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INCENTIVES FOR FOREIGN PARTICIPATION IN NATURAL GAS DEVELOPMENT IN CHINA

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This paper summarizes the results of a workshop organized by Battelle, Pacific Northwest National Laboratory on 31 July 1997 to identify ways to expand natural gas use in China[3]. It provides recommendations to the Chinese government for boosting the exploration and development activities of these companies and to the U.S. government for supporting those efforts. The paper begins with an introduction to China's natural gas sector. Before presenting the workshop recommendations, the paper also discusses why and how natural gas could play a larger role in China's energy mix.

OVERVIEW

Although natural gas currently accounts for less than 2 percent of Chinese primary energy consumption, the country stands on the brink of dramatically increasing use of the fuel. Gas consumption, currently around 20 billion cubic meters per year (BCMY), is conservatively projected to triple by 2010 to 60 BCMY and rise to 115 BCMY by 2015. A combination of technological, economic, political and environmental drivers could raise these figures much higher. We believe China can readily boost domestic production to 150 BCMY by 2015. Coalbed methane, internationally piped gas and LNG imports can add another 250 BCMY. For every BCMY of natural gas used in place of coal to generate electricity (approximately equivalent to the amount used yearly in a 775 MW plant), China would reduce total suspended particulate (TSP), SO_2 and CO_2 emissions by 243,000, 53,000 and 2,590,000 tons, respectively.

NATURAL GAS RESOURCE BASE

The natural gas resource base is an estimate of the amount of natural gas available. It is based on proven reserves (the inventory of natural gas volumes that have already been discovered and are readily available for production and delivery), and economically recoverable resources (those

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[3]The workshop was attended by representatives from four natural gas companies active in China, the U.S. Department of Energy and the Natural Resources Defense Council. To ensure a frank discussion, we agreed that none of the company comments would be for attribution. However, the companies attending were all major firms with deep commitments to China.

additional volumes that have not yet been discovered, but are estimated to be discoverable given current technology and economics). Difficult geology, remote locations, and incomplete surveying have made it difficult to accurately estimate China's traditional resource base.

Table 1 - Chinese Natural Gas Proved Reserves (Trillion m^3)

Amount of Proved Reserves	Source	Date
2.1[4]	CEDIGAZ, Natural Gas in the World, 1996 Survey	1996
1.6	BP, Statistical Review of World Energy, 1997	1996
5.3	Masters	1992
1.2	IEA	1996

Updated from Masters, C.D., Root, D.H., and Attanasi, E.D., 1992, "World Resources of Crude Oil and Natural Gas: Proceedings of 13th World Petroleum Congress".

Estimates of China's proven reserves of natural gas currently range from 1.2 to 5.3 trillion cubic meters (TCM), a small percentage of the world's estimated reserves of 141 TCM (Table 1). At today's consumption rate of 20 BCMY, there is enough gas to fuel the country for 85 years (Table 2). However, both consumption rates and reserves are changing quickly. Economically recoverable resources of 38 TCM are more generous, amounting to almost 9 percent of the world's total. Based on the country's large reserves of coal and oil, most geologists believe there is far more natural gas in China to be discovered since the formation processes of the three fossil fuels are so similar.

In the recent past, Sichuan has accounted for over 40 percent of China's natural gas production. Most of this gas is not associated with oil production. Natural gas output in Shaanxi, Gansu, Ningxia and Xinjiang, on the other hand, results from gas associated with oil production and accounts for most of the remaining on-shore production. Output in these provinces is expected to drive most of the future on-shore growth, but Sichuan may also still have sizeable undiscovered reserves. Off-shore, the South China Sea and Donghai regions produce the remainder of China's output. Production here is also expected to increase rapidly.

[4]This volume, 2.1 trillion cubic meters, is equal to 79 exajoules, or almost 76 quads.

Table 2 - China's Natural Gas Production - Billion Cubic Meters/Year

Year	Production	Year	Production	Year	Production	Year	Production
1981	12.7	1986	13.8	1991	16.1	1996	19.6
1982	11.9	1987	13.9	1992	15.8	1997e	22.2
1983	12.2	1988	13.9	1993	16.8	2005*	45
1984	12.4	1989	14.3	1994	17.6	2010*	60
1985	12.9	1990	15.3	1995	18.0	2015**	113

1997e - China's State Statistical Bureau reports 1997 output of 24.5 BCM, but the*Oil and Gas Journal* reports 20.97 BCM and the China National Petroleum Corporation, 21.18 BCM. The figure in the table is an average of the three.
* Projections by Zhou Fengqi in "Energy Consumption and Prospects in China," World Bank, 1996.
** Enron Oil Outlook, 1997.
All other data from *Zhongguo Nengyuan Fazhan Baogao 1997 (China's Energy Development Report),* Economic Management Publishing House, Beijing.

Coalbed Methane

In recent years, China has gone from viewing coal bed methane (CBM) as a safety hazard to acknowledging it as a major source of clean, new energy. As the world's largest producer of coal, it's natural for China to take a strong interest in CBM. Although currently recovered volumes amount to only about 500 million cubic meters per year (MCMY), reserves are tallied at 35 TCM.

Since China's coal mines are extremely gassy and prone to explosions, worker safety and productivity are low. By first tapping the methane in these mines, China could raise productivity and reduce the number of miners killed each year. Coal bed methane is also a potent greenhouse gas with perhaps twenty times more heat-trapping potential than carbon dioxide on a molecular basis and would otherwise be vented to the atmosphere.

GAS TRADE

Currently, China does not engage foreign countries in trade of natural gas. There are no international pipelines crossing China's borders since Hong Kong rejoined the mainland, nor has China begun to trade liquefied natural gas (LNG).

LNG Imports

China has yet to begin importing LNG despite relatively strong potential demand in Guangdong, Fujian, Jiangsu, Zhejiang and Shanghai**.** Imports to Japan, on the other hand, account for over 60 percent of the world's trade in LNG and fuel over 25 percent of Japan's electricity generation.

Southeastern China is well-suited for LNG imports since large cities in that region are far from coal and hydropower resources and demand for high quality energy is relatively well-developed. In southern China, the levelized cost of LNG derived power and coal-fired power with desulfurization equipment is about the same. Compared to coal-fired plants, LNG fueled plants would operate at much higher efficiencies, require half the initial capital costs, and create a fraction of the other environmental damages**.** As part of the Ninth Five-Year Plan, China began scoping studies to build three LNG terminals in Southern China. The terminals would begin operation in the 2002-2005 time frame.

The technology for producing and transporting LNG is currently capital intensive and relies on economies of scale. Despite the large initial capital requirements, LNG imports to China may be easier to arrange than pipeline imports, which involve greater risk and cooperation among more partners.

International Pipeline Trade

Importing natural gas to China via pipeline has achieved heightened attention over the past few years. With proved reserves of over 56 TCM, countries of the former Soviet Union are a logical first choice of supply. The gas bearing Irkutsk Basin near Lake Baikal in Siberia lies only some 3,000 kilometers from Beijing. Discussions are also underway regarding a pipeline from Kazakhstan that would travel over 6,000 km to China's east coast. A 1996 World Bank study on natural gas trade estimates that the fuel can be brought from Central Asia to China at $3.00/MMBtu at the rate of 27.6 BCM per year**.** Over a distance of 7,600 km, the delivered price would rise to $3.89/MMBtu.

There are many barriers to overcome before pipeline projects of the scale mentioned above could be implemented. Financing is probably the most difficult hurdle since even short pipelines (from Siberia or Irkutsk, for example) would require nearly $7 billion to construct.

DRIVERS OF GREATER NATURAL GAS USE

While none of the developments mentioned thus far appear remarkable alone, several circumstances in China now call for a rapid move to expand natural gas use. These events include expanding oil imports, continued energy shortages, new gas-based power generation technologies, and environmental benefits of gas over coal. A brief description of each of these drivers follows.

Expanding Oil Imports

Rapid economic development combined with stagnating oil production forced China to begin importing oil in 1994. By 2000, forecasters predict the country will be importing nearly 1 million barrels of oil a day. This figure could rise to 3 million barrels a day by 2010. The central

government is uncomfortable depending on the outside world for energy and would prefer to use the foreign exchange for other purchases. Greater reliance on natural gas could help ease these imports. While China does not use oil to generate electricity, a family of fuel cell technologies which use natural gas as an input will be commercialized within a decade. These fuel cells will generate electricity, power automobiles and provide heat and power to buildings.

Energy Imbalance

China's economy is expected to continue growing at over 8 percent a year well into the next decade. While the People's Republic has achieved an energy income elasticity of approximately 0.5 since 1979 (meaning that energy consumption has grown at half the level of economic growth), the country is still experiencing an imbalance of energy supply and demand. To meet the intense demand, over 16 GW of annual electricity capacity additions are planned through the first decade of the new century. Coal is unable to fully satisfy this demand and produces severe environmental damage. Natural gas can help close the energy imbalance and efficiently fuel economic growth.

Power Generation Technologies Using Natural Gas

A new generation of gas turbines and combined cycle gas turbines offer well-suited advantages over coal in China. First, capital costs for these technologies are generally half that of coal-based technologies. Coal-fired steam cycle turbines generally cost between $600-900/kW in China. Adding desulfurization equipment increases the price to approximately $1000/kW. Gas turbine and combined cycle systems are available for between $250-600/kW. The time needed to construct gas-fired plants is about 2 years compared to 4 years for a similar coal-fired unit, an important consideration in power hungry China. Third, using gas to generate power would allow the country to reserve the railroads to transport people and freight instead of coal. Fourth, combined cycle gas turbine systems currently operate at 50 percent efficiency and the next generation of technologies will raise the efficiency to 60 percent. This is twice the level of China's current vintage of pulverized coal plants. Finally, there are many environmental benefits in using gas over coal to generate power.

Environmental Benefits

Regardless of the combustion method, natural gas emits virtually no sulfur and particulate emissions. Low-sulfur Chinese coal (1.2 percent sulfur), on the other hand, emits 10 grams of sulfur dioxide and 50 grams of total suspended particles per kilowatt-hour of electricity generated (Table 3). A 775 MW steam-cycle coal plant would produce, annually, 243,000 and 53,000 tons of TSP and sulfur dioxide emissions, respectively. The same size combined cycle gas turbine plant would produce almost none. Nitrous oxide emissions would also decline by about two-thirds. Carbon dioxide emissions from combined cycle gas turbines are about half as much as from coal-fired plants. The reduction in CO_2 per plant amounts to about 2.5 million tons per year

and waste heat would decline by 25 percent. Note that even simple cycle natural gas-fired power generation would produce only half the carbon dioxide per kilowatt hour as the most advanced coal-fired system, the Integrated Gasification Combined Cycle (IGCC) plant. Moreover, the costs per kilowatt produced would be about the same.[5] Natural gas combined cycle plant systems also use less water than coal-based ones.

Table 3 - Comparative Emissions in Electric Power Production, grams/kWh

Fuel	SO_2	NO_x	TSP	CO_2	Efficiency
Northern Coal[a]	10.0	4.7	47.8	878.8	36%
Southern Coal[b]	20.8	5.1	59.7	949.8	36%
Natural Gas (CCGT)	~0	1.3	.03	425[c]	47%
Heavy Fuel Oil	16.6	4.2	1.0	727.3	36%
Light Fuel Oil	1.2	2.37	0.5	727.3	36%
Biomass	0.1	6.5	50[d]	0	--
Wind[e]	0	0	0	0	--

a - Northern Chinese Coal, 1.2% sulfur content, 20% ash, 9025 btu/lb heating value.
b - Southern Chinese Coal, 2.5% sulfur content, 25% ash, 8350 btu/lb heating value.
c - Since methane is itself a powerful greenhouse gas, leaks in the natural gas sector could relinquish some of natural gas' carbon dioxide advantages.
d - based on PM10 emission levels.
e - net emissions, assuming zero associated emissions.
TSP = Total Suspended Particulates; CCGT = combined cycle gas turbine
Sources: Liu F., W.B. Davis, M.D. Levine, 1992, *An Overview of Energy Supply and Demand in China*, Publication 32275.; U.S. Environmental Protection Agency, 1993, Air *Pollution Emissions*, Publication AP-42; Robert S. Price, U.S. DOE/International Notes, 1997; Greenhouse Gas Technology Information Exchange (Greentie), IEA, http://www.greentie.org/

RECOMMENDATIONS

Pacific Northwest National Laboratory hosted a natural gas workshop on 31 July 1997 to identify ways of boosting U.S. natural gas company involvement in China. Participants suggested and then ranked the barriers which prevented them from increasing their activities in the Chinese natural gas exploration and development sector. Recommendations from the workshop, in order of importance, are as follows:

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[5]From William Chandler, "Electric Power Futures for China," forthcoming March 1998, draft paper for the W. Alton Jones Foundation.

1. Boost gas prices to international market levels

There is little incentive to explore for new natural gas resources if production costs can not be met. Average prices for natural gas in China are currently around Y500/1000m^3 ($1.6/MMBtu), far below the international level of Y781-938/1000m^3 ($2.50-3.00/MMBtu). On an energy basis, natural gas is also priced far below crude oil. When the United States restructured its natural gas sector and removed price controls on natural gas, production expanded and prices fell (See box).

U.S. Natural Gas Restructuring

The structure of the natural gas industry in the United States has changed dramatically since the late 1970's. Prior to 1978, the structure of the industry was simple, although confining. Gas producers, both large and small, explored for and produced natural gas. They sold that gas to pipeline companies, who transported the gas across the country, and, for the most part, sold it to local distribution companies (LCD's). These companies then sold the gas to end users. The price for which producers could sell their gas to interstate pipelines was regulated by the federal government, as was the price for which the interstate pipelines could sell their gas to LDC's. State or local government agencies regulated the price charged by the LDC's to their end users.

The changes in the structure of the natural gas industry have been caused mainly by deregulation of the industry over a period of almost 15 years. The process of change culminated with the release of FERC Order 636 in 1992. Pipelines, which once functioned as both sellers and transporters of gas, now are primarily transporters. Therefore, producers, pipeline affiliates, distributors and marketers can all play a larger role in supplying natural gas to end users.

From 1988 to 1994, the market for natural gas changed dramatically as a result of this restructuring and other economic pressures. Gas production increased by 10 percent, whereas real wellhead prices and proved reserves declined by 11 and 2 percent, respectively. This demonstrated the ability to produce more gas from fewer reserves despite lower real prices and provides evidence that improved efficiency and technology have fundamentally altered the gas supply process.

2. Expand use of gas to industry and power sector

Fertilizer plants and oil field use account for almost 70 percent of natural gas consumption. Only a small percentage of gas is currently used for industrial and power applications. U.S. gas company representatives believe that the Chinese government should allocate more gas to other industrial applications and power plants. They also noted, however, that the current Chinese policy of expanding residential use of gas in place of coal is well-founded and critical to improving human health.

3. Allow access to choice areas for exploration.

Many companies expressed the feeling that they were not offered explorative acreage with enough potential. Only after the Chinese side was relatively sure that the region contained no additional unknown reserves would it be offered to international companies. Gas company representatives recommended the Chinese government allow companies to nominate and lease acreage through a competitive bid route.

4. Develop greater transparency

Americans often list transparency as one of the most difficult barriers to overcome in order to do business in China. This term refers to clarifying contracts, pricing, legal issues such as arbitration, and who has final decision-making authority. In general, the commonly accepted ways of conducting business at the international level are not always followed in China. Legal and financial practices should be clarified and brought closer in line with international standards. Several participants noted that off-shore oil and natural gas operations were much more transparent than on-shore ones, and that transparency became worse as one moved inland.

5. Improve data accessibility

Participants familiar with field operations noted that gaining access to the field data they need is often either impossible or at least very difficult. Data from seismic logs, well logs, and well test and production reports were often managed by different government agencies. The Chinese agencies responsible for managing different pieces of the data do not communicate with one another and can be possessive of their data. A centralized data repository could solve some of these problems.

6. Shift fertilizer subsidies away from producers

Fertilizer manufacturers receive subsidies in the form of artificially low natural gas prices. Of China's 915 nitrogen fertilizer manufacturing facilities, 832 are classified as small-scale. These small plants employ outdated technology and consume about twice the energy they would if they used advanced technologies. By shifting subsidies away from the producers, the government will encourage their modernization. Another problem of subsidizing fertilizer production, especially nitrogen based ones, results in overuse. Many Chinese farmers are not aware of the timing and ratio requirements of fertilizer applications and use far too much. In accordance with agronomic requirements, the Ministry of Agriculture has formulated an optimal nutrient ratio for NPK nitrogen/phosphorus/potassium fertilizer production of 1.00/0.42/0.40. The actual ratio in 1994 was 1.0/0.27/0.08, which underscores the serious structural imbalance in production with respect to optimal use.

7. Raise return on equity for power projects

Most power projects using foreign financing are limited to return on equity of 15 percent. There is a large backlog of power projects in China that could use natural gas as a source of power. Representatives believed that by raising the allowable return on equity, they would be more willing to participate in gas-fired power plant projects. These plants have higher efficiency, lower capital costs and shorter construction times than comparable coal plants.

8. Allow equity investments in *de facto* pipeline monopoly

While foreign entities are not technically prohibited from equity ownership in China's natural gas pipelines, there have been no such investments to do so. Gas company representatives indicated that their risks would be substantially reduced if given the chance to invest in equity ownership of transportation pipelines and local distribution networks. They also noted that development of clearer transmission and distribution tariffs and regulations would also lower their risks.

9. Develop clearer regulatory process for transmission and distribution tariffs

This recommendation is related to the pipeline monopoly issue above. Clear transmission tariffs could help reduce the risk and uncertainty of building new pipeline infrastructure.

10. Clarify LNG authority/policy

There is no single entity in China which regulates and establishes policy for liquefied natural gas (LNG). The government needs to develop a clearer mandate. Authority is too split. LNG, like natural gas in general, needs a champion to push for increased usage.

11. Account for coal's environmental externalities

Workshop participants believed that coal use is unfairly subsidized because its pricing does not take into account all of its costs. Coal use harms human health, ecosystems, land resources, and infrastructure. Chinese and international analysts estimate that environmental pollution costs the Chinese economy about 10 percent of GDP. Internalizing these externalities would make natural gas more competitive and lower the risk of ecological breakdown.

China needs to better enforce its air pollution laws, especially regarding sulfur emissions. The pollution levy system, for example, attempts to fine those enterprises which emit more sulfur than allocated. Currently, these fines are both too low and poorly collected.

12. Provide greater incentives for coalbed methane

Coal bed methane needs special attention to more fully enter the Chinese market. Participants believed that the government could offer tax holidays for coal bed methane producers as it does to other key producers.

13. Increase allocation of gas to the open market

Most natural gas is currently allocated to fertilizer production (about 35 percent) and oil field use (30 percent). Only about 15 percent is allocated to the open market. More gas needs to go to the open market where its true economic value can be realized. Allocating gas in other ways is economically inefficient.

14. Focus greater attention on gas to liquids conversion technology

Natural gas produced in remote areas is often flared because a pipeline infrastructure does not exist to transport it to consumption centers. If an inexpensive liquefaction technology existed, more gas could be put to productive use. The U.S. Department of Energy is currently working to help further develop this technology and believes it has potential in China. The current version of the technology uses a fairly large percentage of raw gas in the liquefaction conversion process.

Appendix: Glossary

BCM - Billion Cubic Meters, multiply by 35.3 to convert to Billion Cubic Feet. To convert BCM to exajoules, divide by 26.5 (that is, 26.5 BCM = 1 EJ). To convert BCM to Quads, divide by 27.9 (that is, 1 Quadrillion BTU = 27.9 BCM).

BTU - British Thermal Unit. The Btu is a unit of measurement for energy. It represents the amount of heat that is necessary to raise the temperature of one pound of water by 1 degree, Fahrenheit. A BTU is equal to 1,052 Joules. (MMBtu represents a million BTU, roughly equal to 1000 cubic feet of natural gas).

Coal Bed Methane - Prior to the mid-1980's, methane from coal seams was classified as an uneconomic resource - one of vast potential, but low value due to poor recovery rates and high associated water production. By applying new production technologies to this resource, coal bed methane has become the single largest new source of gas supply in the past decade. Current estimates show approximately 35 TCM of coal bed methane that appears to be economically recoverable in China.

FERC or The Federal Energy Regulatory Commission - An independent agency of the U.S. Department of Energy that regulates interstate electricity and gas markets. The FERC, and its predecessor, the Federal Power Commission, deregulated much of the natural gas sector during the 1980s, leading to greater incentives to explore for new supplies, and, soon thereafter, lower prices.

Gas Premium (also referred to as the coal-gas differential) - The point at which coal's fuel price advantage is exactly offset by the gas capital and non fuel operating cost advantage. At this point, the cost of generating electricity is equal for both fuels.

LNG or Liquefied Natural Gas - To overcome the difficulties of transporting natural gas over long distances, it can be subject to low temperature (-164 degrees Celsius) and high pressure where it will become a liquid. After being transported, the LNG is re-gasified before using. Japan is currently the largest consumer of internationally traded LNG, accounting for approximately 65% of world imports.

LPG or Liquid Petroleum Gas - Also called propane, is significantly different from LNG. LPG is composed primarily of propane (C_3H_8) and smaller quantities of butane ((C_4H_{10}). LPG can be stored as a liquid in tanks by applying pressure alone.

Methane - Methane (CH_4), is the most common hydrocarbon gas in natural gas. It is colorless and naturally odorless, and burns efficiently without many by products. Methane accounts for

approximately 90 percent of natural gas, with propane (C_3H_8), butane (C_4H_{10}), other hydrocarbons and nitrogen making up the balance of gases.

Million British Thermal Units or MMBtu - A natural gas measure roughly equal, in energy content, to 985 cubic feet of gas.

Natural Gas Co-Firing - Co-Firing refers to the injection of natural gas with pulverized coal or oil into the primary combustion zone of a boiler. Co-firing is not new technology, but efforts to determine optimal natural gas injection levels for both environmental and operational benefits are relatively recent. Co-firing only produces a mild increase in production costs, but benefits plants by offering cleaner overall operation. Slag that builds up inside boilers is reduced, and precipitators, which capture soot and ash from coal or oil firing, foul up less frequently.

Natural Gas Resource Base - An estimate of the amount of natural gas available, based on the combination of proved reserves, and those additional volumes that have not yet been discovered, but are estimated to be "discoverable" given current technology and economics.

Nitrogen Oxide (NO_x) - All fossil fuel combustion produces NO_x. Electric power plants, boilers, furnaces and vehicles are responsible for most nitrogen oxide emissions in China. NO_x is both a potent pollutant itself and an ingredient in the formation of acid rain, ozone and smog. No_x is created in two ways: first, when high combustion temperatures cause the naturally occuring oxygen and nitrogen in the air to combine; and second, when fuel-bound nitrogen reacts with oxygen during combustion. This pollutant can thus be reduced by either lower combustion temperatures or installing pollution-reduction devices such as catalytic converters.

Netback Value - the avoidable cost of alternative fuels, adjusted for any capital savings and efficiency gains through fuel substitution. In the case of feedstock applications, the economic value of the final output, net of any incremental costs for conversion, construction and operation. For example, the World Bank estimated China's netback value of coal replacement with natural gas at $3.4/MMBtu[6].

Proved Resources - The part of the natural gas resource base that includes the working inventory of natural gas - volumes that have already been discovered and are readily available for production and delivery. Reserves that can be estimated with reasonable certainty to be recoverable under current economic conditions. Current economic conditions include prices and costs prevailing at the time of the estimate. Proved reserves must have facilities to process and transport those reserves to market that are operational at the time of the estimate, or there is a commitment or reasonable expectation to install such facilities in the future.

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[6]See World Bank IEN Occasional Paper No. 8, "Natural Gas Trade in Asia and the Middle East", 1996 <www.worldbank.org/html/fpd/energy/occpapers/occpap8/occpap8.htm>.

Quad - An abbreviation for a quadrillion (1,000,000,000,000,000) Btu. For natural gas, a quad is roughly equivalent to one trillion (1,000,000,000,000) cubic feet, or 28 billion cubic meters.

Reserve Additions - Volumes of the natural gas resource base that are continuously moved from the resource category to the proved resources category. Reserve additions represent the volumes that become part of the gas industry's working inventory as producers replace volumes that are sold and used.

Sulfur Dioxide (**SO_2**) - Acid deposition, commonly called acid rain, occurs when sulfur dioxide and, to a lesser extent, nitrogen oxide (NO_x) emissions are transformed in the atmosphere and return to the earth as dry deposition or in rain, fog or snow. Roughly 24 million tons of SO_2 is emitted annually in the People's Republic of China, although the World Bank estimates this could rise to 75 million tons by 2020 (*China 2020: Clear Water, Blue Skies*, 1997). The combustion of natural gas produces virtually no SO_2 and, with proper design, far less NO_x than combustion of coal or fuel oil.

Three Dimensional (3-D) Seismic Imaging - Possibly the single most important advancement in exploration technology in years, the three dimensional seismic allows producers to see into the earth's crust to find promising formations for retrieval of fossil fuel. Taking advantage of highly advanced supercomputers, geologists process millions of pieces of data to generate a detailed, three dimensional image of underground structures. They can rotate and slice these models for closer examination, searching for evidence of hydrocarbons. Using 3-D seismic imaging, drilling has become more precise and the risk of costly dry holes has diminished.

Total Suspended Particulates (TSP) - Total suspended particulate is a general term for airborne particles such as smoke, fume, dust, flyash, and pollen. Suspended particles may be solid or liquid, organic or inorganic. Fine particulates are rained out of the atmosphere; course particulates fall to the ground more rapidly. Most environmental scientists are concerned with the subset of the total suspended particulate, fine particles 10 µm or smaller in size (PM10), due to their potential impacts on visibility and human health.

TCM - Trillion Cubic Meters, multiply by 35.3 to convert to Tillion Cubic Feet. To convert TCM to exajoules, divide by 0.0265 (that is, 0.0265 TCM = 1 EJ). To convert TCM to Quads, divide by 0.0279 (that is, 1 Quadrillion BTU = 0.0279 TCM).