienting tools, unbalanced pressure drilling, and continuous soft pipe drilling are also under development, but lag further behind. Under study are other technologies to deal with more complicated geological conditions using deep wells. While domestic drilling rigs have improved quickly, they are still relatively backwards. Many technologies remain to be mastered and would benefit from foreign assistance. In short, Chinese drilling technology lags by 5 to 10 years the advanced international level.

Testing Technology
Chinese well testing technologies are also relatively unsophisticated compared to those used in industrialized countries. In particular, the following testing technologies need to be further developed: high-pressure, high temperature deep wells; high-pressure gas layers; and horizontal wells.

Development of Oil and Natural Gas Fields
The status of technologies China uses to develop oil and gas resources are as follows:

Water Injection Technology
China's petroleum and natural gas industry has fully mastered this technique, especially in complex layering of water injection and integrative dynamic testing technologies. However, technologies related to unstable water injection are more backwards than in advanced foreign countries.

Technologies for Developing Low Penetrating Oil Pools
Chinese research on pressure injection drawing technology covers a wide range of topics and is generally well developed. Delicate water injection filtering and layering technologies are utilized successfully. At present, horizontal fracturing and related horizontal well technologies are in the stage of research and development. Because of limited availability of natural gas resources and certain geologic conditions, there has been little development of gas injection technologies.

Gas Pool Development Technologies
Technologies for developing gas pools and condensed gas pool circulating injection are now in use in China. Developing gas drainage technology is developing rapidly. Technologies for developing coalbed methane are under study and generally lag foreign levels.

Technologies to Simulate Gas Pools
China is a world leader in developing technologies to study alternating oil, shale and water layers. The ability to accurately describe gas pools is also excellent. However, the ability to

handle data provided by seismic and well logging is insufficient. Software to perform three dimensional imaging and integrated analysis is also relatively backwards.

Data Simulation Techniques
Development of most modeling software is close to international standards, but large-scale software innovation is acknowledged to be weak. China recently imported 10 parallel computers that have a speed of between 2 and 5 billion operations per second.

Natural Gas Treatment and Processing
Natural gas processing in China focuses mainly on treating natural gas liquids. Well-top three-phase separators are the most important type of equipment followed by low-temperature throttling gear. Natural gas treatment principally focuses on light hydrocarbon extraction. China imports most of the equipment to do so including low-temperature expanders.

Treatment of natural gas is focused mainly on controlling acidity and sulfur. China has successfully developed energy-efficient selective absorption techniques to remove sulfur from natural gas. China imports other sulfur recovery and dewatering technologies.

B. Import Potential of Natural Gas

Through mid 2001, China had not yet begun to import natural gas. Plans were accelerating, however, to build cross border pipelines and LNG import terminals. Discussions are underway on at least three international natural gas pipelines into China, with a capacity to import at least 50 BCM of natural gas. LNG import terminals with a capacity to import 10 BCM by 2010 and 20 BCM by 2020 are also in the planning phase.

There are several key advantages to importing natural gas. As mentioned in Section 2, imported natural gas can supplement domestic resources to improve environmental quality, balance the energy structure, balance energy supply and demand, assure energy supply security, and ease transportation bottlenecks. Additionally, imported gas could be cheaper than domestically-developed resources in some instances and thereby help improve economic performance.

Pipeline Natural Gas Import Potential
Western Siberia currently has Russia's most abundant natural gas resources with reserves amounting to 40 TCM, or nearly one-third of the residual exploitable storage in the world. It is a stable platform basin over 3.2 million square kilometers in area. Eight huge gas-fields each containing more than 1 TCM of reserves have been found already. Plentiful resources and high output per well make it an ideal reservoir of natural gas. Eight large gauge gas pipelines have been constructed to date, five to Europe, and three domestically within Russia.

China is studying options for transporting natural gas from Western Siberia to China's east coast. One gas source for a pipeline from Western Siberia to Shanghai might be the huge Zapolyarnoye gas field. The gas field was found in 1965 and has recoverable reserves of 2.6 TCM. The field could likely supply China with 30 BCM of natural gas annually for at least 25 years.

The eastern continental shelf of Russia's Sakhalin Island also has abundant natural gas resources that could be exported to China. Proven reserves total approximately 1.4 TCM. China is studying the possibility of constructing a 2400-kilometer long gas pipeline from Sakhalin to Northeast China. Over one-third of the pipeline would be within Russian territory. After reaching Harbin in Heilongjiang province, the pipeline would likely divide into two, with one traveling west to Daqing, China's aging petroleum base, and the other south to Shenyang, provincial capital of Liaoning province. The capacity of this line would likely be 10 BCM per year.

In East Siberia there is a smaller and older region of natural gas with districts containing proven reserves of 1 TCM each or more. East Siberia has three big oil and gas districts: Yakutia, Irkutsk, and Krasnoyarsk. The primarily proven reserve and available production capacity are shown in Table 4-6.

Table 4-6 Natural Gas Exploration and Development Prospects of East Siberia

Districts	Proven Reserves (BCM)	Capacity per Year (BCM)
Yakute	5000	150
Yerkucik	5410 (exploitable)	42-110
Klasnoyarksk	10000	200
Total	20410	392-460

Source: University of Petroleum-Beijing.

The speed at which these pipelines develop will depend, most importantly, on the ability to create a bilateral or multilateral accord for construction and operation of the pipeline. Related issues include 1) the ability to create stable markets for gas demand, 2) the amount of proven domestic reserves identified and the cost of bringing the gas to market, and 3) changes in imported LNG costs.

LNG Import Potential

Liquefying natural gas by lowering its temperature under pressure is one option for transporting methane when gas pipelines are impractical or too expensive. A typical rule of thumb is that liquefying natural gas is cheaper when the transport distance overland surpasses 5,000 kilometers, or offshore 1,000 kilometers. Clearly, specific local conditions will have an impact on the final cost-benefit analysis.

China is a huge country with heterogeneous population distribution and complex geography. Huge sums of money will be needed to build a unifying gas pipe network over the entire country.

LNG imports can help overcome this problem by making gas available where it is needed most without long-distance pipelines. Natural gas is in large demand on China's southeast coast, while demand for this market using offshore natural gas resources surpasses known supply. Coastal shipping to this region of China is relatively easy, so LNG imports could supplement the piped natural gas that becomes available.

The cost of importing LNG to southeastern China can be estimated based on similar costs to Korea and Japan. With much lower labor costs, China could enjoy a significantly lower final cost. Technical and economic analysis by Chinese and international researchers has shown the feasibility of importing LNG to this region.[8]

LNG Supply Options

The number of LNG exporting nations has increased significantly during the late 1990s. By the end of 2000, there were 12 LNG production and export countries. (See Table 4-7.) Indonesia was the biggest producer and exporter of LNG and accounted for just over one-quarter of the world's total trade. Egypt, Iran, and Yemen are expected to become LNG exporters in the near future. Most LNG supply contracts are structured for the long-term due to the large scale of investment and the need to satisfy lenders. The Asian financial crisis of the late 1990s led to a temporary oversupply of LNG and raised opportunities for shorter-term contracts.

Table 4-7 Worldwide LNG Trade in 2000 (Billion Cubic Meters)

Importer / Exporter	US	Western Europe	Japan	South Korea	Taiwan	Apparent Export
US			1.7			1.7
Trinidad & Tobago	2.7	0.8				3.5
Algeria	1.3	25.1				26.4
Libya		0.8				0.8
Nigeria	0.6	5.0				5.6
Oman	0.2	0.1	0.1	2.2		2.6
Qatar	1.3	0.5	7.9	4.4		14.1
United Arab Emirates		0.3	6.3	0.3		6.9
Australia	0.2		9.8	0.1		10.1
Brunei			7.7	1.1		8.8
Indonesia			24.3	8.4	3.1	35.8
Malaysia		0.2	14.8	3.3	2.8	21.1
Total Imports	6.3	32.8	72.6	19.8	5.9	137.0

Source: BP Statistical Review of World Energy 2001. Note: Round off may result in conflicting summations.

[8] See, for example, "China's Electric Power Options: An Analsysis of Economic and Environmental Costs," by Battelle Memorial Institute.

Proposals for LNG Import Terminals

China has laid out solid plans for at least one LNG terminal in the Pearl River Delta of Shenzhen, near the Hong Kong Special Administrative Region. The terminal is slated to begin operations in 2005 with an initial 3 million tons of capacity per year. The port will include facilities to handle both offshore natural gas from the South China Sea and imported LNG. The two types of resources will be provided to gas-burning, combined-cycle power plants and to municipal customers in cities along the Zhujiang Delta. Two million tons of the capacity is slated for the power plants having a capacity of 2.6 GW, with the remainder going to residential and industrial consumers. In early 2001, China furthered plans to build the country's first LNG import terminal in Guangdong and chose a foreign partner for the project.

After gaining experience operating the terminal, China plans to expand the capacity of this terminal and build others to match market demand. Likely places for other LNG import terminals outside of Guangdong include Xiamen, Zhejiang, and Shanghai. China will carefully plan and execute its LNG import program because of the high risk involved. Difficulties in raising capital, competition between LNG and pipeline gas, price stability, and supply security are all factors that will influence the magnitude and pace of importing LNG.

Summary of Key Upstream Issues

- China has considerably more gas than once thought. Recent discoveries in Inner Mongolia and Xinjiang have muted concerns about supply sources for the West-East natural gas pipeline. High development costs, however, remain an issue.
- China's first LNG import terminal project in Guangdong is moving ahead. While planners will proceed cautiously with this project, others could soon follow if project objectives are met.
- Studies are also underway to import gas from Russia and Kazakhstan, although progress has been slow due to complexity and risk.
- New opportunities for on-shore foreign investment have been realized, but could expand rapidly given Chinese priority.
- Chinese upstream technology is not as advanced as that used in most industrialized countries. The gas sector would benefit from using a greater combination of advanced technology and management, perhaps through specialized gas service companies.

V. Midstream Issues – Transporting and Storing Natural Gas

The decision to build the West-East transmission pipeline is probably the single most important development in China's natural gas sector to date. International experience indicates that large-scale development of natural gas can only begin after the construction of transmission pipelines, distribution networks, and underground gas storage facilities. This section considers these key issues.

Present Situation and Problems

China's gas pipeline infrastructure is at an early stage of development and there is a long way to go to establish a comprehensive gas grid across the country. Gas pipelines have recently been constructed from offshore Hainan to Hong Kong using a sub-sea system, from Shanxi to Beijing using a modern pipeline system, and from offshore to Shanghai using a short sub-sea system. For China, these three pipelines are the start of a policy aimed at introducing advanced international pipeline technologies across the country. To complement renovation of the pipeline network in Sichuan province, China also plans to build a pipeline from Chongqing to Wuhan beginning in 2002. A second pipeline from the Ordos basin is also in the planning phase to supply additional gas to Beijing. Currently, all other pipelines in China are short-range, small-diameter pipelines.
The existing problems regarding China's gas pipelines are described below.

Unbalanced Distribution & Formless System

The Sichuan and Chongqing gas fields account for 40 percent of the country's trunk pipelines, extending 1500 kilometers and forming a circular gas network around the basin. Other pipelines wind mostly through the northeast and northcentral region. By comparison, in the west, among the future production areas, there are only four short pipelines in place: Shanshan—Urumqi, Tazhong—Lunnan, Cainan—Karamay and Sebei—Golmud. In contrast to the rich reserves of the west, the delivery capacity is extremely limited. Except for Sichuan province, producers send their output to designated end-users on an as-available basis.

Ageing Pipelines and Antiquated Technology

Most existing pipelines in China were built in the 1960s and 1970s. These pipelines have outlasted their design life, and now require high maintenance levels. As a result, costs are high. The World Bank has been leading a project since 1994 to renovate Sichuan's aging pipeline system.

Poor Storage Facilities

Most end-users receive gas from a single source. Moreover, there are no storage facilities to control peak demand. This causes a dilemma. First, pipeline capacity cannot be fully utilized because of the fluctuation of consumption among individual users. Second, maintenance and small diameter pipelines influence the stability of supply.

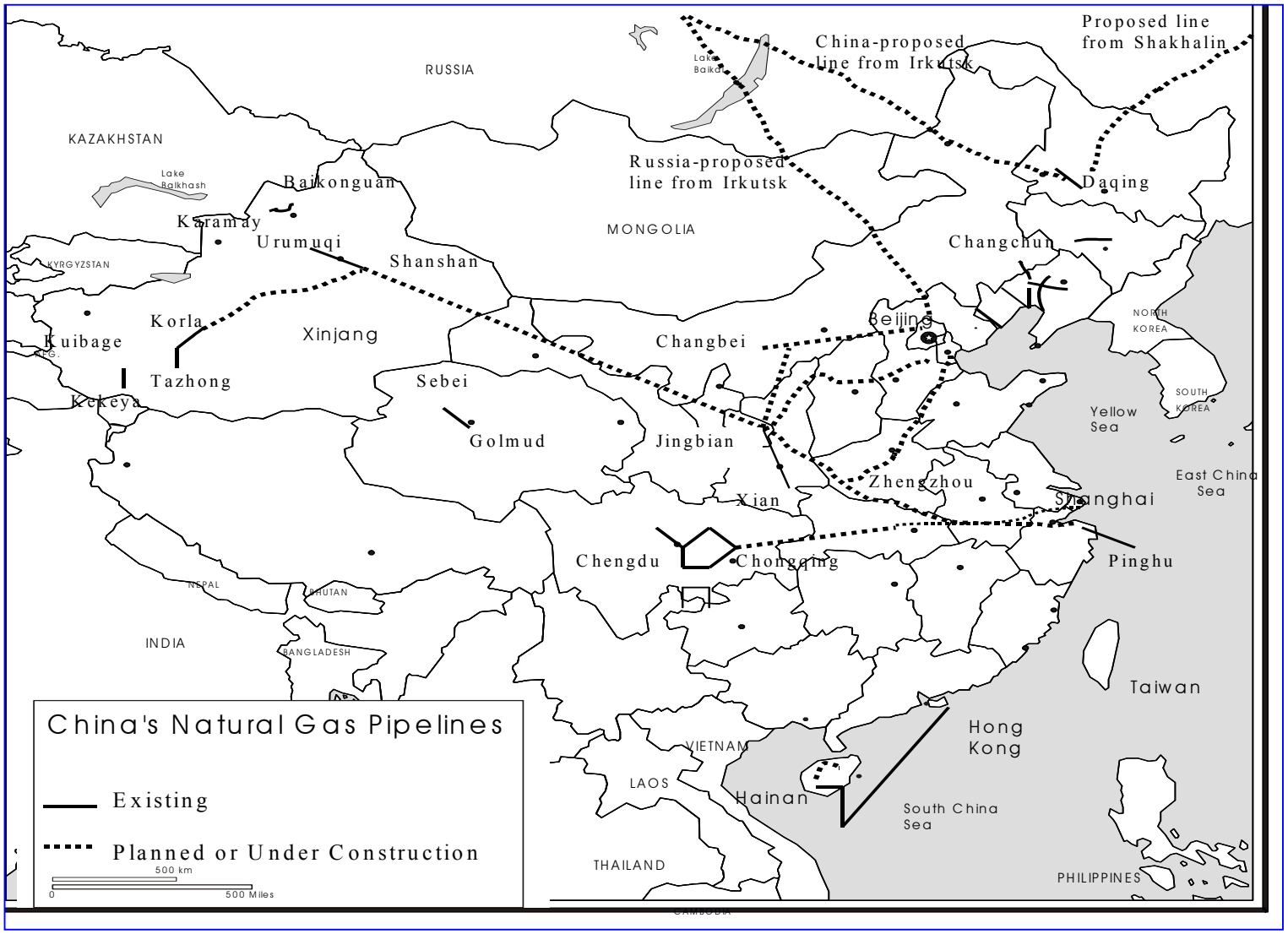


Figure 5-1 Exiting and planned pipelines in China

A. Proposed Gas Pipeline Projects

Since the 1990s, China has increased its natural gas output, and made progress in the construction of gas pipelines. In recent years, several natural gas pipelines have been built, including ones from Jingbian (Shaanxi province) to Beijing and Xian, from Yincuan (South China Sea) to Hong Kong, and from the Pinghu (East China Sea) to Shanghai. Other pipeline projects are on the drawing board to send gas from Sichuan to Wuhan and from Xinjiang to Shanghai.

At the present time, many provinces and cities are making plans to use natural gas, indicating that China's natural gas industry could develop rapidly if appropriate policies are enacted. But with most gas resources concentrated in western China and consumption areas in the eastern region, massive transport of gas would be required. The West-East Natural Gas Pipeline Project is slated to help address this imbalance.

West-East Natural Gas Pipeline Project

The West-East Gas Pipeline will be constructed section by section and put into operation phase by phase, based on gas resources and market conditions. There are two main sections to the pipeline:

East Section—This initial phase of the pipeline project will join supplies in Changqing gas field (near Jingbian, Shaanaxi province) with users in Shanghai.

West Section—This section of the pipeline will deliver gas from the Tarim Basin (Xinjiang) to the beginning of the eastern section in Shaanxi.

The pre-feasibility study and the feasibility study for the pipeline were completed in 2000. The State Development Planning Commission (SDPC) is currently in the process of designing projects to create demand for the natural gas. In early 2001, PetroChina had signed letters of intent to supply 33 firms with natural gas, including 20 urban gas projects, nine gas-fired power generation projects, two industrial fuel projects, and four chemical fuel projects.[9] Construction on the US$4.8 billion, 4,200 km pipeline is scheduled to begin in early 2002. The first gas would reach Shanghai in 2003 and the pipeline would also supply the provinces of Henan, Jiangsu, Zhejiang and Anhui.

In 2002, construction of the pipeline section from Tarim to Jingbian will commence. In 2003, the pipeline section from Jingbian to Shanghai will be completed, allowing up to 2 BCM of natural gas to be sent from the Changqing gas field to Shanghai and Hangzhou. (See Figure 5-2.) The trunk pipeline will be completed in 2004 when it will be available to send natural gas from Tarim

[9] "PetroChina Signs Up First Customers for Natural Gas Project," *China Online*, March 8, 2001.

to the Yangtze River Delta. By 2005, the annual capacity of the gas supply pipeline will reach 12 BCM.

Figure 5-2 View and Schedule for Construction of the West-East Pipeline

Preliminary plans envision the pipeline starting in Lunnan of the Tarim Basin, and passing through, from west to east, Xinjiang, Gansu, Ningxia, Shaanxi, Shanxi, Henan, Anhui, Jiangsu and ending in Shanghai. The trunk pipeline will cross large rivers like the Yangtze River and the Yellow River six times and medium-sized rivers over 500 times. Major highways will be crossed over 500 times and trunk railways 46 times. The pipeline will pass through 2500 kilometers that have seismic intensity of VI or below, 800 kilometers with an intensity of VII, and 700 kilometers with intensity of VIII.

Prediction of Benefits

Preliminary analysis envisions an 8 to 10 year period for recovery of the 40 billion RMB investment, with a rate of return of 12 percent. Chinese calculations indicate that the pipeline will become profitable after reaching a transmission volume of 8.5 BCM. The project has attempted to minimize risk with a 12.5 BCM capacity. Key to success of the project will be developing end-use markets for the gas. Planners learned an important lesson in building the first natural gas pipeline to Beijing when demand failed to materialize as planned. (See Text Box 5-1.)

Box 5-1 Experience with the Changqing-Beijing Pipeline Project

The Jingbian-Beijing pipeline provides key lessons in how institutional and market-based constraints can slow development of natural gas projects. The 853 km pipeline linking gas supplies in the Ordos Basin with customers in Beijing and Tianjin began transporting gas in 1997. However, average throughput remained far below design capacity until late 2000. Difficulties in meeting the project's capacity were largely due to institutional factors, notably the conflicting interests between the pipeline's lead operator, CNPC/PetroChina, and its municipal off-taker, the Beijing city government.

Gas development in China occurs against an unusual backdrop of competing interests. First, the usual assortment of planning authorities, environmental agencies, large employers, city governments, and state-dominated energy enterprises each pushes projects according to its own vision. Adding to this complexity are the uniquely Chinese structural problems that result in diluted central authority. Governmental agencies are responsible to the vertical hierarchy within which they lie, but loyal to the provincial, county, or local government whom they officially represent. Chinese energy firms also remain beholden to both cadre and shareholder as they struggle to adopt to recent structural reforms. The Chinese system under which the gas industry develops is long on overlapping jurisdictions, and short on clear, centralized authority to push projects through.

Jingbian held unique appeal to each of the main participants. Beijing municipality sought to improve local air quality and hoped to benefit from central funds that the project could attract. China's state planning agencies sought a "framework" project for gas development and a test-case for new gas pricing practices. CNPC's ambitions drove an interest in long-distance pipelines to eastern gas markets. Thus, support for the pipeline grew during the early 1990s such that State Council approval came early in 1994 and the project received "key status" in the 9th Five-Year Plan.

In this environment, CNPC and the Beijing government created a joint-venture pipeline operations company with central government support. CNPC took a 60 percent ownership share in the $500 million pipeline and signed a "take-or-pay" supply contract—one of China's first—with Beijing's municipal gas utility. CNPC accelerated its field development and pipeline construction, completing the pipeline ahead of schedule. Beijing meanwhile began the process of building new distribution lines and converting existing ones in preparation for initial deliveries scheduled for 1997.

According to the original terms of the agreement, the Jingbian project would have brought 3 BCM of natural gas to Beijing after a standard ramp-up period. In fact, deliveries started nearly three months late and began far below contracted volumes. Ramp-up was unexpectedly slow due to low field output and problems with onsite desulfurization units. By September 1998, one year after commissioning, throughput in the pipeline had reached approximately 300 MCM per year and by the end of the second year, grown to an annual average of just 590 MCM.

(Continued on following page)

Jingbian Pipeline Experience, Continued

In Beijing, meanwhile, a few industrial customers were ready to convert to natural gas, but the majority was reluctant to shift from coal and oil. Residential demand was also slow to materialize as grid development ran into major delays and cost overruns. Environmental regulations designed to promote the use of gas were only gradually enforced and watered down. Beijing municipality was not able to fulfill its contracted off-take, and abrogated the "take-or-pay" provisions of the contract on grounds that payment requirements were unreasonable.

Eventually, CNPC arranged a series of dispute resolution meetings with the central-level authorities to hammer out a solution. The central government increased its disbursement of funds to Beijing, pipeline tariffs were renegotiated downward, and a new schedule of off-take buildup was arranged. In late 2000—over three years after first flows—the pipeline was finally approaching its originally planned throughput.

The legacy of Jingbian is clear in the minds of Chinese energy companies: downstream market development must be implemented before or simultaneous with upstream development. Further, signing large consumers to take-or-pay contracts is difficult. Fortunately, government planners and regulators have been persuaded that these are key issues. Municipalities also learned important lessons about the time and cost required to build gas distribution infrastructure. While this experience should benefit future development of China's gas markets, some localities may be destined to "relearn" the lessons if central authority remains weak.

Source: Cambridge Energy Research Associates, Beijing.

China is researching the possibility of importing natural gas from Russia. In addition to the pipelines mentioned in Section 4, China may also import gas via Russia's Irkutsk region to the northeastern cities and the Bohai Sea region. China currently prefers that the pipeline not travel through the third nation of Mongolia. Other pipeline options include bringing gas to China from Sakahlin or from Kazakhstan.

Most transnational pipeline projects are too large and complex for any single financier to handle. Multilateral cooperation is therefore required. The project can often be divided into a number of subprojects, with each builder bearing a predetermined amount of risk. Bolivia and Brazil overcame some challenging obstacles in developing a recent pipeline between their two countries. (See Text Box 5-2.)

Box 5-2 The Brazil—Bolivia Natural Gas Pipeline Case

The recently completed Brazil-Bolivia natural gas transport project demonstrates how the two countries secured funds to finance the initial costs and committed themselves to establish competitive markets for gas. Bolivia was endowed with excess natural gas supply while neighboring Brazil had growing energy demand and a lack of natural gas resources. However, the cost of constructing the pipeline could not be borne entirely by the respective countries' public sectors. The dominant state hydrocarbon fuel monopolies—Brazil's Petrobras and Bolivia's Yacimientos Petroliferos Fiscales Bolivianos (YPFB)—thus worked together to seek financing from the private sector and multilateral lending agencies.

Petrobras formed a transport consortium with British Gas, Tenneco (now El Paso Energy), and Broken Hill Proprietary to establish shared equity in exchange for partial access to downstream markets with market-based pricing policies. Bolivia's YPFB formed a similar private sector transport project between Shell, Enron, and Bolivian pension funds. Still, country and regulatory risk as well as uncertainty about the extent of natural gas supply in Bolivia deterred early stage lenders.

The World Bank recognized the importance of the increased competition and privatization of each country's hydrocarbon sectors as well as the barriers to financial resources. In December 1997, the World Bank evaluated the economic viability and environmental impacts of the projects and agreed to lend $130 million to the Brazilian pipeline and to provide the transport consortium with a $180 million credit guarantee. Ultimately, the project would be 40 percent World Bank senior debt financed, 40 percent financed through bilateral lending to Petrobras, and 20 percent equity financed. The Bolivian government was unwilling to make sovereign guarantees for loans and only 20% of the necessary capital was available through private equity. Petrobras overcame this financial vacuum by financing a fixed portion of the Bolivian pipeline in exchange for waiver of future transport tariffs and pre-purchasing a portion of the upstream capacities.

It is worth noting that Petrobras recognized its potential reward from satisfying Brazil's growing energy demand and that the projects' limiting factor was initial investment. As a result, Petrobras decided it was necessary and practical to take on the bulk of the risk in both the Brazilian and Bolivian pipelines. Petrobras assumed risk related to uncertainty over the viability of natural gas demand as well as creation of a natural gas distribution network in an economy and fuel infrastructure so far dominated by high-sulfur oil. Specifically, Petrobras was made contractually obligated to pay for transportation services and accepted construction risk in both projects. At the same time, The World Bank included conditions for the Brazilian government to prevent long-term dominance by Petrobras in the country's hydrocarbon sector. The phasing out of fuel price subsidies, deregulation of petroleum product prices, and implementation of distance-based transport tariffs were required.

Source: Modified from Law, P. and N. de Franco. 1998. "International Gas Trade—The Bolivia-Brazil Gas Pipeline," Public Policy for the Private Sector Note No. 144, Washington, DC: World Bank.

B. Distribution Networks

Many municipalities are also currently planning the construction of new natural gas distribution infrastructure or expansion of existing coalgas (town gas) networks. Some large cities already have limited pipelines in place to distribute town gas and only relatively minor modifications might be needed to convert them to use natural gas. Most, however, will need to build their distribution network largely from scratch. In both cases, storage and dispatch facilities will be required. Enormous amounts of capital would be required to develop these municipal distribution networks if natural gas is to become a significant source of energy among urban Chinese residents. Municipal bonds, infrastructure company stock offerings, and foreign investment are likely to be the main sources of funding to build these networks.

Municipalities would also need to develop their human resources to efficiently manage urban distribution networks. Few cities have the market-oriented expertise in regulation, technology management, and financial analysis needed to construct and administer efficient, safe distribution networks. Regulations on natural gas safety are critical and will need to be strictly enforced. The authors believe that international cooperation on capacity building in this regard is probably the single most feasible option to pursue and offers the highest likelihood of success. (See Section 8 for more information.)

Despite the decentralization witnessed in most sectors of China's governance and economy, strong central government authority may be needed to ensure development of distribution infrastructure. Some municipalities and large towns attempt to raise revenue by adding fees and taxes on utility services such as electric power and may try to do the same with natural gas. This could result in stunted market demand. Proposed amendments to China's Pricing Law whereby any proposed changes in utility prices must be accompanied by public hearings could help improve transparency and minimize excessive fees.[10]

Summary of Key Midstream Issues

- Construction of the West-East pipeline is widely considered the most important step taken so far to expand China's gas sector.

- Foreign investment is now allowed in both transportation and distribution networks, although there is some uncertainty about which regions and projects are open.

- Creating distribution networks within cities will be key to getting the greatest environmental and health benefits from gas. Downstream market development must be implemented before or simultaneous with pipeline construction.

[10] "SDPC Orders Monopoly Industries to Hold Hearings When Setting Prices," *China Online*, July 19, 2001.

- Developing human resource skills to plan, construct, and maintain efficient and safe distribution networks is critical. International cooperation on training in this regard is a priority.

VI. Downstream – Building Natural Gas Markets

This section explores issues related to end-use consumption of natural gas. Building market demand for natural gas is likely to be the single most important hurdle to overcome in developing China's natural gas industry. Decades of cheap coal have created the perception among some end-users that natural gas is an expensive luxury fuel. More can be done to level the playing field between different energy sources and encourage demand for natural gas.

A. Consumption

Gas consumption in China has been constrained by such things as limited supply, a fairly rigid allocation system, and absence of a national pipeline grid. Natural gas consumption as a percentage of total energy use, which had accounted for 2 percent or less of the nation's commercial energy demand for many years, recently increased due to falling coal use. In 2000, gas consumption rose to approximately 3.1 percent of total commercial consumption, still far below the world average of 25-30 percent.

Consumption Areas

Without a national gas pipeline network, gas is largely consumed where it is produced. Only in recent years with development of Shanganning and South China Sea gas fields, have the long-distance transmission pipelines began delivering gas to Beijing and Hong Kong. Table 6-1 shows China's gas consumption by regions.

Table 6-1 China's National Gas Consumption by Region (BCM)

Year	Yangtse River Basin	Northeast	Pearl River Delta	Southwest	Northwest	Total
1991	3.4	4.1	0	6.7	0.7	14.9
1992	3.5	4.1	0	6.5	0.8	15.0
1994	3.7	4.6	0	7.4	1.1	16.8
1996	3.1	4.4	0.3	8.0	1.3	17.1
1997	3.7	4.4	3.6	8.3	1.3	21.3
1998						20.5
1999*						22
2000*						25

* estimated.

In China, the State Development Planning Commission allocates gas output directly to large consumers and to provincial planning commissions each year for redistribution to local users. The largest consumers are fertilizer production facilities. Other users are those in petroleum fields and in the residential sector. (See Table 6-2.)

Over 38 percent of all natural gas is used as a feedstock for fertilizer production. Gas used in petroleum production in the field accounts for over 25 percent of consumption, so the actual

volume of natural gas available for sale is quite limited. Residential gas use accounts for only about 10 percent of the total. From a health perspective, it is probably most important to expand use of natural gas as a substitute for coal in this sector since indoor air pollution from coal combustion is very dangerous.

Table 6-2 China's Natural Gas Consumption by Sector (%)

Time	Industry	Transportation	Commercial	Residential	Others
1997	86.80	0.50	0.94	10.70	1.06
1998	84.40	3.10	0.80	10.90	0.80

Very little methane, only about 13 percent of the total, was allocated toward power generation in 1998. Coal, hydro, natural gas, and nuclear resources are used to produce 76, 18, 4 and 1 percent, respectively, of China's power generation. It is worth noting that the gas loss rate in recent years stands stood at 8 to 10 percent. Most of the gas—produced during oil extraction—is flared, particularly during summer months. As more pipelines are constructed, this wasteful practice should diminish.

The number of gas-fueled vehicles in Chinese cities is also growing rapidly. Municipalities like Beijing now have a considerable share of public transportation fleets dedicated to natural gas use. Twelve cities were named as demonstration sites to experiment with natural gas vehicles (NGV) and liquid petroleum gas vehicles (LPGV). Ford Motor Company expects development of NGVs as shown in Table 6-3. In addition, local legislations (such as in Beijing, Shanghai and Sichuan) have also established additional policies in support of NGVs.

Table 6-3 Estimates of Natural Gas Vehicles in the Transportation Sector

City/Province	Number of Natural Gas Vehicles		Number of Refueling Stations		Note
	2000	2010	2000	2010	
Beijing	3,000	100,000	40	500	All buses to convert to CNG by 2001
Chongqing	10,000	90,000	66	450	
Sichuan	20,000	100,000	70	300	
Shanghai	500	50,000	32	300	5400 buses in operation by 2005
Xi'an	1,000	20,000	15	100	
Urumuqi	1,000	5,000	5	20	
Changchun	1,000	10,000	11	40	
Tianjin	2,000	40,000	15	300	
Hainan	5,000	35,000	25	100	
Total	43,500	450,000	299	2110	

Source: Personal Communication, Ford Motor Company, 11 June 2001.

For the past decade, major NGV effort has been focused on the conversion of diesel-driven public buses to natural gas buses in order to greatly reduce vehicle emissions in major urban areas. In Beijing, all buses will be forced to run on compressed natural gas (CNG) by the end of 2001, and all taxis and other fleet vehicles will run on CNG in the next two years. In Shanghai, all taxis will be converted to NGVs before 2005. Within the next ten years, diesel-driven buses will be phased out and most taxis will run on CNG in all large cities in China. While almost all NGVs in China are converted from gasoline or diesel driven vehicles, many manufacturers have now started to offer CNG passenger cars in the China market.

B. Estimating Future Demand

This section presents forecasts of natural gas demand in power generation, chemical production, industrial uses, and residential applications. It does not include upstream uses such as in petroleum production.

The coming decade is a critical period for China. It will try to fully realize strategic development goals by improving performance of state-owned enterprises, maintaining high levels of employment, and establishing a social security network. The national economy is expected to continue growing rapidly, by a nominal 7 to 8 percent until 2010. Rapid growth will likely result in greater demand for primary energy, although not necessarily in a one to one ratio. In the case of natural gas, if demand grows by 7-8 percent annually, China will need from 100 to 120 BCM a year by 2010. Meanwhile, the share of gas in the primary energy mix would be pushed up to 8 or 9 percent.

According to Chinese market surveys, natural gas usage will primarily be focused in power generation, followed by the chemical industry as feedstock, the industrial sector as fuel, and residential sector as a cooking and heating source. End-users are likely to be located in northeast China, near the Bohai Sea, along the Yangtse River Delta, and along the southeast coastal provinces. The following surveys provide estimates of future demand in several sectors, but should be viewed with caution since true “markets” for natural gas do not yet exist in China. More important than these estimates is the policy framework the Chinese government chooses to enact it will affect costs and, ultimately, prices paid by end-users.

Demand for Natural Gas in Power Generation

The power sector can help to anchor new markets for natural gas, which in turn can help to drive construction of natural gas pipelines. While the power sector does not have the highest environmental priority for fuel switching, it is the easiest way to ensure strong demand that developers need before investing large resources into exploration and infrastructure. The power sector can thus build markets for natural gas infrastructure development, which can later have positive impacts on residential and small industrial applications where greater environmental

benefits can be achieved.

Eastern China is the region where gas will most likely be used to generate power. Currently, only Hong Kong and a number of oil fields possess gas-fuelled power stations, although several are under construction. A total of 3.7 BCM of gas was used for power generation in 1997. It should be noted that this value is limited by available supply, and not the actual demand. If 10 percent of the estimated new power generation by 2010 is met with natural gas, approximately 27 BCM of gas would be required. Table 6-4 lists the details.

Table 6-4 East China Demand for Natural Gas in 2010 (BCM)

Regions		Power	Chemical	Industry	Residential
Yangtse River Delta	Shanghai	4.5	1.5	0.3	1.5
	Jiangsu	4.0	/	0.67	1.0
	Zhejiang	7.2	/	0.98	0.84
	Subtotal	15.7	1.5	1.95	3.34
Bohai Sea Region	Beijing	/	–	0.7	0.65
	Tianjing	/	–	3.93	0.58
	Hebei	3.0	1.2	/	0.55
	Shangdong	2.7	2.74	2.7	0.80
	Subtotal	5.7	3.94	7.33	2.58
Northeast China	Heilongjiang	0.8	1.77	3.44	0.72
	Jilin	1.8	2.19	1.8	0.89
	Liaoning	3.1	1.07	2.27	1.31
	Subtotal	5.7	5.03	7.51	2.92
Total		27.0	10.47	16.79	8.84

Source: University of Petroleum-Beijing.

In southeastern coastal areas an additional 16.3 BCM of natural gas could be needed for power generation by 2010. Approximately two-thirds of this will be used in the Zhujiang Delta area.

If China's power sector is to serve as an effective anchor for natural gas development, new policy guidelines would probably be needed to help overcome problems related to securing long term power purchase agreements.

Chemical Industry Demand for Natural Gas

Most of the gas currently used by the chemical sector is for fertilizer production. Even though 44 percent of the gas produced in China is used for chemical production, gas accounts for only 6 or 7 percent of the total feedstock consumed by the chemical industry. In China, coal still plays the dominant role in this sector. The primary chemical product in China relying on natural gas is synthetic ammonia, with more limited production of methanol and acetylene.

Synthetic Ammonia

Synthetic ammonia is used in fertilizer production and uses more natural gas than any other

chemical product in China. Currently, about 17 percent of synthetic ammonia is made from natural gas compared to the world average of 80 percent. By the end of 2000, China's synthetic ammonia capacity reached approximately 36 million tons per year, requiring 9 BCM of natural gas. By 2010, China will probably add an additional 5 million tons of synthetic ammonia capacity, all of which could use natural gas as its feedstock. As a result, marginal demand could grow by roughly 14 or 15 BCM. Additional demand could be created by fuel switching from units that currently use coal or petroleum products. Benefits of doing so would include lower capital costs and short construction periods. If gas prices are attractive and availability of fuel is ensured, greater demand is likely. As China's economy becomes more market oriented however, there may be greater incentives to use scarce natural gas resources for processes other than fertilizer production. Reformers may find that it would be cheaper to import fertilizer and use the limited domestic supplies of natural gas where the market derives the most value from it.

Regionally, northeastern China is likely to have the highest demand for natural gas among chemical producers, with the Bohai Sea region following. (See Table 6-4.)

Methanol and Acetylene Production

The production and consumption of methanol in China is increasing rapidly. From 1990 to 2000, production more than quadrupled, growing from 640 thousand tons to almost 2.8 million tons. By 2010, production capacity is expected to nearly double again to 4.2 million tons. At present, methanol production uses coal and crude oil for 82 percent of its feedstock. The remaining 18 percent is manufactured using natural gas. The market suffers distortions, but has a potential for expansion in the coming decade. China is now actively setting up methanol plants at places where natural gas is produced.

Currently, calcium carbide is also emerging as a feedstock for acetylene production. The heavy use of calcium carbide gives rise to high power consumption, low-efficiency, and environmental degradation. An acetylene industry based on natural gas as a feedstock is in its infancy and consequently stands a good chance of evolving given proper incentives.

Industrial Sector Demand for Natural Gas

Chinese forecasts predict that the volume of natural gas needed as a fuel in industry and transportation will account for one-fifth of total production in China by 2010. Demand from this sector may top 23 BCM by then. From a regional perspective, gas consumption in Chinese industries is likely to be highest in the northeast and the Bohai region. (See Table 6-4.)

Coal, coal gas, and fuel oil are currently the chief fuels in China's refinery, metallurgy, construction material, electronics, glass, textiles and food subsectors. The Chinese government has decided to replace at least some of these fuels with natural gas. Natural gas is likely to compete cost-effectively with coal gas and fuel oil, but the low price of coal will make fuel substitution more difficult in these applications.

It was not until 1994 that China initiated significant promotion and development of natural gas fueled vehicles. Although it is now only being used on an experimental basis, the sector has a high potential for growth. In 1997, CNPC had predicted that 30,000 natural gas fueled vehicles would be on the road in 2000, up from 6000 in that year. Ford Motor Company, in a more recent estimate, claimed that there were over 43,500 vehicles fueled with natural gas in 2000. (See Table 6-3.) Natural gas vehicles currently consume about 0.5 BCM of natural gas each year. If projections to 2010 are realized, China's 100,000 natural gas fueled vehicles will consume over 1 BCM of gas annually.

Residential Sector Demand for Natural Gas

The residential sector includes household and public utility natural gas consumption. Public utilities include various service sectors like catering, hotels, and hospitals. At present, coal gas and bottled liquid petroleum gas (LPG) play very important roles in domestic residential gas. Pipeline natural gas is rare, available in only 25 cities and accounting for about 7.2 percent of total gas consumption.

Urban residents have a strong potential demand for natural gas, although high costs could curtail actual use. The government has established a policy of "using natural gas first, controlling coal gas, and standardizing the use of LPG." In cities such as Beijing, Tianjing, Shanghai, Nanjing, Changchun, Shenyang, Jinan, and Qingdao, efforts are underway to expand pipeline infrastructure and convert from coal gas to natural gas. In these cities, there are pipeline networks for coal gas in place, so the goal can be at least partially achieved through relatively minor renovations. Other cities will require building distribution infrastructure from scratch.

By 2010, China's population will be roughly 1.4 billion with 40 percent of these living in cities. Assuming a gasification rate of 80 percent and half of that met with natural gas, urban residential demand would reach 35 BCM. Adding rural demand of 10 BCM, residential gas demand would reach 45 BCM in 2010. Residential demand is expected to be highest among the wealthy residents of the Yangtse River Delta. (See Table 6-4.)

Total Demand Projection

Chinese researchers have also produced aggregate demand forecasts for natural gas through 2015. The average results are presented in Table 6-5. A sensitivity factor of 15 percent is included for upper and lower bound estimates.

Table 6-5 Average Natural Gas Demand Forecasts (Billion Cubic Meters)

Year	2005	2010	2015
Low Scenario	49.1	81.0	125.7
Baseline Demand	57.7	95.3	147.8
High Scenario	66.4	109.6	170.0

Source: SDPC and UPB, 1999.

The gap between domestic gas supply and demand will likely grow rapidly over the next 15 years. Balancing the two will probably require importing pipeline gas and LNG. (See Table 6-6.)

Table 6-6 Natural Gas Supply and Demand Forecasts (Billion Cubic Meters)

Year	2005	2010	2015
Output	52.6	79.2	107.9
Demand	57.7	95.3	147.8
Balance	5.1	16.1	39.9

Downstream Technology Assessment

Chemical Sector

China first imported equipment to synthesize ammonia in the 1960s and later brought in technologies to produce methanol, acetylene, and carbon black. China has little ability to manufacture these technologies domestically and could benefit from technology cooperation.

Gas Turbines

China can manufacture small gas turbines and has participated in joint ventures to manufacture larger units. It does not currently have the ability to manufacture domestically large, efficient gas turbines that are used in modern combined-cycle power plants.

Natural Gas Vehicles

China has developed its own technologies and cooperated with foreign countries to further perfect technologies for vehicles that use natural gas and for natural gas filling stations. At least one U.S. company is currently working with a Chinese enterprise to help develop a natural gas vehicle. China is also conducting research aimed at developing fuel cell vehicles that could use methane-rich gases, but lags in the applied aspects of development.

Gas-to-Liquids (GTL)

China is actively engaged in development of gas-to-liquids technology as it could add commercial value to many of the smaller, remote fields. Chinese companies would like to cooperate with U.S. partners to help develop their understanding of the technology.

Summary of Key Downstream Issues

- Forecasting natural gas demand in China is currently questionable since markets for gas do not yet exist and the development framework China chooses for the industry has not yet been fully established.

- Gas allocation to the fertilizer industry may not be the most economically efficient use of the fuel.

- Large combined-cycle plants can anchor demand for gas and thereby build markets quickly, but the greatest environmental and health benefits can be achieved in the residential sector. Additionally, investment in China's power sector has high risks associated with long-term power purchase agreements.

- Without market demand for natural gas, new pipeline projects will suffer. Creating "no coal zones" can be an effective way to build these markets, but other incentives are also needed. Raising and enforcing emissions fees on polluting industries will help level the playing field.

- More R&D is needed on key end-use technologies such as gas turbines, GTL, and fuel cells.

- Enforcing existing environmental regulations and creating new incentives to lower air pollution will help level boost demand for natural gas.

VII. Further Sino-U.S. Cooperation to Expand Gas Use

This section outlines potential areas where bilateral cooperation could be expanded. These efforts are not necessarily restricted to a bilateral framework and could include multilateral banks, other countries, and non-governmental organizations. Discussions at a September 2001 workshop in Beijing indicated that training and capacity building was one of the most encouraging options.

A. Training and Capacity Building

Present State of Personnel in China Petroleum and Natural Gas Enterprises
Chinese petroleum and natural gas enterprises face challenging issues related to personnel. Most enterprises are severely overstaffed, resulting in very low efficiency. Profitability per employee is much lower than in enterprises in other countries. Academic training is improving, although most workers have a narrow range of expertise. There are shortages of certain highly trained technicians, administrators, and managers, especially those with knowledge of market economics. China petroleum and natural gas enterprises have established a number of education and training centers, most with their own trainers. They are now focusing on expanding the expertise of their employees by trying to use advanced training methodologies focused on improving content knowledge and management skills.

Some Chinese companies have made headway, in cutting staff and improving efficiency. PetroChina, for example, agreed to cut over 10 percent of its workforce as part of an initial public offering on the Hong Kong and New York stock markets. Generic economic reforms in China are beginning to have a greater impact on enterprise overstaffing, helping in many cases to produce more efficient, flexible firms.

One promising area of capacity building where China and the U.S. might cooperate is in business plan training. These trainings would focus on building skills in market development and financial analysis. While many of China's workers have exceptional technical skills, they often have trouble translating these "command and control" qualities into market know-how. This training program would prepare more Chinese managers to function in the newly emerging market system. They need training to learn the latest ideas in natural gas technology, financing, and management. This project will provide experience for both Chinese and foreign partners that will help make the Chinese market more transparent and influential.

A fundamental barrier in many gas sector projects is the lack of knowledge to prepare business plans. These plans are important in any market economy, but particularly so in a country like China where risks are high, macroeconomic problems are pervasive, and managers with experience in business planning and project finance are rare. Improved knowledge of business

planning, which includes skills in accounting, market analysis, and financing, will not only help Chinese managers attract more investment, but also boost the chance of successful projects.

A program could be established with modest funding to train several hundred participants each year. Trainees would include entrepreneurs, municipal gas managers, central government policymakers, and analysts. The training center would become self-supporting after several years by charging participants a modest tuition fee. Other important topics at the training center include safety, operations and maintenance, and gas pipeline planning. The center could expand into other areas later as further needs are identified.

B. Technology Transfer

China's gas sector is constrained by outdated technology and the knowledge needed to operate it cost-effectively. Sections 4 and 6 of this report assessed general technology needs in the upstream and downstream sectors, respectively.

Probably the most promising means of transferring these "hard" technologies to China is through joint venture or licensing agreements with foreign companies. The U.S. government would probably not assist in these maters directly as it cannot order private companies to transfer technology, and is not likely to buy the rights to the technologies so that they can be transferred. The U.S. could help bridge the gap, however, by helping identify barriers to the formation of such joint ventures and licensing agreements. It could also establish scholarly exchange programs focused on sharing research and development of natural gas technologies. One such set of exchanges, for example, could provide assistance for Chinese researchers to visit publicly-funded organizations in the U.S. focusing on development of natural gas technology.

C. Incentives to Boost Foreign Investment

Many foreign oil and gas companies would like to expand their business operations in China but have been constrained by both real and perceived barriers. Most of these companies have been encouraged by recent changes in China's gas sector, but claim that they could do much more if given the opportunity. Greater inflows of foreign investment would help China solve shortcomings in finance, management, and technology, although not without benefits for the investors.

Some barriers preventing greater inflow of foreign investment are generic to all foreign companies, like the claim that transparency is poor. Others are specific to the gas sector, such as the feeling among some companies that only very risky or poor quality development parcels are offered for exploration.

One of the most direct ways of boosting foreign investment would be to offer more exploration blocks and production sharing contracts, especially onshore, to foreign companies. Another would be to officially expand foreign investment and ownership in all pipeline and downstream projects. A final relatively direct method would be to allow more gas to be sold at market prices and loosen the allocation of gas to particular industries.

Other methods of boosting foreign investment are less direct and associated more with generic economic reforms. Enforcing laws according to contracts, publishing information on who holds final decision-making authority, clarifying policy priorities, and promoting inter-institutional communication would all help to lower the market risks perceived by potential foreign investors.

D. Policy Development

The Chinese government has played a more active role in announcing natural gas policies that have accelerated development of the natural gas value chain. Major policy initiatives have included construction of the west-east natural gas pipeline, the Guangdong LNG import terminal, and the Changqing-Beijing pipeline.

Greater success might be achieved if official policy pronouncements were available in one document that was widely distributed and acknowledged as authoritative. Chinese and foreign companies would benefit from the prioritization of natural gas objectives by lowering risk and optimizing the focus of their efforts.

Chinese planners have experimented with a huge variety of reforms since beginning the move to a market economy. The U.S. might be willing to assist China in additional policy reforms related to expansion of the natural gas sector, but acknowledges that it is not in a position to tell China how to reform. Only Chinese planners are capable of defining these issues for themselves. If China chooses to further moves toward a market economy, U.S. specialists might be able to advise on issues related to policy, institutional, and regulatory development. The existing U.S.-China Oil and Gas Industry Forum—a collection of public and private experts from the two countries that has been meeting since 1998 to explore ways of developing reliable and economical oil and gas resources—has already considered some of these issues and may be capable of recommending advisors. If China prefers a less formal environment for discussing policy and regulatory issues, other options exist.

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IX. Conversions

Energy

1 gigajoule = 1 x 10^9 joules
1 exajoule = 1 x 10^{18} joules

1 exajoule = 0.95 quadrillion British thermal units (Btu)
= 34.1 million tons of standard coal equivalent (Mtce)
= 47.8 million tons of Chinese average raw coal
= 23.9 million tons of Chinese average crude oil
= 26.5 billion cubic meters of standard natural gas
= 25.6 billion cubic meters of Chinese average natural gas
= 19.2 million tons liquid natural gas (LNG)
= 84.4 billion Kwh of electricity
= 59-71 million tons of air-dried firewood
= 62-83 million tons of air-dried crop residues

1 kilowatt (Kw) = 1 x 10^3 watts
1 megawatt (MW) = 1 x 10^6 watts
1 gigawatt (GW) = 1 x 10^9 watts
1 terawatt hour (TWh) = 1 x 10^{12} watt hour or 1 x 10^9 Kw

Currency

As of July 27, 2001

$1.00 = RMB8.27
RMB1.00 = $0.12