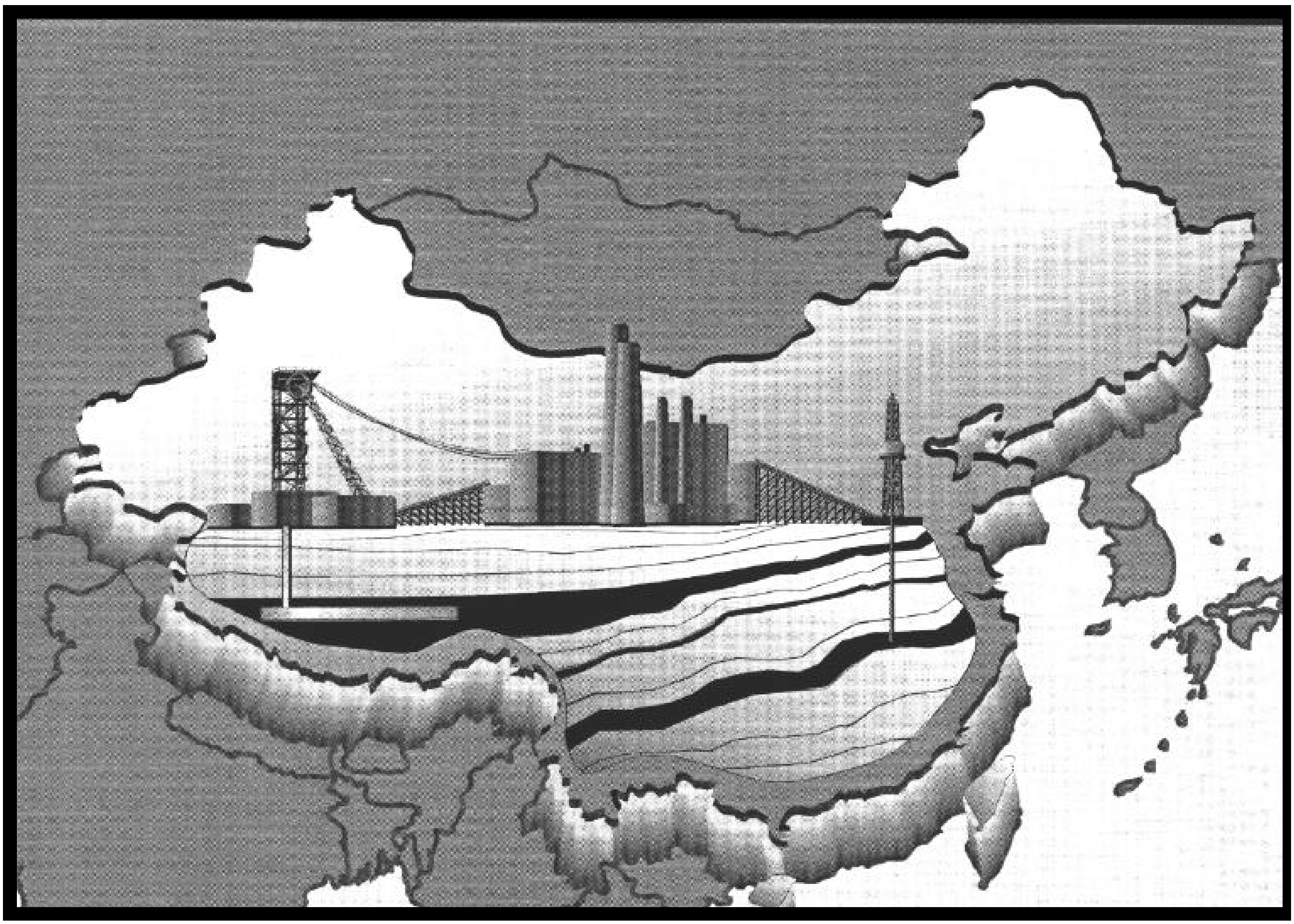
United States
Environmental Protection
Agency

Air and Radiation
6202J

EPA 430-R-96-005
July 1996

REDUCING METHANE EMISSIONS FROM COAL MINES IN CHINA: The Potential for Coalbed Methane Development

Public Review Draft



Reducing Methane Emissions From Coal Mines in China: The Potential for Coalbed Methane Development

Public Review Draft

JULY 1996

ATMOSPHERIC POLLUTION PREVENTION DIVISION
U.S. ENVIRONMENTAL PROTECTION AGENCY

Disclaimer

ACKNOWLEDGMENTS

The U.S. EPA acknowledges Raven Ridge Resources, Incorporated, the Coalbed Methane Clearinghouse at the China Ministry of Coal Industry, and the Research Division at the China Coal Information Institute for authoring this report. The U.S. EPA also acknowledges members of the Fushun Branch of the Central Coal Mining Research Institute for their important contributions to the report.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

TABLE OF CONTENTS (CONTINUED)

LIST OF TABLES

LIST OF BOXES

ABBREVIATIONS AND ACRONYMS

Weights and Measures: All units are metric system (S.I.)

cm	centimeter - = 10 $^{-2}$ meter
GJ	gigajoules = 10^9 Joules
GW	gigawatts = billion Watts = 10^9 Watts
EJ	exajoule = 10^{18} Joules
kg	kilogram = 10^3 grams
kJ	kilojoules = 10^3 Joules
km	kilometer = 10^3 meter
km^2	square kilometer
kt	kilotons = 10^3 tons
kW	kilowatt = 10^3 Watts
kWh	kilowatt hours = 10^3 Watt hours
m	meter
m^3	cubic meter
md	millidarcies = 10^{-6} Darcies
MJ	megajoules = 10^6 Joules
mm	millimeter = 10^{-3} meter
MPa	megapascals = 10^6 Pascals
Mt	megatons = 10^6 tons
Mtoe	million tons oil equivalent = 10^6 tons oil equivalent
MW	megawatts = 10^6 Watts
MWh	megawatt hours = 10^6 Watt hours
MWh_{el}	megawatts of electricity
MWh_{th}	megawatts of thermal energy
t	ton = metric ton = 10^3 kg

Acronyms

BHP	bottom hole pressure
BOT	build-operate-transfer
CAAA	Clean Air Act Amendments
CBM	Coalbed Methane
CCAO	Central China Administration of Oilfields
CII	China Coal Information Institute
CCMRI	Central Coal Mining Research Institute
CMA	Coal Mining Administration
CNAGC	China National Administration for Coal Geology
CNCC	China National Coal Corporation
CNG	compressed natural gas
CNOOC	China National Offshore Oil Company
CNPGC	China National Petroleum and Gas Corporation
DCPU	Department of Coal Processing and Utilization

Acronyms (Continued)

DRCCU	Department of Resource Conservation and Comprehensive Utilization
EIA	Energy Information Administration
EIC	Energy Information Center
EIU	Economist Intelligence Unit
ERNGC	Eastern Regional Natural Gas Center
FYP	Five Year Plan
GDP	Gross Domestic Product
GEF	Global Environment Facility
GRI	Gas Research Institute
IC	Internal Combustion
IEA	International Energy Agency
IPCC	International Panel on Climate Change
LMA	Local Mining Area
MEPI	Ministry of the Electric Power Industry
MGMR	Ministry of Geology and Mineral Resources
MOCI	Ministry of Coal Industry
MSHA	US Mine Safety and Health Administration
NCPBG	North China Bureau of Petroleum Geology
NGV	natural gas vehicle
PPP	purchase power parity
PSA	pressure swing adsorption
REI	Resource Enterprises, Incorporated
RMB	Renminbi (yuan)
UK	United Kingdom
UNDP	United Nations Development Program
USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency

CHAPTER 1

COALBED METHANE IN THE ENERGY ECONOMY OF CHINA

1.1 INTRODUCTION

The Peoples Republic of China (China) produces and consumes the largest quantity of coal in the world. In 1992, an estimated 12.5 to 19.4 billion cubic meters (8.4 - 13 teragrams) of methane were emitted to the atmosphere from coal mining activities in China, contributing one-third of the world's total from this source (USEPA, 1993). Not only is China the largest coal producer in the world; it is unique in that underground mines produce over 95 percent of the nation's coal. Underground mines tend to have higher methane emissions. Coal mines are located throughout China, with the greatest number of large mines located in the north and northeast.

Methane is a major greenhouse gas, second in global impact only to carbon dioxide (CO_2). It tends to increase tropospheric ozone and smog formation, and may contribute to stratospheric ozone depletion. Increasing methane emissions are associated with population growth and human activities that release methane to the atmosphere. Major human-related sources of methane include rice cultivation, livestock, biomass burning, coal mining, oil and natural gas operations, and landfills. It is estimated that coal mining accounts for about 10 percent of the total human related methane emissions (Kruger, 1993).

The production and consumption of over one billion tons of hard coal annually in China has serious environmental impacts. The resulting emissions of methane and CO_2 are of global significance. China also suffers from severe local air pollution problems due to intense coal use, characterized by high levels of SO_2, NO_x and particulate emissions. In 1993, the total amount of SO_2 emitted was 17.95 million tons, of which coal combustion caused an estimated 90 percent (DRCCU, 1994). Chinese cities, such as Shenyang and Chongqing, have some of the highest particulate and SO_2 concentrations in the world. Acid rain is another serious environmental problem resulting from the intense coal use.

Coalbed methane, a natural gas, is detrimental to the environment if vented to the atmosphere, but is a remarkably clean fuel when burned. Natural gas combustion produces no SO_2 or particulates, and only half of the CO_2 associated with coal combustion. In many countries, methane produced by coal mines has historically been vented and become a wasted resource. China, on the other hand, has one of the longest histories of using coalbed methane recovered from its mines. Recent experience in the US confirms that coalbed methane represents a low cost energy source and emission reduction opportunity. Methane can be recovered either before, during, or after coal mining and used as a fuel for power generation or consumed directly for industrial and residential energy needs.

In addition to its value as an energy source, drainage and use of methane from coal mines increases mine safety and productivity. Methane released during underground mining is not only an environmental concern, but also is a serious safety hazard due to the explosive nature of methane in relatively low concentrations (5 - 15 percent in air). In the US and other coal-producing countries, mines install ventilation systems, supplemented in highly gassy mines by recovery systems to reduce methane concentration in the mines' workways.

Worldwide, several thousand fatalities have been recorded from underground coal mine explosions, where methane was a contributing factor. As coal mines deplete shallower coal reserves, there is a shift to mining deeper, gassier coal beds. In general, underground mines release more methane than surface mines because methane storage capacity increases with greater depth and pressure. In China, where underground mines produce over 95 percent of the coal, and half of the largest state-run mines are considered highly gassy or prone to outburst, mine ventilation and methane drainage is critical for mine safety. Since the 1980's, China's coal mines have greatly improved their safety record. From 1980 to 1993, mines reduced the fatality rate from 8.2 to 4.6 people per 1 million tons of coal mined (DRCCU, 1994). The goal of the "Mine Safety Law", implemented in 1992, is to further increase safety in the coal mines, especially at township and village mines. The Chinese government recognizes the importance of mine safety, and plans to increase drainage and recovery of coalbed methane associated with mineable reserves of coal as a major strategy for the industry.

This report focuses on the potential for expanding recovery and use of coalbed methane in China. It includes a review of China's primary energy sources, current energy strategy, and an assessment of the potential role of coalbed methane in meeting China's future energy needs. The report describes the magnitude and location of coalbed methane resources, and analyzes factors affecting recoverability of resources, use options, and profiles of specific regions with high potential for coalbed methane development. Finally, the report identifies actions necessary to encourage development of coalbed methane in China and overcome existing barriers. It also recommends follow-up technical assistance activities to help ensure efficient use of this resource.

1.2 THE ENERGY SECTOR IN CHINA

1.2.1 OVERVIEW

1.2.1.1 <u>Economic Growth</u>

China is currently the fastest growing major economy in the world. In 1993, gross domestic product (GDP) increased 13 percent over the previous year, reaching 3,138 billion Renminbi (RMB) yuan ($US 545 billion). For nearly every year since 1982, China has averaged an economic growth rate of over 10 percent. Even when compared to other fast-growing Asian economies such as Thailand (averaging 7 percent annual increase in GDP) or Indonesia (averaging 6 percent), China's economic growth rate is truly impressive.

As incomes grow, however, so does the use of automobiles, appliances and the need for new power plants. China's energy sector thus suffers significant shortages, because supply has not kept pace with economic growth. For example, China's continued reliance on coal requires that by the year 2000, total coal production will increase by 22 percent over current levels to 1.4 billion tons (according to Ministry of Coal Industry projections). Three-fourths of the nation's electricity is generated from coal, and with electricity demand growing by 3 percent per annum (IEA, 1994), large increases in coal production will be required to meet electricity demand alone. These burgeoning energy demands are creating serious air quality problems in China, whose efforts to control air emissions have been frustrated by its rising use of coal, as well as automobiles. Concern is also spreading about China's contribution to global warming. Its heavy reliance on coal—the fossil fuel with the highest carbon content—makes it the second largest contributor to rising levels of carbon dioxide. It is also the world's largest contributor to methane emissions from coal mining.

The following subsections examine China's energy production and consumption trends in more detail. Section 1.2.3 discusses how coalbed methane can help China meet the challenge of reducing its dependence on coal, without relying heavily on imported fuels.

1.2.1.2 Energy Production and Consumption

China's energy production and consumption have increased over the past several years, and because of its tremendous economic growth, will likely continue rising. Until the 1960's, China was still primarily an agriculture-based economy. The overall growth rate of the economy, and especially of industry, increased following reforms of the late 1970's. Industry, especially the collective and private sectors, experienced the fastest growth rate. Private companies and township and village enterprises now produce about half of China's industrial output. Since the 1970's, China's energy consumption and economic growth have been steadily increasing. Figure 1 shows growth in energy consumption and GDP from 1980 through 1993.

FIGURE 1. ENERGY USE AND GDP, 1980-1993

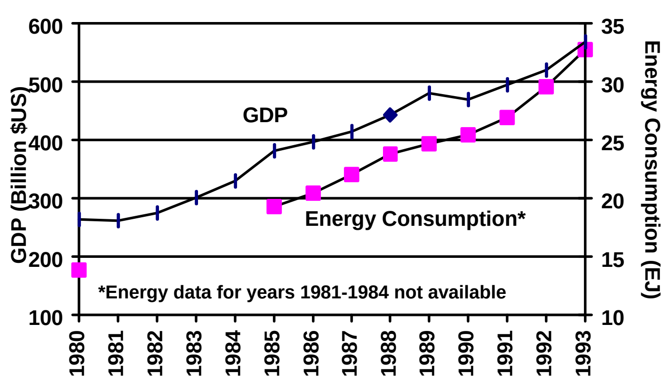
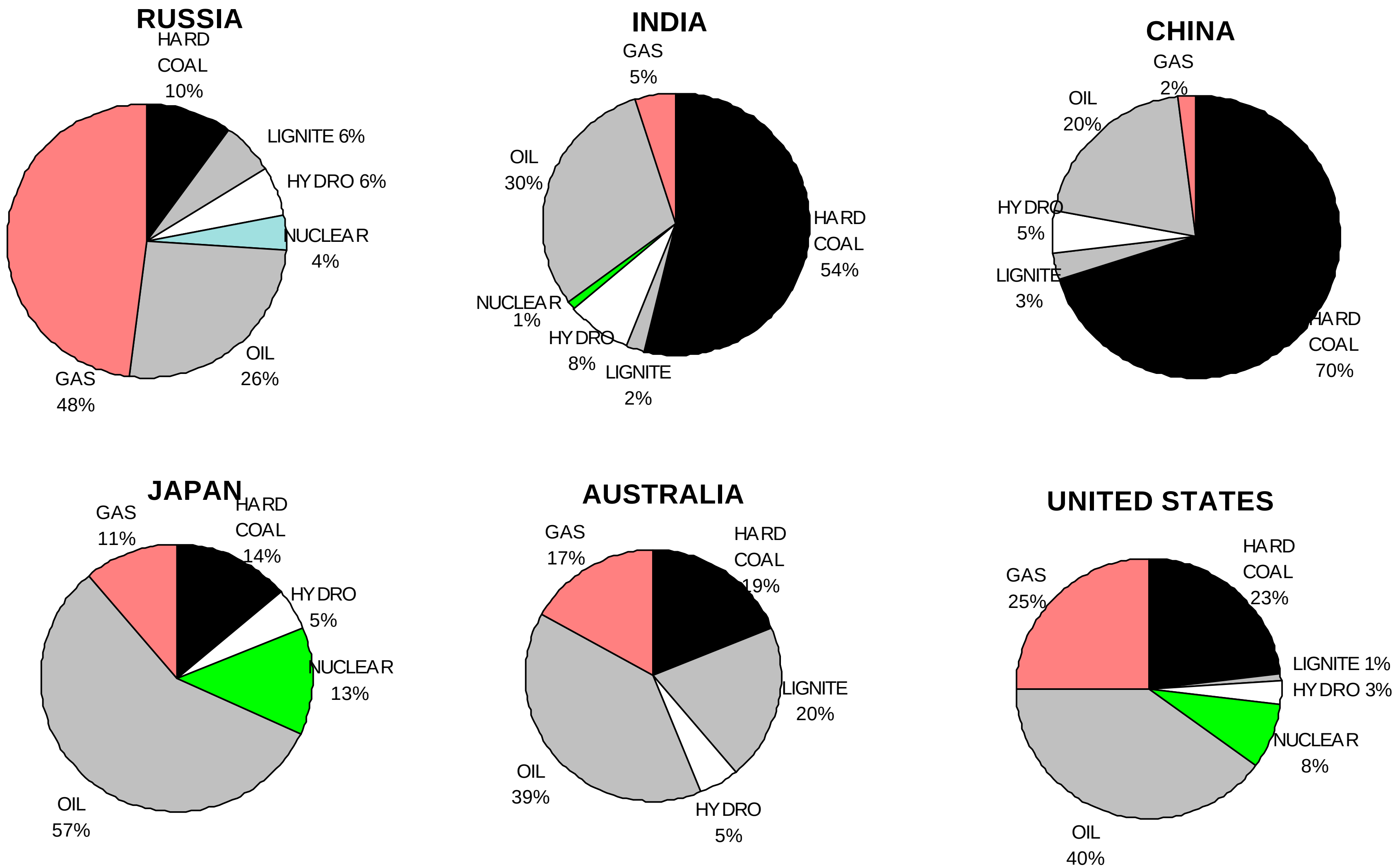


Figure 2 shows the 1993 fuel mix for China and other selected countries. Of the countries shown in Figure 2, China is most similar to India in its primary energy consumption; both countries receive more that half of their energy from coal. India, however, uses slightly larger percentages of each of the other primary fuels. The developed countries of Japan, Australia, and the United States, as well as Russia, differ from China in their much larger reliance on oil and gas, which account for over half of their primary energy demand. The United States and Russia consume relatively large amounts of oil and natural gas, and relatively small amounts of nuclear energy and hydroelectricity. Due to insignificant fossil fuel resources, Japan's fuel mix differs most from China's, with Japan relying heavily on nuclear energy, imported oil, and hydroelectricity.

Figure 2- FUEL MIX OF SELECTED COUNTRIES, 1993

SOURCE: U.S.DOE/EIA, 1995



From 1980 to 1993, China's per capita energy consumption increased more than 34 percent (USDOE/EIA, 1995). Despite this increase, per capita energy consumption in China is still low (27.8 GJ/person) compared to that of westernized "neighbors" Japan (160.8 GJ/person) and Australia (224.7 GJ/person). As economic growth and industrialization continue, however, the amount of energy consumed per capita in China is likely to continue climbing.

1.2.1.3 Sectoral Energy Consumption in China

China's final energy demand in 1993 was 33 exajoules[1] (EJ), up from 31 EJ in 1992 (USDOE/EIA, 1995). Figure 3 shows 1992 sectoral end use divided into three categories: Industry (includes manufacturing, mining, and construction); Domestic (includes residential, agriculture, and commercial enterprises); and Transportation (includes rail, road, water, and air). In 1992, the industrial sector was the largest consumer at 67 percent of total demand (DRCCU, 1994); the domestic sector used 27 percent, and the transportation sector used 6 percent of the total energy.

FIGURE 3. ENERGY DEMAND BY SECTOR, 1992

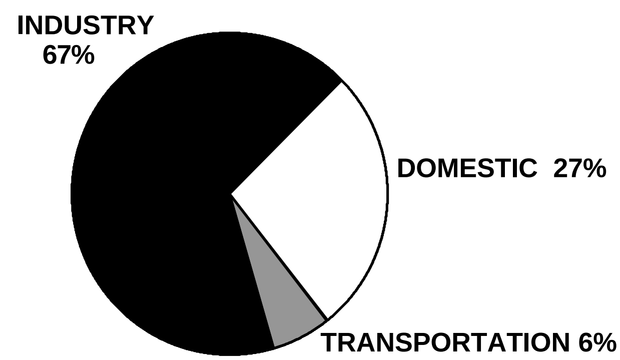
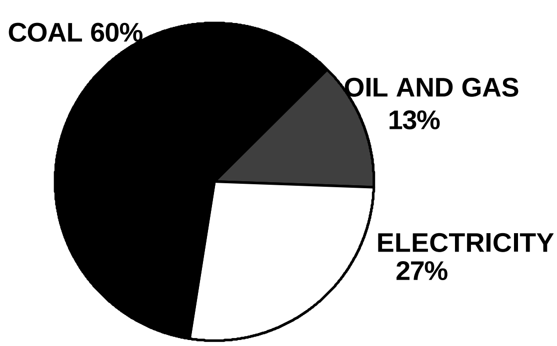


FIGURE 4. INDUSTRIAL SECTOR ENERGY SOURCES IN CHINA, 1992



China is intensely industrialized. As shown in Figure 4, coal dominates the industrial sector's fuel mix (60 percent), followed by electricity (27 percent) and oil and gas (13 percent). The chemical, metallurgical, smelting, and building materials sub-sectors represent the largest industrial end-users. These industries are centered in northern and northeastern China, near the largest coal mining complexes. Industry's share of energy consumption is much larger than that of any other country, including the former Soviet Union, on which China's development was modeled. This is related to the fact that China's energy intensity is three times the world average.

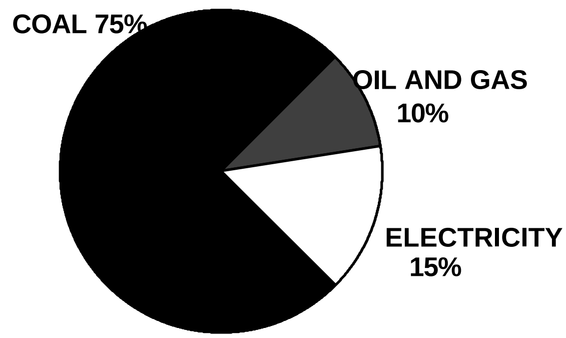
Projections indicate that the industrial sector's energy demand will fall from its current share of 67 percent to just over 50 percent by 2010 (IEA, 1994). This decline will reflect the small drop in the share of industry in GDP, as well as the transport sector's increasing share. The absolute level of industrial energy demand, however, is expected to grow by 3.3 percent annually through 2010. Given that industrial output is projected to grow by close to 10 percent annually through 2010, this implies further declines in industrial energy intensity.

[1] 1 EJ = approximately 1 quadrillion (10^{15}) BTUs = 277.7 terawatts

In 1991, over 80 percent of China's electricity was generated from thermal, mostly coal-fired, plants, while 18.3 percent was hydroelectric. At the end of 1992, power generating capacity in China was 165 GW and included around 40 GW of hydroelectricity, just under 115 GW of coal, 9 GW of oil and very little gas. The IEA (1994) projects that by 2010, China's power generating capacity will be 428 GW; of this, thermal plants will account for 294 GW, hydroelectric plants for 124 GW, and nuclear plants for less than 11 GW.

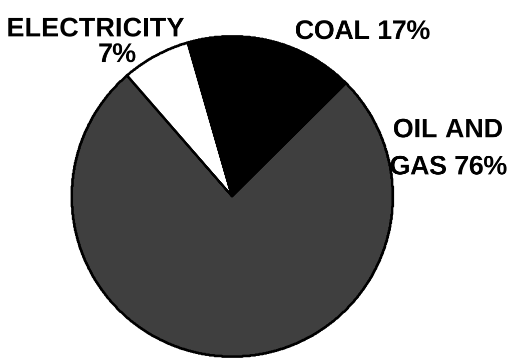
The domestic sector is the second largest end-user of energy in China. As with industry, coal is the dominant fuel consumed (75 percent); electricity (much of which is generated using coal) has recently grown in importance to 15 percent, and oil and gas represent 10 percent of the total (Figure 5). Of the three components of the domestic sector (commercial, agricultural, and residential), residential users comprise by far the largest share, using twice as much energy as the commercial and agricultural sub-sectors combined.

FIGURE 5. DOMESTIC SECTOR ENERGY SOURCES IN CHINA, 1992



While direct use of coal will remain dominant in this sector, it will decline, replaced by increased electricity consumption. Projections show that residential and commercial energy demand is forecast to increase from 10.2 Mtoe in 1991 to 65.7 Mtoe in 2010 (IEA, 1994). This growth stems from the increase in appliance use and electrification of rural areas. The share of gas in the residential and commercial sub-sectors could rise significantly, as new government policies promote increased use of natural gas. The overall trend for these two sub-sectors is reduced coal use (IEA, 1994).

FIGURE 6. TRANSPORTATION SECTOR ENERGY SOURCES, 1992



Oil and gas provide 76 percent of the energy consumed by the transportation sector. Coal comprises 17 percent, and electricity the remaining 7 percent (Figure 6). The rail system consumes approximately one-third of the transportation sector's total energy, and most of its coal and electricity. China's steam locomotives are rapidly being phased out, replaced by cleaner and more efficient diesel and electric locomotives (Sinton, 1996).

Based on the growing economy and associated increase in road travel, number of vehicles, and truck freight, projections show energy demand in the transportation sector increasing substantially over the next decade. The demand for oil in the transportation sector will increase about 7 percent per annum. By the year 2010, the transportation sector will use only oil products and some electricity, phasing out coal entirely (IEA, 1994).

1.2.2 PRIMARY ENERGY SOURCES OF CHINA

1.2.2.1 Coal

Since 1985, China has been the largest producer and consumer of coal in the world. Of the 4.4 billion tons of coal produced worldwide in 1993, China accounted for 1.2 billion tons, or more than 27 percent (USDOE/EIA, 1995). Of the total coal produced in China, more than 95 percent is hard coal, and the remainder is lignite[2]. Currently, coal accounts for 74 percent of China's total primary energy production and 73 percent of its total primary energy consumption (DRCCU, 1994).

As of 1992, demonstrated reserves of coal in China were 986.3 billion tons, of which proven in-place reserves, as defined by the World Energy Commission, accounted for 30 percent, or 295.9 billion tons (see Appendix B for further explanation of reserve classification systems). Recoverable reserves were 114.5 billion tons (DRCCU, 1994). Of the economically minable reserves, about 75 percent are bituminous (40 percent steam coal and 35 percent coking coal), 12 percent are anthracite, and 13 percent are lignite. Despite the vast reserves, production has been impacted by the scarcity of adequate modern mining equipment. While tunneling, extraction, loading, and conveying are over 95 percent mechanized in most Western countries, the level of mechanization in China, even in the large, modern, state-run mines, is only about 50 percent (EIU, 1993).

For the past several years, China's coal production has grown steadily, and it reached 1.15 billion tons in 1993 (Table 1). China exports only a relatively small quantity of coal, since coal production and consumption are approximately equal. In 1993, China exported 19.8 million tons of coal, or less than 2 percent of the coal produced. Currently, about 75 percent of the coal is directly burned; only 25 percent is converted to secondary energy. Demand for electricity generation is growing rapidly, however, and the IEA (1995) predicts that by 2000, power stations will account for about half of the total coal demand in China.

Rail is the primary means of coal transport in China. Over sixty percent of the coal produced is transported by rail, and coal uses 40 percent of China's railway system capacity (Yunzhen, 1991). In 1993, only about 18 percent (230 million tons) of raw coal was washed; nearly all washed coal is used in coking. Therefore 80 percent of the coal is transported with large amounts of non-coal material, which not only increases the burden on the rail system, but also may result in inflated coal production values. Major rail projects are currently underway, which should improve China's coal distribution and export capacity (IEA, 1995).

Over 95 percent of coal production is from underground mines. Many of the large, underground mines are located mostly in northern and northeastern China. Figure 7 shows that in 1993, there were seven provinces whose annual production exceeded 50 million tons: Shanxi (306.6 Mt); Henan (92.8 Mt); Sichuan (79.4 Mt); Heilongjiang (72.3 Mt); Shandong (68.0 Mt); Inner Mongolia (55.2 Mt); and Liaoning (52.6 Mt). In 1993, there were a total of 16 large mining areas containing state-owned key coal mines that produced over 10 million tons of coal each.

---

[2] Lignite is a low rank, low quality soft coal, with generally higher moisture content and lower heating value (4,240-8,800 kJ/kg) than hard coal. It is intermediate in rank between peat and sub-bituminous ("old brown") coal.

TABLE 1 - COAL PRODUCTION AND CONSUMPTION IN CHINA *
(IN MILLION TONS)

YEAR	PRODUCTION (By Type of Mine) State-Run	Local	Township	TOTAL	CONSUMPTION
1985	406.3	182.8	283.2	872.3	816.0
1986	413.9	181.4	298.7	894.0	860.1
1987	420.2	181.1	326.8	928.1	928.0
1988	434.5	193.9	351.5	979.9	993.5
1989	476.8	205.3	365.3	1047.0	1031.4
1990	N/A	N/A	N/A	1080.0	1038.5
1991	480.6	247.8	355.9	1084.3	1092.0
1992	482.5	251.3	380.7	1114.5	1092.4
1993	458.0	204.0	**482.8	**1149.7	1140.0

* Includes both hard coal and lignite; hard coal accounts for about 95% of total
** 1993 data includes 52.93 Mt of coal that was mined from privately owned small mines, a category that was not included in previous years

Source: China Coal Industry Yearbook, 1993; USDOE/EIA, 1994; DRCCU, 1994

The remaining 5 percent of coal production is from surface mines. Modern, large-scale open pit mining methods were introduced to China in the 1980's. The proportion of coal produced by surface mines is not expected to increase significantly in the future, however, because only 7 percent of China's total coal reserves are suitable for open pit mining.

In 1993, China consumed 1.14 billion tons of coal; of this, approximately 1.10 billion tons were hard coal and the remaining 40 million tons were lignite. Approximately 32 percent of the total coal consumed was used for power generation. The outlook for coal consumption in China is continued growth, approximately 3 percent per year between 1994 and 2010 (IEA, 1994). Much of the growth will be in the electricity generation sector. Coal will also continue to be important in the residential sector, replacing traditional rural (biomass) fuels. Constraints to growth include the existing transportation and distribution networks, which need to be modernized and expanded to meet current and future demand.

China's overall dependence on coal has actually decreased over the past decades. In the 1950's, 96 percent of China's total energy output was from coal. During the 1960's, this percent fell to 89 percent, and has stabilized over the past several years at around 75 percent. However, a steady increase in coal production is expected to continue, with an annual average increase of 5 percent from 1985 to present. As shown in Table 1, China's coal production has grown steadily since 1985, with over 1.1 billion tons produced in 1993. The Chinese government has set 1.4 billion tons of coal as a production target for year 2000.

Figure 7. Map of China Showing 1993 Coal Production (in Million Tons) From Provinces Producing More than 50 Million Tons of Coal

Coal Industry Organization

The coal industry of China has recently undergone major reform and restructuring. Prior to 1993, the China National Coal Corporation (CNCC), a company under the Ministry of Energy, administered the industry in China. Later, several other regional coal companies controlled the state-run mines in northern and northeastern China. The China National Local Mine Development Corporation managed China's thousands of small local and provincial mines; its primary function was enforcing government safety regulations (JP International, 1990).

In March 1993, the Chinese government established the Ministry of Coal Industry (MOCI) with the intent of restructuring the coal industry. According to the China Coal Industry Yearbook (1993), the MOCI's main functions are to develop policies for the coal industry related to:

- increasing use of coal resources;
- conducting coal industry science and technological research;
- optimizing production; and
- creating more diversity in coal markets and economic systems to make the industry more efficient.

The establishment of the MOCI will encourage efficient and cost-effective use of China's coal resources, and may help eliminate existing barriers to increase coalbed methane development. Sections 1.2.4 and 1.3.3 of this report discuss the organization of China's energy and coalbed methane sectors, respectively.

China has three principal types of coal mines, as shown in Table 1: State-run (central government); Locally-controlled; and Township and Private mines. Through the 1970's, state-run mines accounted for all coal production in China. Since the 1980's, however, local and township mines have become increasingly important, and now over one-half of all coal produced comes from these smaller mines. The fastest growth in production has occurred in the township mines. In 1993, the production from state-run key coal mines decreased by 5 percent, while total production from township and privately owned mines exceed production from all of the state-run mines.

State-Run Mines

As of late 1993, there were 105 Coal Mining Administrations (CMAs) operating 626 state-owned mines, which produced about 40 percent of China's coal (458.0 million tons in 1993, as shown in Table 1) (DRCCU, 1994). State-run mines employ more than 3.5 million workers.

China established these mines to meet production quotas for coal defined under the central plan, and placed them under control of the CNCC. In general, state-run mines are larger, more modern and relatively highly mechanized, many using longwall mining methods. Typical mechanization includes cutting equipment and hydraulic pumps, and the more modern mines have power roof supports and mechanized loading equipment. However, many of the state-run mines still lack mechanization, with extraction by drilling and blasting or pneumatic pick and shovel. Due to the overall low degree of mechanization, coal production at government mines averages about 1.4 tons per man shift. Annual production in these mines typically ranges from 100 thousand tons to 5 million tons of coal, with production at the largest state-run CMAs exceeding 10 million tons per annum.

Historically, the state allocated all of the coal produced according to the coal distribution plan. Today, the government allows a considerable amount of coal to be freely traded on markets, while maintaining some control of sales activity to ensure necessary supplies for key infrastructural projects.

China removed coal price controls in early 1994 (Dorian, 1995). The price of coal has increased because of transport shortages, and the government has made great efforts to solve this infrastructural deficiency. Along with price reform, the government has implemented other measures, including laying off surplus laborers and developing lucrative businesses, in an effort to reduce costs and improve efficiency.

Locally-Controlled Mines

There are approximately 1800 locally-controlled mines in China, which include county, provincial, and prefectural mines. Typically, a local mining area (LMA) contains several of these mines, and may span an entire coal-producing area between two or more cities. These LMAs employ more than 1.3 million people. As shown in Table 1, local mines produced 204.0 million tons of coal in 1993, or nearly 18 percent of the total coal produced (DRCCU, 1994).

The larger locally-run mines operate similarly to the non-mechanized government mines and their annual production ranges from 50 - 100 thousand tons. These mines are financed and owned by local governments, with a minimum of central government investment. Coal produced from these mines is used locally, with a portion allocated to the state coal distribution plan. These mines operate with more local control and options, but are significantly less mechanized than the state-run mines.

Township (Collective) and Private Mines

In the past several years, the number of township mines has grown tremendously (there are currently an estimated 79 thousand). In 1993, township mines produced 429.9 million tons of coal (DRCCU, 1994). These are collective, privately financed and operated mines. There is essentially no government investment involved. Though the production of coal from township mines is increasing, they have the lowest level of mechanization, as well as the poorest safety records. The smallest township and private mines mine coal seasonally by hand pick and shovel.

Private mines are a recent development in China, with coal production data available only since 1993. In 1993, privately owned, small coal mines produced 52.9 million tons of coal, accounting for 5 percent of the total coal produced. These mines may become larger as reforms within the coal industry create competition in coal markets.

1.2.2.2 <u>Oil</u>

China is the world's fifth largest oil producing country, with approximately 2 - 3 percent of global reserves. Oil production was 20 percent of China's total energy supply in 1993. There are 151 oil-bearing basins onshore and on the continental shelf of China. Total estimated oil resources are 40-60 billion barrels, and proven oil reserves are 24 billion barrels (West, 1994).

The first oil production in China was at the Daqing oilfield, Manchuria (now Heilongjiang Province) in 1959. Another large field, the Shengli field in Shandong Province, also added significantly to total production in the early 1960's. Although both of these fields showed strong growth through the 1970's, their production appears to have peaked. Many other oil fields have since developed, mainly in the north and northeast (Figure 8; Box 1). Production reached an initial peak in 1979 at 106 million tons, declined in the early 1980's, then gradually increased to 145 million tons in 1993 (Table 2).

BOX 1. SUMMARY OF OIL AND GAS DEVELOPMENT IN MAJOR CHINESE BASINS

According to the DRCCU (1994) and West (1994) there are several basins with significant oil and gas activity underway, and additional exploration and development is planned:

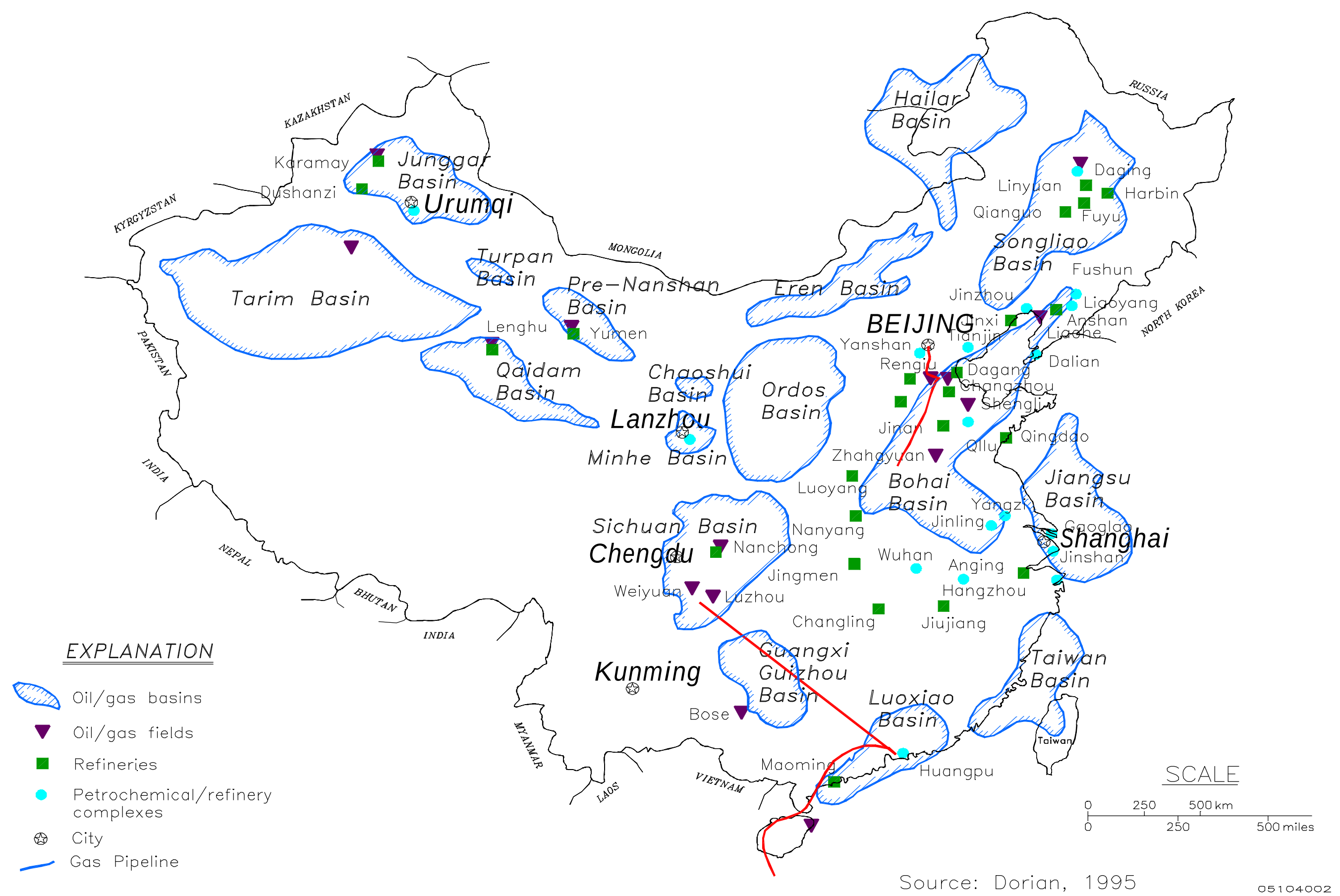
- **Tarim Basin, Xinjiang.** The Tarim Basin, in southern Xinjiang Ugyur Autonomous Region, is the most prospective in China. Forty drilling rigs were working in this basin at the end of 1993. The basin contains eleven oil fields which produced approximately 2.4 Mtoe in 1994. Most of this oil was produced from five fields in the northern and central portions of the basin.
- **Junggar Basin, Xinjiang.** The Junggar was the earliest basin developed in northwestern China. In the 1990's, several other oil fields were discovered in the central and outer parts of this basin.
- **Sichuan Basin.** In recent years, there have been some exploration breakthroughs in Chuandong. In Daianchi, a series of large gas fields have also been found. Gas fields have also been discovered in Chuanzhong and Chuanxi.
- **Ordos Basin.** The gas field in the central portion of this basin (sometimes called the Shaan Gan-Ning Basin) shows strong potential for development to meet the gas needs of large cities.
- **Songliao and Bohai Bay Basin.** Several undeveloped fields have been found in the Fuyang oil reservoir in the Liangjiang area, the beaches of Bohai Bay, and the Kailuan Basin and Erlian Basins.

TABLE 2 - CRUDE OIL PRODUCTION AND CONSUMPTION IN CHINA (IN MILLION TONS)

YEAR	PRODUCTION	CONSUMPTION
1980	105.9	87.6
1985	124.9	91.7
1986	130.7	97.3
1987	134.1	103.1
1988	137.1	110.9
1989	137.6	118.6
1990	138.3	114.7
1991	139.6	124.6
1992	141.1	131.2
1993	145.2	155.2
Source: China Energy Databook, USDOE/EIA, 1994; Oil and Gas Journal, 1994; USDOE/EIA 1995.		

Exploration, development and production of onshore oil and natural gas in China is planned and managed by the China National Petroleum Corporation (CNPC). It administers 20 oil and gas enterprises. In the 1980's, China began developing offshore oil with the assistance of Western companies. To provide incentives for foreign investment, the China National Offshore Oil Corporation (CNOOC) was established to explore, develop, produce and market offshore oil. Current activity is near Hainan Island and the Pearl River Mouth Basin. Exploration is also underway in the Wan'an Bei area (Spratly Islands) of the South China Sea, although China is disputing ownership of these waters with Vietnam (China Energy Report, 1994).

Figure 8. Map of China's Oil and Gas Deposits, Refineries and Petrochemical Complexes



Recent discoveries in the Tarim Basin in northwest China may shift onshore activity westward. China's largest new discovery, it has proven in-place reserves of 3.6 billion barrels, and has attracted foreign investment. There are barriers to developing the Tarim Basin, however, particularly its remote location, lack of infrastructure, and associated developmental costs.

Rapid economic growth has caused a significant increase in the demand for petroleum products. In 1993, import of crude oil and petroleum products increased sharply, export decreased, and China became a net importer of crude oil (Table 2) and petroleum products. This occurred at least two years earlier than most energy analysts had predicted, caused by substantial increases in the use of motor gasoline, diesel fuel, and fuel oil. Despite domestic shortfalls, China continues to export crude oil (an estimated 15 million tons in 1995) because of desperately needed foreign exchange earnings. China imported an estimated 23 million tons of crude in 1995, primarily from Indonesia, Oman and Malaysia. China also imports petroleum products from Singapore, South Korea, the US, and several other countries. The long-term projection for oil demand by year 2000 is 200 million tons (Oil and Gas Journal, 1994), of which China will import 65 million tons (Ryan and Flavin, 1995).

1.2.2.3 <u>Conventional Natural Gas</u>

The earliest significant natural gas production in China was in 1960. Associated gas (gas in association with oil) was produced at the Daqing oil field in Sichuan Province. Since the 1970's, Sichuan has become the dominant gas-producing region of China, and accounts for almost one-half of total natural gas production. Recent discoveries in the Tarim Basin of northwest China and off Hainan Island show great potential.

As shown in Table 3, China produced nearly 16 billion cubic meters of natural gas in 1993. The Chinese government plans to increase natural gas production, but at present it still represents little more than 2 percent of China's total energy mix. Industry consumes over 80 percent of the total natural gas produced. The main end-uses include feedstock and fuel for chemical fertilizer manufacturing and ammonia plants. A large portion of consumption occurs within the oil production industry itself. Over the past several years, however, use by the residential sector has been increasing.

According to recent estimates, China's proven reserves of natural gas may be in excess of 1.5 trillion cubic meters (Dorian, 1995); undiscovered gas resources are estimated at 8.5 trillion cubic meters (Sinton, 1996). Despite large resources of natural gas, China's gas industry has received only a fraction of the funds provided to the oil industry. On an oil-equivalent basis, the ratio of oil to gas production in the United States and the former Soviet Union is roughly 1:1; in China, it is 10:1 (East-West Center, 1993).

From the 1950's to the 1980's, China's natural gas prices were frozen, even though production costs doubled over this period. As the Chinese government recognized the value of natural gas resources in the mid-1980's, it adopted some changes in policy that provide incentives to revitalize the industry. However, natural gas prices are still significantly below operation and financing costs. Along with reforms affecting the market price of coal, China plans to free prices of natural gas to provide production incentives. Now the government also promotes the use of natural gas for residential sector and municipal activities.

TABLE 3 - NATURAL GAS PRODUCTION AND CONSUMPTION IN CHINA
(IN BILLION CUBIC METERS)

YEAR	PRODUCTION	CONSUMPTION
1980	14.4	14.2
1985	13.0	12.9
1986	13.6	13.7
1987	13.9	14.0
1988	13.9	14.2
1989	14.4	14.3
1990	14.4	14.4
1991	15.0	14.9
1992	15.0	15.1
1993	15.9	15.8
1994	16.7	NA
Source: USDOE/EIA, 1995; Dorian, 1995		

Principal barriers to increased gas production in China are insufficient pipeline and gathering systems to transport gas from fields to markets. Pipeline construction peaked in the 1970's, and most existing pipelines are concentrated in Sichuan Province. Long-distance pipeline transport is still relatively rare. Chapter 3 (Section 3.4.2) contains additional information regarding gas pipeline systems in China.

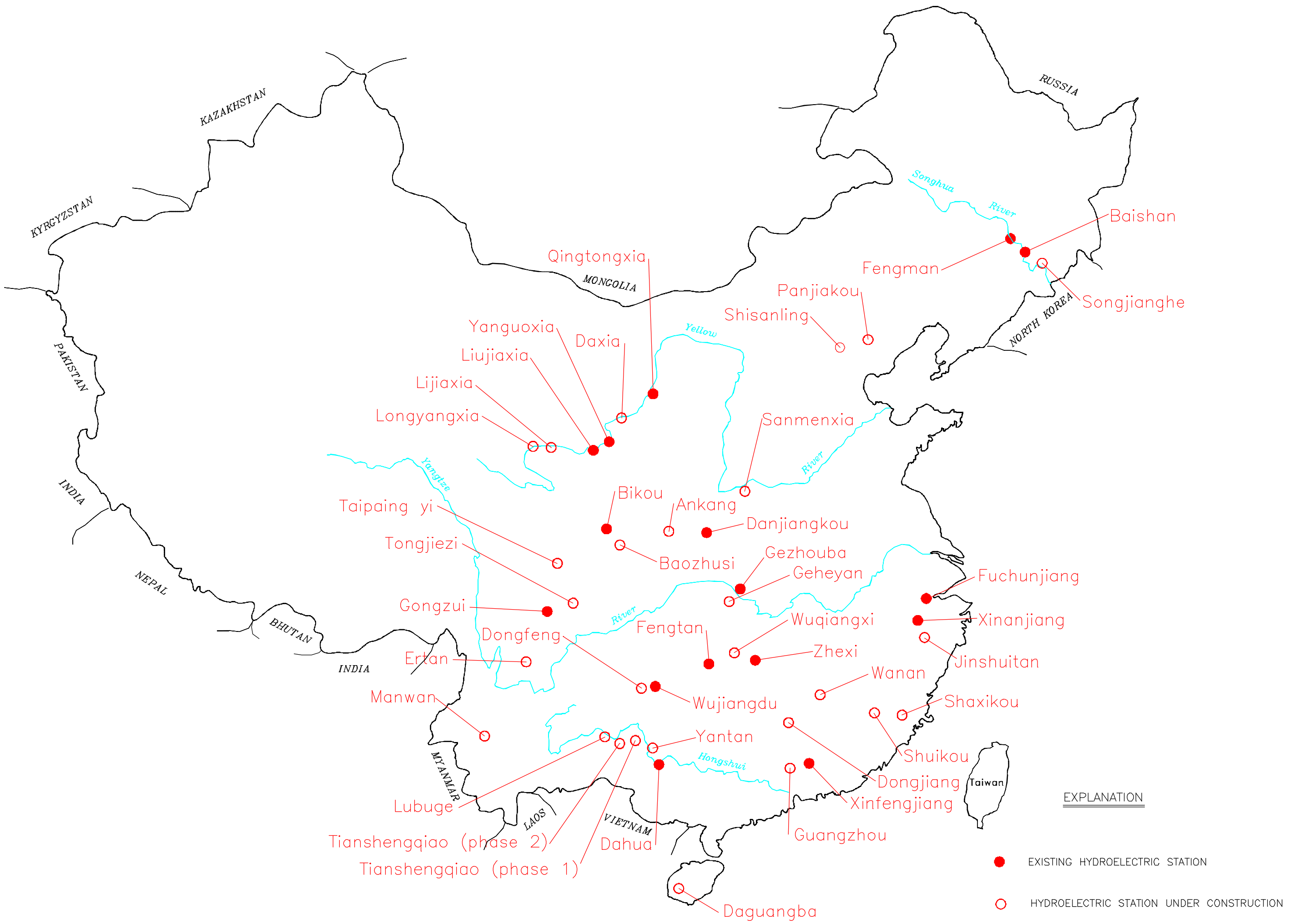
1.2.2.4 Hydroelectric Power

Hydropower accounts for over 5 percent of China's total energy consumption, and about 19 percent of its electricity generation. The nation's hydroelectric potential is the largest in the world. According to official figures, this potential amounts to 676 gigawatts (GW), of which 380 GW is suitable for exploitation (DRCCU, 1994). The current available capacity is about 40 GW, but official plans project that it will double to 80 GW by 2000. Figure 9 shows the location of existing and planned hydropower developments.

The majority of existing hydroelectric plants are very small scale. According to the Asian Development Bank, around 60 percent of the 2000 counties in China have their own mini-hydroelectric schemes, and over half of them rely solely on hydroelectricity for their power. Over the period 1980 to 1990, production of hydroelectric power in China more than doubled, increasing from 58.2 billion kilowatts to 126.4 billion kilowatts. Consumption is keeping up with production, and demand is expected to increase into the next century.

Approximately one-third of the 60 GW of electricity generation plants in China currently under construction are hydroelectric (IEA, 1994). About 80 hydroelectric power stations are under construction, with a total projected capacity of over 20 GW. The majority of large sites are in southwestern China, which possess two-thirds of the country's generation potential. To provide auxiliary operation for large thermal power stations and nuclear power stations with peaking capacity to the power system, a group of pumped storage stations are also under construction.

FIGURE 9. EXISTING AND PLANNED HYDROELECTRIC STATIONS IN CHINA



Source: DRCCU, 1994

Several large hydroelectric projects are planned; of these, the largest is the Three Gorges project on the Yangtze River. With a capacity of over 17 GW, it could make a significant contribution to China's electricity demand. The project, however, is not proposed for completion until 2010. The large hydroelectric projects tend to be in remote areas that are difficult and expensive to develop. Potential problems include flooding of agricultural lands, dislocation of villages, and degradation of adjacent lands and deltas. Several medium-scale hydroelectric projects are also planned, as are small scale, local power stations.

1.2.2.5 Other Energy Sources

Nuclear and biomass energy comprise less than 1 percent of the fuel mix in China. China possesses nuclear fuel resources, but until 1993, had only one small nuclear plant in operation. The first phase of the Qinshan Nuclear Power Station (300 MW) in Zhejiang, and two units of Daya Bay Nuclear Power Station in Guangdong Province are operational. The second phase of Qinshan Station and a second nuclear power station in Guangdong Province will be constructed by the year 2000. A number of coastal provinces are conducting feasibility studies, and other plants may be established in the future (EIU, 1993).

In certain regions of China with intense energy demand, particularly eastern, southern, and northeastern coastal regions, nuclear power can potentially increase local energy supplies. Official plans for the year 2000 have targeted 6 GW of available capacity and 6 GW under construction, to increase to 1.2 GW per annum after 2000 (IEA, 1994). If the installed capacity after 2000 can grow at this rate, production will reach 15 GW by 2010. These may be optimistic targets, given the long periods of construction required for nuclear plants, but the importance of nuclear energy will continue to increase in China.

Biomass, a renewable energy source, is the main source of energy for many rural households; wood, crop wastes, and dung are the primary fuels. While rural industry uses some of this energy, the residential sector consumes the majority, primarily for space heating and cooking. Over the past 10 years, the annual growth rate of energy consumption in rural areas was about 9 percent, higher than the nationwide energy production growth rate.

Approximately 4.6 million biogas digesters, producing 1 to 1.5 cubic meters of biogas per digester per day for six to eight months per year, are currently in use, mainly in southwestern China (Sinton, 1992). There were 5.25 million users of biogas digesters in 1993, producing an average of 273 m^3 per household in rural areas. Most serve individual families, but some community and factory digesters are also in operation. There are over 600 large scale projects treating organic sewage from industries and agricultural operations, which can provide biogas to over 84,000 households in urban areas year around (IEA, 1994).

1.2.3 CHINA'S CURRENT ENERGY STRATEGY

In its drive for modernization, China is confronted with serious challenges in its energy sector. Energy production is insufficient to meet the needs of its rapidly growing economy, and China faces population, environmental, and resource pressures, as well as the need for updated technology. In order to solve these problems, China must undertake a new, non-traditional development strategy aimed at maintaining sustained development. According to the Coal Information Institute, China's new development strategy, which will differ from those used in both developed and developing nations, is basically conceived as follows:

Energy Conservation: A Priority

Since the early 1990's, China's government has taken various steps toward conserving energy. Reforms in energy pricing, taxes and financing have improved energy savings. The government has also invested large amounts of capital in energy conservation programs. Much remains to be done, however. If China's energy efficiency were increased to the levels of developed countries, energy consumption could be reduced by at least 30 percent. Implementation of this strategy is key to maintaining sustained, stable and coordinated development of China's economy, and is the most economical means of reducing air pollution and CO_2 emissions.

Improvements to the Energy Sector

At present, the main challenges in China's energy sector are:

- heavy dependence on coal;
- under-use of electricity and natural gas;
- low level of conversion of primary energy into electric energy;
- low rate of electric power consumption;
- high rate of industrial sector energy consumption, relative to that of the communication and transportation sectors;
- heavy dependence (70 percent) on biomass energy consumption in the rural areas;
- lack of coordination between the coal, electricity and transportation industries ;
- inefficient energy industry infrastructure, with too many small-scale coal mines and thermal power plants;
- lack of coordination between the oil extraction and refining industries;
- a serious imbalance in the distribution of energy from producing regions to consumers; and,
- excessive export of crude oil, despite a domestic supply shortfall, because of the need for foreign exchange earnings.

Therefore, China's energy strategy will focus on optimizing resource use and diversifying the energy mix, using recent scientific and technological advances. This is also a fundamental means of ensuring that energy and the economic development take place in an environmentally sound manner. The main features of China's energy strategy include improvements in:

- coordination of scientific and technological advances to optimize energy use to the greatest benefit of the economy and society;
- maximizing benefits from the diverse primary and secondary energy types that can be used in China;
- coordination of energy production with transportation and consumption needs;
- balancing energy development and consumption with preservation of the environment;
- coordination of the pace, magnitude, and sequence of energy development projects;
- optimization of capital distribution;
- use of rational economic policy; and,
- use of appropriate technologies.

End User-Oriented Principle

The energy strategy proposed by the Chinese government is based on end user consumption. Energy needs should be determined by the energy value of a given fuel in relation to the overall cost to produce and distribute that fuel. In most cases, fuel needs can be met by various forms of energy; it is therefore necessary to select the best fuel both in terms of technology and economy in order to provide energy services to end users at the lowest cost. With the current shift from a planned economy to a market economy in China, there exists a favorable environment for implementing this strategy.

Developing Natural Gas Resources, Including Coalbed Methane

Since the 1960's, the worldwide growth rate of natural gas exploration and production has been higher than that of petroleum. During the period 1971 to 1990, the annual growth rate of natural gas production was 3.68 percent, while that of petroleum was only 1.31 percent. The annual growth rate of proven natural gas reserves was 5.5 percent, compared to a 3 percent growth rate for petroleum. Natural gas accounts for 25 percent of the world's primary energy production, and 22 percent of its consumption. In China, however, consumption and production of natural gas account for only about 2 percent of the nation's total energy mix. China must place strong emphasis on the development of natural gas, and must adopt pricing, taxation and investment management policies that will promote development of the natural gas industry.

Coalbed methane has great potential in the China's future. The United States uses surface wells to recover coalbed methane from non-mining areas, and a variety of techniques to recover coalbed methane from mining areas. Production of coalbed methane in the United States began in 1982 and increased to more than 21 billion cubic meters in 1994, exceeding the current production of natural gas in China. Given its abundant coal resources, and the gassy nature of that coal, it is not unrealistic to expect that China could achieve similar coalbed methane production levels over a comparable time period. This would more than double China's current natural gas production, and increase the share of natural gas in its fuel mix from the current level of 2 percent to 4.6 percent. In addition, because coalbed methane liberated during the mining process is a greenhouse gas, recovery of this methane will help protect the global environment.

Developing Clean Coal Technology

China's coal consumption accounts for about 24 percent of total world coal consumption. Coal constitutes 75 percent of China's primary energy consumption, and provides 76 percent of its electric energy. It also provides 75 percent of the energy required by China's industrial sector, 60 percent of the raw materials for its chemical industry, and 80 percent of the energy used by the commercial and residential sectors. The predominance of coal in the energy mix is not expected to change significantly in the near future.

The environmental problems associated with coal combustion are severe, seriously restricting social and economic development in China. This is particularly true in large cities and in regions where high sulfur coal is burned. China's neighboring countries have already expressed their deep concern over emissions of SO_2 and NO_x resulting from high amounts of coal combustion in China. In addition, global warming associated with emissions of CO_2 from coal combustion has become a focal point of the international community.

Even if China is successful in its attempts to diversify its fuel mix, the nation will continue to consume large quantities of coal. Given that fact, China believes that the most practical way to address associated pollution problems is to develop clean coal technology, thus reducing pollutant emissions. MOCI has stated that China must adopt clean coal technology as part of a mid- to long-term energy strategy.

1.2.4 GOVERNMENT ORGANIZATION OF CHINA'S ENERGY SECTOR

In 1993, China restructured the government organization of its energy sector in order to expedite the shift from a planned economy to market economy. At the central government level, China created a National Economic and Trade Commission; dissolved the Ministry of Energy; and reestablished the Ministry of Coal Industry and the Ministry of the Electric Power Industry. Concurrently, six specialized investment corporations, including the Energy Investment Corporation, that were all under the State Planning Commission were merged into the State Development Bank.

Figure 10 is a schematic of the organizational structure of China’s energy industry. The key components of the industry are discussed below.

State Planning Commission

This commission oversees the Energy and Transportation Department, which is responsible for formulating national development policy and strategy. The department also formulates annual- and long-term plans for the energy sector, and reviews and approves key construction projects.

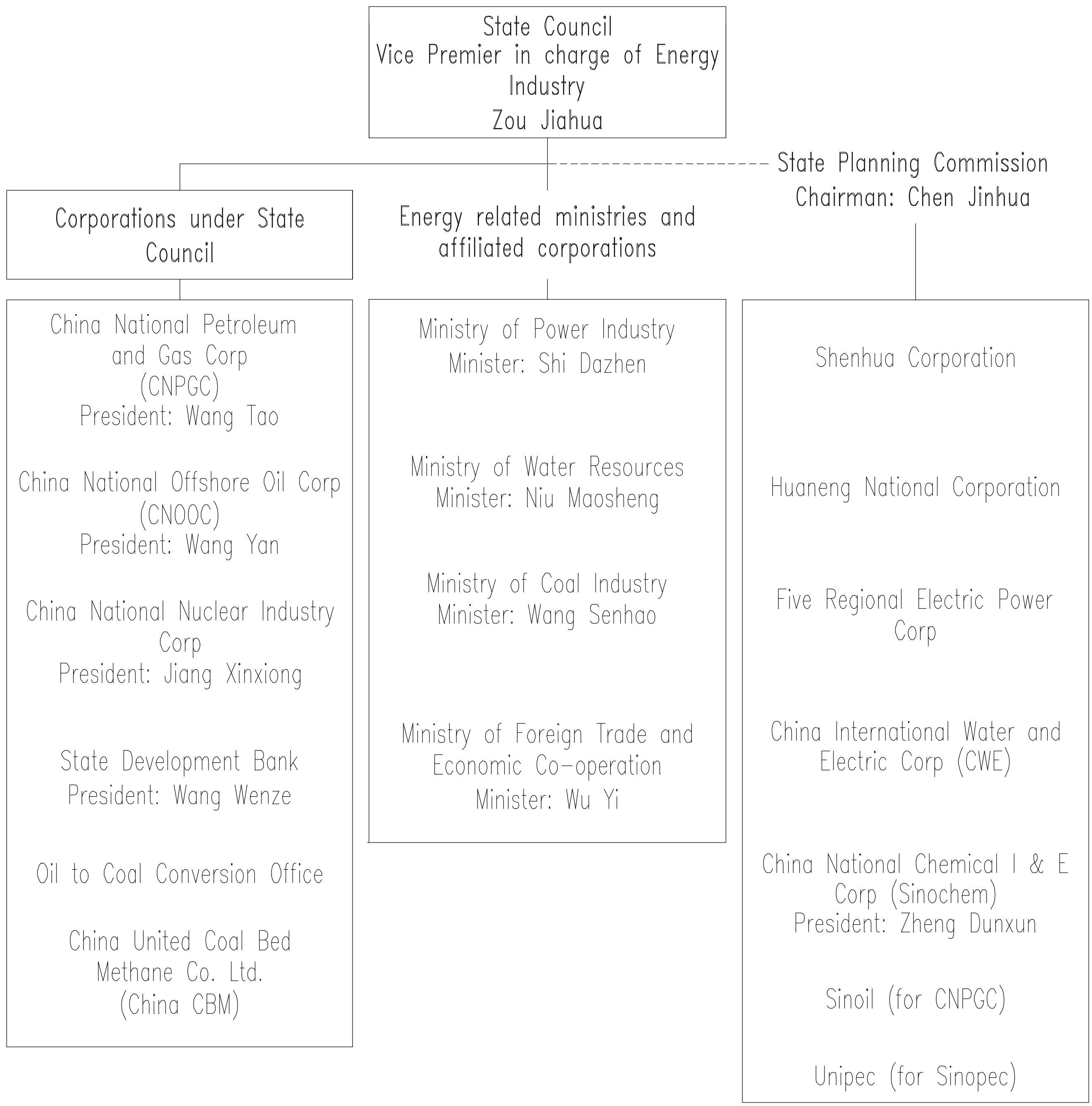
State Economic and Trade Commission

This commission includes the Department of Resource Conservation and Comprehensive Utilization (DRCCU), which manages the use of energy and raw materials (including renewable energy). It will be involved in formulating the national energy development strategy policies and plans, as well as reviewing and approving key projects for technical modernization in collaboration with the State Planning Commission. It also oversees the prevention of industrial pollution.

State Science and Technology Commission

This commission oversees the Department of Science and Technology, which is involved in the formulation of science and technology development strategies, policies and plans related to energy sector, in collaboration with the State Economic and Trade Commission and State Planning Commission. It is also responsible for organizing and coordinating the implementation of important science and technology programs, with input from various central departments, local organizations and technical universities. It is in charge of organizing and implementing the international exchanges and co-operation at the governmental level.

Figure 10. Organizational Structure of China's Energy Industry



Source: Dorian, 1995; CII, 1995

05139001

Ministry of Coal Industry (MOCI)

As noted in Section 1.2.2.1, MOCI is the leading organization of China's coal sector, whose responsibilities include formulating coal industry development strategy, policies, and annual- and long-term plans. MOCI also formulates regulations and rules for the coal industry; reviews and approves projects; manages key personnel in the enterprises under its direct control; supervises of mine safety throughout the country; supervises and manages national assets in large coal enterprises; develops coal markets; manages science, technology, and education work within the coal sector; supplies information services; and organizes and manages governmental and international economic and technical co-operation.

Ministry of Electric Power Industry

In 1993, the Ministry of the Electric Power Industry (MEPI) was established with the dissolution of the Ministry of Energy. MEPI is an administrative organization that manages the national electric power sector in China, and its responsibilities are similar to those of MOCI for the electric power industry. MEPI is charged with direct management of five electric power groups in Northeast China, North China, East China, Central China and Northwest China; direct control of electric companies in the six provinces of Shandong, Fujian, Sichuan, Guangxi, Guizhou and Yunan; and management of Huaneng Group's electric company and South China Electric Corporation. The Ministry also performs sectoral management of electric power companies in Guangdong, Hainan and Tibet.

Other Energy Organizations

Several other national corporations perform administrative functions as authorized by the central government. These ministry-level corporations report directly to the State Council and are responsible for the business aspects of energy production. They include the China National Offshore Petroleum Corporation, China National Petroleum and Gas Corporation, China National Petrochemical Corporation, China Nuclear Industry Corporation, and the China United Coalbed Methane Company, Ltd. (China CBM). Formed in 1996, China CBM has exclusive authority for administering coalbed methane development in China. Section 1.3.3 contains additional information on this new company.

1.3 THE ROLE OF COALBED METHANE

As the world’s largest coal producer, China has enormous coalbed methane reserves, and great potential to recover this energy source. Recovery and use of coalbed methane contained in coal seams in conjunction with mining results in the production of two resources instead of just one. Coal mine methane drainage and recovery allows increased coal production and safety in the mine environment. China’s vast coal reserves also create an opportunity for coalbed methane recovery in unmined areas.

This section provides a brief history of coalbed methane production and use worldwide, with a special focus on recent coalbed methane production in the United States as a potential model for China.

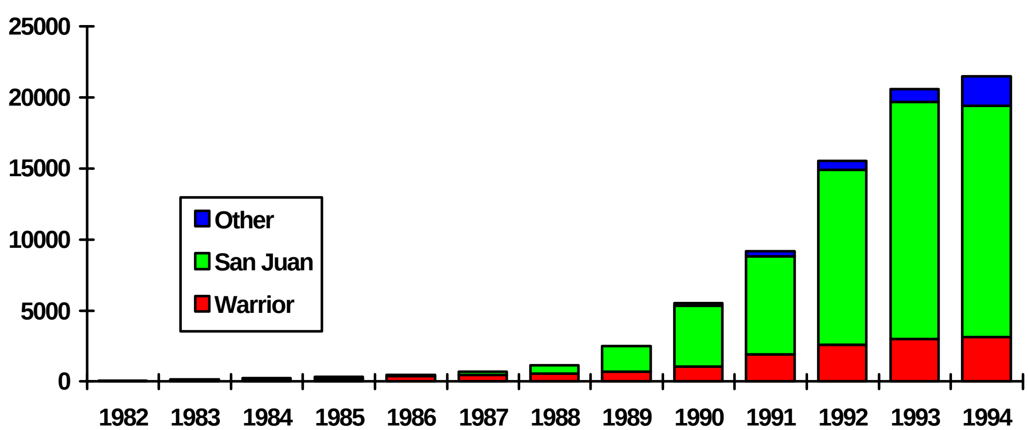
1.3.1 HISTORICAL PRODUCTION WORLDWIDE

Historically, methane has been collected and vented from coal mines worldwide, primarily for safety reasons. The earliest experience with methane drainage is from Europe, where coal mining has a long history. The first attempts to isolate and pipe gas from a coal mine in Great Britain occurred as early as 1733. In an explosion at another coal mine in 1844, an investigation determined that gas accumulations in the gob was the cause. Investigators recommended that in the future, pipes should drain the gob, carrying gas to the surface. In-mine, cross measure holes were used in Wales in the late 1800's to drain gas from virgin coal beds. The first successful large-scale use was in a German colliery in the 1940's (Diamond, 1993). By this time, numerous coal mines worldwide were using various methods of underground methane drainage methods to remove gas associated with mining.

Only recently has coalbed methane gained attention as a source of competitive, saleable natural gas. Coalbed methane has been produced in commercial quantities in the United States since 1981. The industry has evolved to include not only degasification in conjunction with underground coal mines, but also stand-alone projects for the commercial production of natural gas. Conventional oil and gas production practices have been modified for coalbed methane's unique reservoir characteristics and production techniques. These include low wellhead pressure; separation of gas and water; compression of gas; and procedures to produce and, in many cases, dispose of large volumes of water. At active coal mines, strategies for commercial production of methane can be incorporated into existing in-mine and gob gas drainage systems. At mines worldwide, recovery technologies can be adapted to employ methane as an energy source, rather than venting it into the atmosphere.

In the United States, coalbed methane production has grown rapidly over the past decade, particularly in the past several years. Figure 11 illustrates the tremendous increase in coalbed methane production from 1982 to 1994. Production in 1991 exceeded 9.0 billion cubic meters, and by 1994 had exceeded 20 billion cubic meters. Over 90 percent of the 1994 production came from two major coal basins, the San Juan and Black Warrior. Within the past four years, several other basins have also begun producing commercial quantities of coalbed methane. Expanded production is projected over the next decade, from currently producing areas as well as from new basins.

FIGURE 11. U.S. COALBED METHANE PRODUCTION (IN MILLION CUBIC METERS)



Source: GRI, 1993; Petroleum Information, 1994 and 1995; ERNGC, 1

Figure 12 shows the major US coal basins and associated in-place coalbed methane resources. Table 4 summarizes 1994 US coalbed methane production by state. Most of the production is from vertical wells, in areas without existing underground coal mining. However, coal mine methane recovery and use has proven profitable at mines in Alabama, Virginia, Utah and West Virginia. Collectively, gas production at these mines exceeded 800 million cubic meters in 1994. Chapter 3 describes current projects for recovering and using coalbed methane in conjunction with coal mining, in the United States as well as other countries.

TABLE 4 - SUMMARY OF 1994 US COALBED METHANE PRODUCTION FOR USE

STATE	NUMBER OF WELLS	PRODUCTION (Million m^3)	RECOVERY METHOD (Type of Well)
Alabama	2,956	3,155	Vertical, Gob, Horizontal
New Mexico	1,663	11,734	Vertical
Colorado	1,006	5,558	Vertical
Virginia	492	800	Vertical, Gob, Horizontal
Wyoming	136	71	Vertical
Utah	104	136	Vertical, Horizontal
West Virginia[3]	<50	~69 -143	Gob, Horizontal
TOTAL	> 6,357	>21,523	

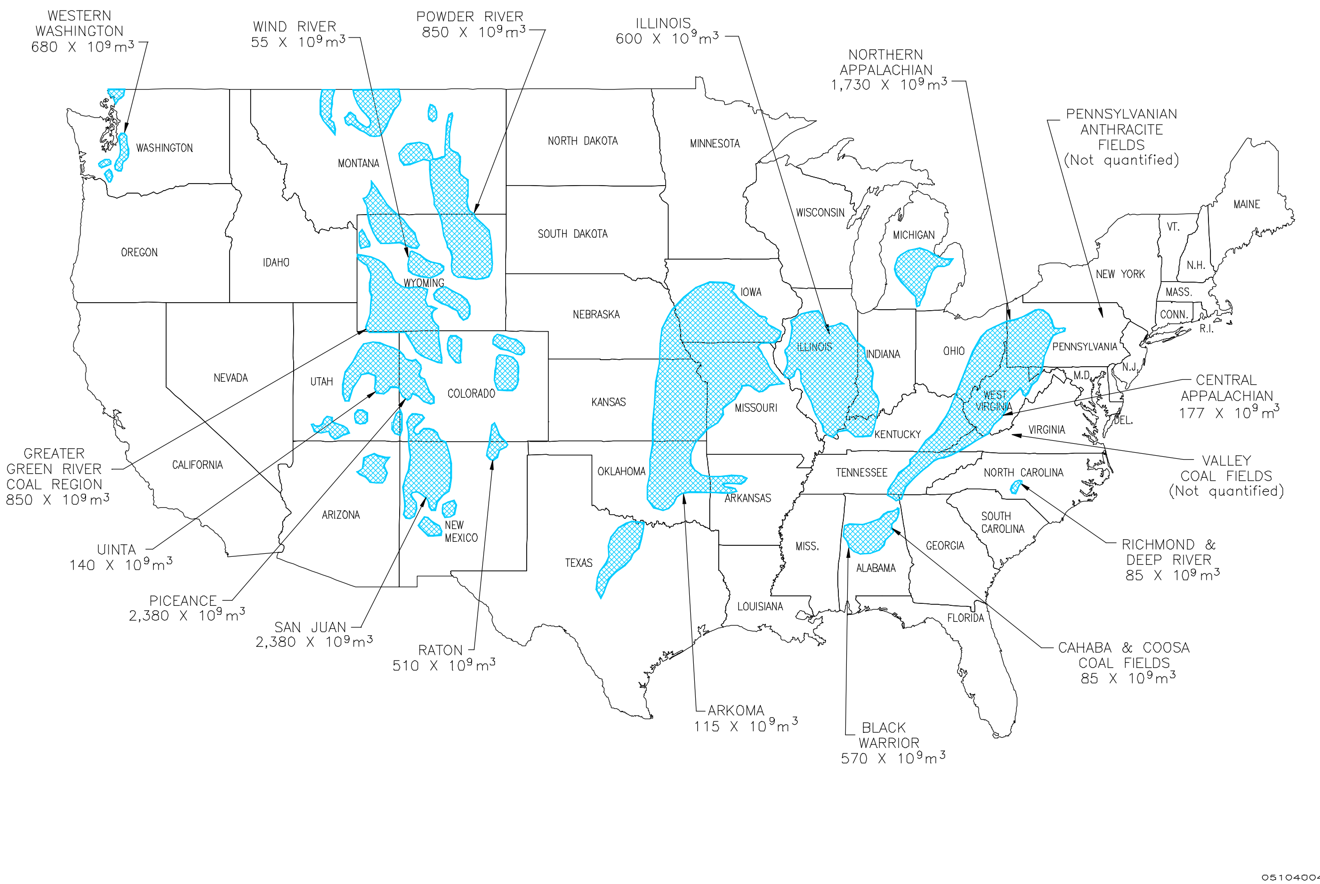
SOURCES: GRI Quarterly, 1993 (for data through 1992); Petroleum Information, 1994 and 1995 (for 1993 and 1994 data on western states); Lewis, 1995; USEPA, 1995a; Byrer, 1995; Biggs, 1995 (for data on West Virginia).

Worldwide, preliminary estimates of coalbed methane resources range from 113 to 255 trillion m^3 (4000-9000 TCF) (USEPA, 1993). Encouraged by the success of the US coalbed methane industry, activities have increased in several other coal-producing countries, which now have coalbed methane projects in various stages of development. Countries with strong potential include Australia, Canada, China, Czech Republic, Germany, India, Poland, Russia, South Africa and Ukraine. Table 5 lists coal production and estimates of associated methane resources and methane emissions from mining for the top ten coal-producing countries of the world; collectively, they account for 90 percent of total global methane emissions from coal mines. China, the United States, the United Kingdom, and the Former Soviet Union (primarily Russia and Ukraine) account for approximately 70 percent of global emissions from coal mining. These countries also contain the greatest potential methane resources.

Historically, relatively few countries have collected detailed coalbed methane emissions data. The U.S. Bureau of Mines estimates methane emissions using Mine Safety and Health Administration (MSHA) reports on mine ventilation emissions. However, these estimates contain assumptions and carry a level of uncertainty, particularly relative to total methane flux. Emissions data from coal mines in other countries contain these same uncertainties; for many countries, less data exists. Therefore, the emissions estimates presented in Table 5 are considered preliminary.

[3] West Virginia state agencies do not collect or release coalbed methane production data; numbers presented here reflect estimates based on personal communication with the sources listed above.

FIGURE 12. PRINCIPAL COAL–BEARING BASINS OF THE U.S. AND ESTIMATES OF IN–PLACE CBM RESOURCES
(after Rice, 1993)



The nature of coalbed methane within seams is complex and accurate resource estimation is difficult. The estimated coalbed methane resources in Table 5 are based on gross assumptions concerning the gas contents of different coals and a large amount of geological data already gathered on coal resources in each country. As more information becomes available, estimates can be refined.

TABLE 5 - WORLDWIDE COAL PRODUCTION, ESTIMATED METHANE RESOURCES, AND ESTIMATED EMISSIONS FROM COAL MINING (1990)

COUNTRY	**COAL PRODUCTION (In Million Tons)**		**EST. METHANE RESOURCE (Trillion m^3)**		**EST. METHANE EMISSIONS (Billion m^3)**	
	UNDERGROUND	SURFACE	LOW	HIGH	LOW	HIGH
CIS	393	309	42.5	79.0	7.1	8.9
China	1,023	43	30.0	35.0	14.0	24.5
United States	385	548	11.3		5.3	8.4
Australia	52	154	8.5	14.5	0.7	1.2
South Africa	112	63	3.9		1.2	3.4
India	109	129	1.4		0.6	0.6
Germany	77	359	2.8		1.5	1.8
United Kingdom	75	14	1.7		0.9	1.3
Poland	154	58	0.4	1.3	0.9	2.2
Czech Republic	22	85	.05	0.37	0.4	0.7
TOTAL TOP 10	**2,401**	**1,762**	**102.5**	**151.3**	**32.6**	**53.0**
WORLD TOTAL	**4,740**		**113.2**	**254.7**	**36.0**	**58.4**
Sources: USEPA, 1993; Schraufnagel, 1993; DRCCU, 1994						

1.3.2 COALBED METHANE RESOURCES AND THEIR POTENTIAL FOR DEVELOPMENT

China is the largest coal-producing country in the world, producing about 1.2 billion tons in 1994. Coal resources in China are characterized by large reserves, wide distribution, varied coal ranks and numerous coal seams. Currently, proven reserves of coal amount to 986 billion tons. CII estimates that coalbed methane reserves to depth of less than 2000 m are 30-35 trillion cubic meters. Section 2.4 in Chapter 2 discusses the coal basins, their geology, and methane potential in detail.

Estimated in-place coalbed methane resources in China are 30 to 35 trillion cubic meters. This compares to 11 trillion cubic meters of in-place resources in the United States, or about 1/3 of China's estimated resources. Without more detailed data, it is not possible to give an accurate estimate of the time and costs that would be involved in developing China's resources. Once site-specific coalbed methane projects and markets are identified, estimates of methane recovery costs could be compared with prices of competing fuels, in order to determine the break-even costs for each specific project.

A review of the 15 year history of the US coalbed methane industry, including exploration and development, production trends, and costs, provides useful guidelines for the percentage of in-place resources that may potentially be recovered in China. In the US, a total of 5,865 wells were drilled by 1994, producing 21.5 billion cubic meters of methane annually. From 1984 to 1994, coalbed methane production was 77.7 billion cubic meters, less than 1 percent of the total US in-place resources (Petroleum Information, 1994 and 1995; ERNGC, 1995). This 10-year period coincides with aggressive coalbed methane development in the San Juan and Warrior Basins of the US, which was driven by an energy tax credit. Also during this time, several US agencies were providing incentives for companies to develop coalbed methane projects[4].

From 1975 to 1992, the Gas Research Institute, Department of Energy, US Bureau of Mines, and gas producers and service companies provided over $4.6 billion for investment in coalbed methane research, drilling and production technology, and pipelines (Schraufnagel, 1994). Significant funds were allocated to improving technologies of vertical well gas recovery, such as improved hydraulic fracturing technology, optimizing well spacing, and recovering gas from multiple, rather than single seams. Most of the coalbed gas produced in the US is of pipeline quality, and a pipeline infrastructure is in place, allowing the sale of methane from major coal mines directly to nearby pipelines.

The above-described conditions in the US thus provide a ready supply of pipeline quality gas. The major considerations in determining pipeline project profitability are the quantity and quality of gas produced, proximity to a pipeline that can purchase gas, and the price at which the gas can be sold. In China, due to the lack of existing pipeline infrastructure, power generation projects are an attractive use option for coalbed methane. Methane can be used to meet on-site electricity needs, as well as sale of any surplus energy to a nearby utility. Primary factors for profitable power generation projects are the level of electricity that can be generated, on-site electricity needs of the mine, the price the mine currently pays for electricity, and the buy-back rate offered by the local utility. Some mines may have the additional use option of selling methane to nearby industries or institutions with large natural gas needs. Profitability of a local user option is determined by natural gas needs of the potential user, distance between the user and the mine, the price at which the gas can be sold, and the cost of converting an existing fuel system to operate on coalbed methane (USEPA, 1995b).

The area in the United States most analogous to China's coal-producing regions is the Warrior Basin of Alabama. In the late 1970's to early 1980's, all coalbed methane production from this basin was from coal mining regions; since then, significant production has come from vertical wells in unmined regions of the basin. The Warrior is a large coal basin, covering nearly 91 thousand km^2, with most of the coal mines occurring at depths ranging from 300 to 500 m. Over the past 15 years, a total of 3,000 coalbed methane wells have been drilled, and annual methane production for 1994 was almost 3.2 billion cubic meters.

1.3.3 CHINA UNITED COALBED METHANE COMPANY, LTD. AND ORGANIZATION OF THE COALBED METHANE SECTOR

Until recently, three separate organizations administrated coalbed methane development in China: MOCI, the Ministry of Geology and Mineral Resources (MGMR), and the China National Petroleum and Gas Corporation (CNPGC). The responsibilities of these three organizations overlapped to some degree, resulting in confusion and disputes on the extent of administrative power. In May 1996, therefore, China's highest governing body, the State

[4] It is now becoming clear that the coalbed methane industry in the US can stand alone without special tax breaks (Stevens et al, 1996). While the Section 29 tax credit undoubtedly accelerated investment in coalbed methane, many coalbed methane "plays" remain profitable without tax incentives. Production, new well completions, and reserve additions all continued to grow after the tax credit expired.

Council, established the China United Coalbed Methane Company, Ltd. (China CBM). As a single, trans-sectoral agency, China CBM is responsible for restructuring the coalbed methane sector by commercializing the exploration, development, marketing, transportation, and utilization of coalbed methane.

The State Council has also granted China CBM exclusive rights to undertake the exploration, development, and production of coalbed methane in cooperation with foreign partners. China CBM will jointly map out target areas for international cooperation and will conduct invitations for overseas bidding, negotiation, and signing and execution of contracts for proposed projects upon approval of the State Planning Commission. In addition to these duties, the new company will also act as a government watchdog and address some the country's energy-related environmental problems (China Energy Report, 1996).

Since China CBM will coordinate coalbed methane development work between the coal, petroleum, and geology and minerals sectors, it is jointly owned by MOCI, MGMR, and CNPGC. Following is an overview of these three organizations, as well as other groups involved in coalbed methane development in China.

The Ministry Of Coal Industry

MOCI departments involved with coalbed methane development include:

- **Planning and Development Department.** Manages coalbed methane activities within MOCI.

- **Science Technology and Education Department.** Responsible for identifying key issues regarding technological aspects of coalbed methane development and use.

- **Safety Department.** Responsible for general management of underground drainage.

- **General Bureau of Coalfield Geology**: Responsible for implementing coalbed methane assessments.

- **China Coal Utilization and Energy Conservation Corporation**: Responsible for construction and management of surface facilities for use of coalbed methane.

- **China Coal Information Institute:** Responsible for management of the China Coalbed Methane Clearinghouse, collection and exchange of information from China and other countries, and publication of the journal *China Coalbed Methane*;

- **Star Mining Corp**: Helps the planning and development department conduct management and coordination work relating to coalbed methane; organizes and participates in coalbed methane development and use projects with other enterprises; responsible for publication of the *Bulletin on Coalbed Methane*.

Ministry of Geology and Mineral Resources

The Ministry of Geology and Mineral Resources is responsible for the exploration and management of national mineral resources. For more than ten years, MGMR's North China

Bureau of Petroleum Geology (NCBPG) has been involved in coalbed methane exploration and development projects. In the 1980's, the NCBPG evaluated the coalbed methane resources of north China and neighboring areas, and carried out preliminary experiments on coalbed methane exploration and development in Kailuan. In 1991, the NCBPG began implementing a study on geological evaluation, target area selection, and techniques of coalbed methane exploration and development. Since 1993, the NCBPG has also been carrying out the Deep Coalbed Methane Exploration Project funded by the United Nations Development Programme (UNDP). The immediate objective of the latter project is to acquire the technologies, methodologies, training and practical experience that will enable MGMR and others to produce methane from coal seams that are too deep for mining (Sun and Huang, 1995).

China National Petroleum & Gas Corporation

CNPGC established the New Area Exploration Corporation which comprehensively manages coalbed methane projects of the CNPGC. Its research institutes include the Well Completion Division of Langfang Branch, the Research Institute of Petroleum Exploration & Development, and the Well Completion Technology Research Center of Southwest Petroleum Institute. The CNPGC has participated in the Fengcheng coalbed methane project, the Lengshuijiang coalbed methane project in Hunan Province, and the Dacheng coalbed methane project.

Other Research Institutes

The research institutes in the coalbed methane sector are the Fushun Branch of the Central Coal Mining Research Institute (CCMRI), which is engaged in research and development of coalbed methane drainage techniques; the Xi'an Branch of the CCMRI, which is engaged in exploration and evaluation of coalbed methane resources, and have personnel trained in the methodologies and equipment required for coalbed methane testing; and the Gas Geology Research Institute of the Jiaozuo Mining Institute, which has been working at research on gas geology.

Other Organizations

In addition, several CMAs, including Songzao, Kailuan, Tiefa, Huaibei, Huainan and Pingdingshan, have established leading groups for coalbed methane development which have become decision-making organizations for each coal mining administration. Enterprises engaged in coalbed methane development include the Jindan Energy Research and Development Company of the Jincheng CMA, and the Yuneng New Technology Development Co. of the General Bureau of Coalfield Geology.

1.3.4 MULTIPLE BENEFITS: ENVIRONMENT, ENERGY, SAFETY

Given China's reliance on coal, current plans to construct new mines, and with the trend towards mining deeper, gassier coal seams, it is likely that emissions of methane from coal mining will continue to increase. Now more than ever, recovered coalbed methane can greatly contribute to China's energy sector, economy, and environment. China's attention to this will lead to the following benefits:

- An additional natural gas resource
  One of the goals of China's energy development strategy is to expand natural gas production and use. New conventional gas supplies may develop slowly due to the lack of infrastructure and the remote location of these fields relative to industrial and population centers. Coalbed methane resources, by contrast, are concentrated in major coal producing regions, which are also large industrial and population centers. China's government recognizes the potential contribution of coalbed methane as an energy resource, and has included plans to increase development as part of its energy strategy.

- Improved economy
  Costly government subsidies are being withdrawn as China's coal mining industry becomes more market driven, while demand increases for an inexpensive, domestic energy source. Increased use of coalbed methane could reduce reliance on coal and costly imported fuels.

- Improved mine safety and profitability
  Previously, coal mines have viewed liberation of coalbed methane into the mine workings as a mine safety hazard, and have vented coal mine methane to the atmosphere. Mining coal at increasing depths generally means higher methane concentrations, which increase safety hazards resulting in higher mining costs and the need for larger ventilation systems. Coalbed methane drainage reduces the potential for methane explosions and sudden outbursts of coal and gas, thus improving safety conditions. Methane recovery also increases coal production, increasing mine profits, because mines can safely produce more coal without delays taken to reduce excess levels of methane.

- Improved local environmental quality
  Coalbed methane is a clean-burning fuel. When burned, methane emits essentially no sulfur or ash, and only a small percent of the nitrogen oxides, carbon dioxide and volatiles that are emitted by the burning of coal. Coalbed methane could offset the use of coal by industrial and residential consumers; improving local air quality. A high degree of coal combustion is common in China's cities, leading to public health problems. Adverse environmental impacts associated with atmospheric methane emissions include depletion of stratospheric ozone and increases in tropospheric ozone, which contributes to smog formation. Reducing methane emissions near population centers, lowers tropospheric ozone creation and associated smog.

- Improved global environmental quality
  Methane currently accounts for over 15 percent of expected warming from climate change (USEPA, 1993). It has a sizable contribution to potential future warming because it is a potent greenhouse gas and because methane's concentration has been increasing dramatically. Due to methane's high potency and short lifespan, stabilization of methane emissions will have a rapid impact on mitigating potential climate change. Higher methane concentrations may also contribute to stratospheric ozone depletion.

  China is the world's largest emitter of methane from coal mining, with estimated emissions of 12.5 to 19.4 billion cubic meters annually, or about one-third of the world's total emissions from this source. Increased recovery of methane from China's coal mines has great potential for reducing global methane emissions. Currently, less than 5 percent of total mine methane emissions are being recovered, with the balance being emitted to the atmosphere by ventilation systems. Increasing the recovery rate to 40 percent at the state-owned mines alone (some of which liberate as much as 50 cubic meters of methane per ton of coal mined) would reduce emissions by an estimated 4 to 5 billion cubic meters annually.

1.3.5 FOREIGN INVESTMENT IN CHINA: IMPLICATIONS FOR COALBED METHANE PROJECTS

For the benefit of US companies considering investment in coalbed methane in China, this section contains an overview of China's investment potential. More detailed information on policies to encourage development of coalbed methane is presented in Chapter 6. In addition, Chapter 5 includes a discussion of issues related to joint venture development. China's economy is attracting numerous global investors, and because deployment of foreign capital is a critical component of China's long-term strategic policy for economic development, the government is making efforts to further encourage foreign investment. In encouraging the establishment of joint ventures with foreign capital, China gives energy development the highest priority; and, at present, most foreign capital in this sector is used in oil prospecting and coal exploitation (Dorian, 1995).

In 1993 China renewed efforts to revise its taxation system as a means of better attracting foreign investment. Toward this end, six new laws and regulations were adopted during the year and put into effect January 1, 1994. These laws and regulations included the enterprise income tax law and the individual income tax law, as well as regulations on the following: a value-added tax; a consumption tax; a business tax; and a resource tax.

Recognizing the potential benefits of increased coalbed methane development, China's government is taking an active role in encouraging development of coalbed methane. In order to provide a regulatory and legal framework for coalbed methane exploration in China, MOCI issued the "Provisional Regulation and Rules for the Management of Exploration and Development of Coalbed Methane" in April 1994 (China Coalbed Methane Clearinghouse, 1995). The government's desire to develop this resource, together with a strong desire to establish joint energy ventures with foreign capital, create a favorable climate for foreign investment in coalbed methane projects.

1.3.6 SOURCES OF ADDITIONAL INFORMATION

As discussed in Chapter 3, numerous coalbed methane projects are currently underway in China. Several of these involve joint ventures between large US energy companies and Chinese mining enterprises. The China Coalbed Methane Clearinghouse has been instrumental in providing foreign companies with the assistance and information needed to assess methane development opportunities in key coal mining areas. It has also helped these companies by explaining the procedures for management of coalbed methane projects in China, and proposing target areas for coalbed methane development. The China Coalbed Methane Clearinghouse remains an excellent source of information and assistance for firms interested in developing coalbed methane in China. Readers may contact the Clearinghouse at the address listed in Appendix A.

Potential investors may also wish to read the publication "Investment in China", compiled jointly by China's Foreign Investment Administration, the China Economic and Trade Consultants Corp., and the Ministry of Foreign Trade and Economic Cooperation (whose address is listed in Appendix A). It includes the text of laws on Chinese-foreign contractual joint ventures, procedures for approving joint ventures, and many other regulations and topics of interest.

CHAPTER 2

COALBED METHANE RESOURCES OF CHINA

2.1 INTRODUCTION

Throughout China, there are abundant coal resources, and associated coalbed methane resources. The CII estimates that total coalbed methane resources contained in coal less than 2000 m deep are 30 - 35 trillion cubic meters (Sun and Huang, 1995). The bulk of these resources are contained in the Ordos, Qinshui, North China, Tu-Ha, and Junggar Basins, and the Yunnan and Guizhou coal-bearing regions. Each of these basins or regions contain coalbed methane resources in excess of 1 trillion cubic meters. The following sections of this chapter present an overview of China's major coal basins, and describe the geologic factors affecting coalbed methane recovery.

Throughout this chapter, tables containing coal and methane resource data are organized according to coal field or province rather than by basin, as this is how the data are typically reported in China. Generalized discussions of coal and methane resources in this chapter, however, will refer to coal basins where appropriate. Chapter 4 profiles coal mining administrations considered by the Ministry of Coal Industry (MOCI) to have the greatest coalbed methane development potential.

2.2 TECTONIC FRAMEWORK OF CHINA'S COAL BASINS

China has undergone a long and complex tectonic history dominated by compressional deformation, but influenced by episodes of rifting as well. The geologic history of the coal bearing regions of China is the result of complex overprinting of various tectonic events, one upon the other. Figure 13 depicts the location and geologic age of the major tectonic elements that formed the structural framework for the development of the China's sedimentary basins The unique geologic evolution of basins within a given region affected the deposition of the coal bearing strata and the associated generation of gas, as well as the subsequent trapping or dispersal of this gas.

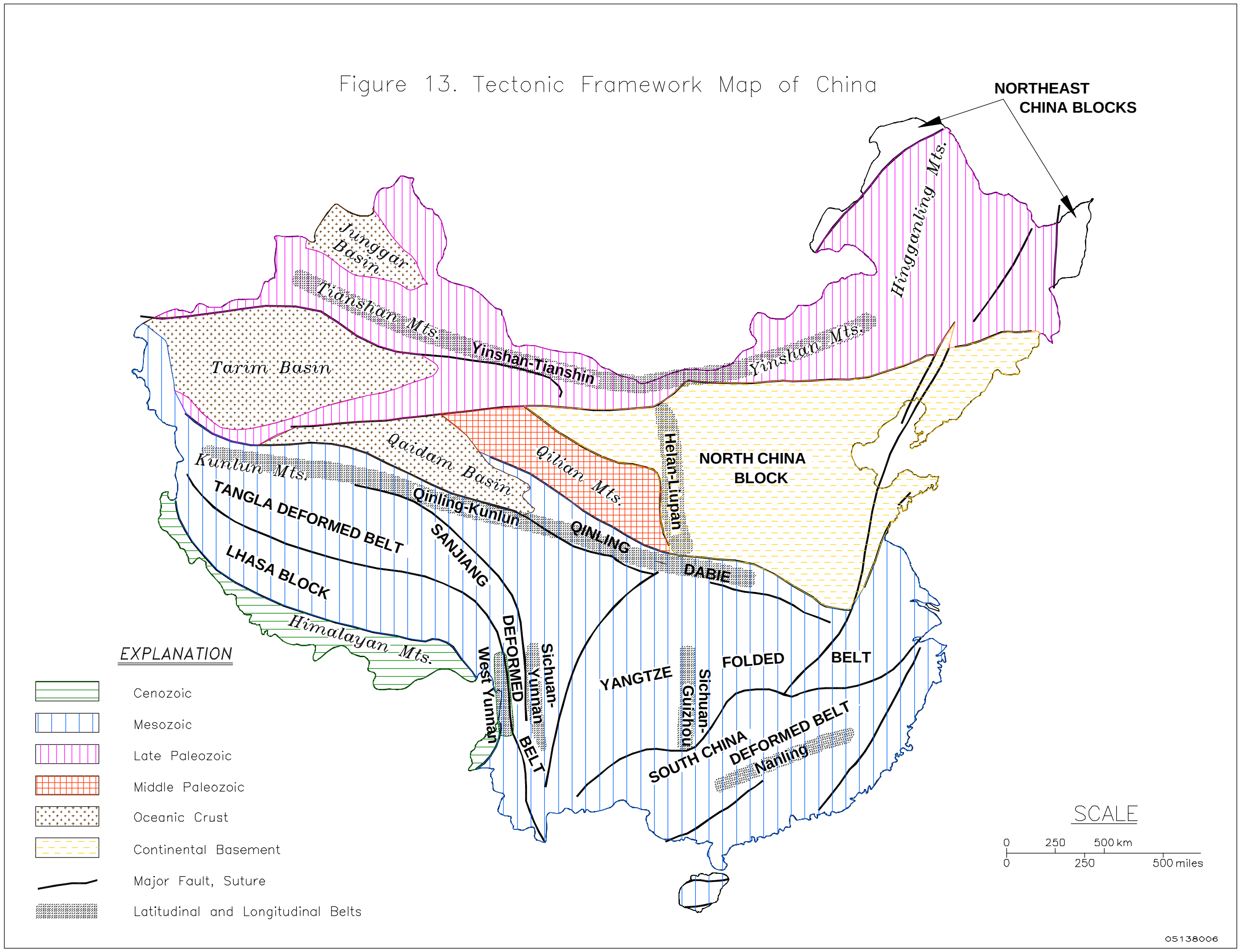


Figure 13. Tectonic Framework Map of China
NORTHEAST CHINA BLOCKS
Junggar Basin
Tianshan Mts.
Tarim Basin
Yinshan-Tianshin
Yinshan Mts.
Hingganling Mts.
Qaidam Basin
Qilian Mts.
Helan-Liupan
NORTH CHINA BLOCK
Kunlun Mts.
TANGLA DEFORMED BELT
Qinling-Kunlun
QINLING
DABIE
SANJIANG
LHASA BLOCK
Himalayan Mts.
West Yunnan
DEFORMED BELT
Sichuan-Yunnan
YANGTZE FOLDED BELT
Sichuan-Guizhou
SOUTH CHINA DEFORMED BELT
Nanling
EXPLANATION
Cenozoic
Mesozoic
Late Paleozoic
Middle Paleozoic
Oceanic Crust
Continental Basement
Major Fault, Suture
Latitudinal and Longitudinal Belts
SCALE
0 250 500 km
0 250 500 miles
05138006

The tectonic evolution of northern China differs dramatically from that of southern China. North and south China were at one time separate microcontinents, or plates, which collided during Permian time (Liu, 1990). The northern plate acted as a relatively stable platform throughout the depositional history of the coal-bearing sequences. It is known as the North China Block. Basins lying in northeastern China produce large, economically important amounts of coal. These basins were formed during a major rifting event that resulted in a thick and relatively undeformed marine Paleozoic stratigraphic sequence which accumulated as the rift basin opened. This thick sequence underlies the coal strata that was deposited in a sequence dominated by terrigenous rocks.

Back arc basins develop in the region behind interactive tectonic plate margins. This is the locus of downwarping of the crust that occurred during a compressional period which resulted from the collision and subduction of oceanic crust under accreting continental crust. The geologic record suggests that the Tarim, Junggar and Qaidam Basins are back arc basins situated to the west of the North China block, north of the accretionary terrain that comprises southern China.

In contrast to northern China, episodic tectonic events and marine transgressions largely controlled southern China, resulting in frequent disruptions in coal deposition. South China was not a stable platform, but a composite terrain comprising numerous severely deformed and folded belts similar in structure to the Alps of Europe or the Appalachians of the US (Hsu, 1989).

Dramatically different tectonic history resulted in unique coal basin geology within the north and south regions. In the north, clastic sequences dominate sediments of the coal-bearing sections, and coal seams generally are fewer, thicker, and more laterally continuous. In the south, where marine influence and tectonic activity prevailed, the coal sequences contain carbonates and volcanic rocks, and the coals tend to be more numerous, but thinner and laterally discontinuous.

These differing tectonic histories have several broad implications for coalbed methane development in China. The North China Block and the sedimentary basins of northeastern China are the least deformed areas. Southern China, in contrast, has undergone widespread, complex faulting and folding, which will greatly affect the reservoir characteristics of the gassy seams found in this region. In some cases, structural complexity may reduce the permeability of the reservoir; where in others areas it may enhance permeability. It is likely that the permeability enhancement will be localized, and identification of these higher permeability zones will be key in achieving high recovery efficiencies. Mining also enhances permeability; in fact, in some places, the only areas that are likely to produce methane are those where mining has caused relaxation of the strata, thus acting as massive reservoir stimulation.

The deposition of coal resources is controlled by major tectonic structures recognized by Chinese geologists as directly affecting the occurrence, development, and distribution of coal seams. These structures comprise latitudinal and longitudinal tectonic belts. Three major latitudinal tectonic systems are present in China. From north to south, they are the Yinshan-Tianshan Tectonic Belt; the Qinling-Kunlun Tectonic Belt; and the Nanling Tectonic Belt (Figure 13). These belts divide China into major structural elements, which acted at various times as controls on deposition of the coal-bearing sequences. Coal-bearing sediments occurring in the Yinshan-Tianshan Tectonic Belt range in age from late Jurassic to early Cretaceous; those of the Qinling-Kunlun and Yinshan-Tianshan Tectonic Belts are older, predominantly Permo-Carboniferous and Jurassic in age. South of the Qinling-Kunlun Belt, the coal-bearing formations are mainly late Permian in age.

The coal resources in the area north of the Qinling-Kunlun Belt account for 93.6 percent of the total coal resources in China. The area south of this tectonic belt accounts for only 6.3 percent of the total coal resources in China. Of these resources, 91 percent are concentrated in Yunnan, Guizhou and Sichuan Provinces.

The longitudinal tectonic belts are generally compressional systems. The four major north-south tectonic belts are the West Yunnan Tectonic Belt; the Sichuan-Yunnan Belt; the Sichuan-Guizhou Belt; and the Helan-Liupan Belt. The Sichuan-Yunnan Belt and Helan-Liupan Belts are located in central China; these two belts divide China into eastern and western structural zones, as well as coal producing regions. Tectonic events, primarily Mesozoic and Cenozoic in age, resulted in a relatively stable platform to the east and a tectonically active area to the west. The coal basins contained in the eastern area thus differ dramatically from those in the west.

In summary, the tectonic history of China creates a framework for understanding the distribution of coal and associated coalbed methane resources. Figure 14 illustrates the major sedimentary basins of China. As expected, the major coal mining areas are situated on the margins of the sedimentary basins. Estimated methane resources are also indicated for select basins. The sedimentary basins are contained within four large geographic regions - Northeast, North, South, and Northwest. Each region has unique characteristics that are directly related to their tectonic history. Figure 14 shows these four regions; their key features relative to the coal deposits are as follows:

- **Northeast**: The coals occurring in this region were deposited within a rift basin; coal seams are thick and laterally continuous. Major coal basins are the Sanjiang-Mulinghe, Songliao, Donhua-Fushun, and Hongyang-Hunjiang (detailed in Section 2.3.2).

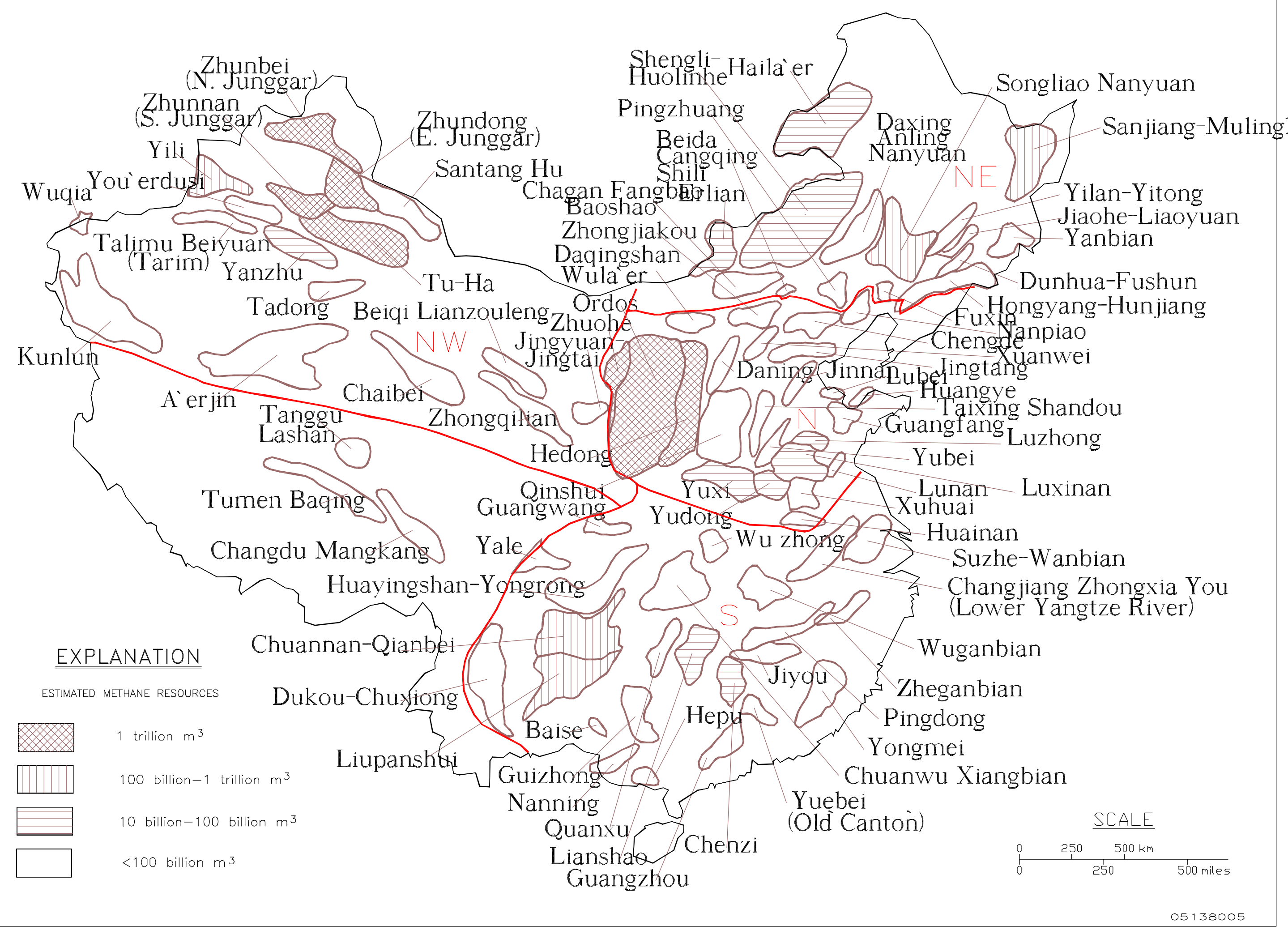
- **North**: The north is dominated by a stable platform (the North China block) underlain by continental basement rock, formed as rift and foreland basins. Major coal basins are the Taixing-Shandou, Qinshui, Daning, Ordos, Hedong, Yuxi, Xuhuai, and Huainan (detailed in Section 2.3.3).

- **South**: The south consists of accretionary terrain that comprises a series of fold belts. Coal seams in this region are thinner; and coal deposits are frequently disrupted relative to those in the north and northeast. Major coal basins are the Chuannon-Qianbei, Huayingshan-Yongrong, and Liapanshui (detailed in Section 2.3.4).

- **Northwest**: This region contains back-arc basins underlain largely by oceanic crust. Major basins are the Tarim, Qaidam, and Junggar Basins (detailed in Section 2.3.5).

The regions designated in the text above are the basis of organization used to discuss coal and coalbed methane resources in Sections 2.3 and 2.4, respectively.

Figure 14. Location Map of China's Coal Basins and Estimated Methane Resources



2.3 COAL RESOURCES

2.3.1 INTRODUCTION

In 1992, China's demonstrated coal resources totaled 986.3 billion tons, with proven in-place reserves accounting for 30 percent, or 296 billion tons. Recoverable reserves totaled 114.5 billion tons. Appendix B describes the coal reserve and rank classification systems used in China. The coal deposits are distributed throughout China and vary in age, structural complexity, and rank. Of the total coal resources, 75 percent are bituminous, 12 percent are anthracite, and 13 percent are lignite.

The economically important coal seams in China occur in Permian, Carboniferous, Jurassic, and Tertiary-age sediments. The stratigraphy of China's major coal-bearing groups for the Northwest, South, North, and Northeast regions is shown on Figure 15; composite stratigraphic sections are shown for key coal basins within each of the four regions. Northern, northwestern, and northeastern China contain 84 percent of the total in-place coal reserves; of these, the provinces of Shanxi, Shaanxi, and Inner Mongolia account for 75 percent. Coal reserves suitable for open cast mining are comparatively small (7 percent of total); 70 percent of these surface-mineable reserves are lignite (DRCCU, 1994). Abundant coal reserves occur in northwestern China; however, a large portion of the reserves are unexplored, infrastructure is absent, and the region is distant from population centers.

China's coal and coalbed methane resources will be discussed below according to the four geographic regions designated in Section 2.2. Although there are coal basins in Tibet, these resources were not evaluated under the scope of this report.

As described in Chapter 1, China's state-run coal mines are divided into Coal Mining Administrations (CMAs). Currently there are 108 CMAs in China, which manage approximately 650 mines. MOCI has identified major coal-producing areas, which contain large CMAs, throughout China. Figure 16 shows the four geographic regions, the location of selected CMAs. Table 6 summarizes 1994 coal production for all CMAs that produced over 500,000 tons per annum.

Included within the following sections is a brief description of the major coal basins found within each region. Following each section of text describing a particular region is a map of that region indicating the location, coal production and coal type for major CMAs contained within the region. Most of the information in the text that follows came from MOCI and articles by Sun and Huang (1995) and Bai (1995). This overview of coal basins serves as a guide to the size of basins, age, number of seams, thickness, rank, and depth of seams. Chapter 4 provides detailed profiles of ten key CMAs within these basins.

Figure 15. GENERALIZED STRATIGRAPHIC COLUMN OF MAJOR COAL-BEARING GROUPS

Composite Sections From Key Basins in Northwest, South, North and Northeast China

SYSTEM	SERIES	NORTHWEST Junggar Basin	SOUTH Sichuan-Guizhou Area	NORTH Ordos and North China Basin	NORTHEAST Shulan, Fushun Fuxin, Jilin
TERTIARY	Pliocene			Zhaotong	
	Miocene			Shuange	
	Oligocene				Shulan/ Fushun
	Eocene				
	Paleocene				
CRETACEOUS					
JURASSIC	Upper				Fuxin/ Wulin
					Naizishan
	Middle	Xishanyao		Datong/ Yan'an	
	Lower	Badaowan			
TRIASSIC					
PERMIAN	Upper		Changxing		
			Longtan	Shihezi	
	Lower		Tongziyan	Shanxi	
CARBONIFEROUS	Upper			Tiayuan	
	Middle			Benxi	
	Lower		Ceshui (Seshui)		

Sources: CII; Xi'an Coal Branch; Liu, 1990; Lee, 1989; Hendrix et al, 1995

05139002

Figure 16. Location of the Four Coal Regions

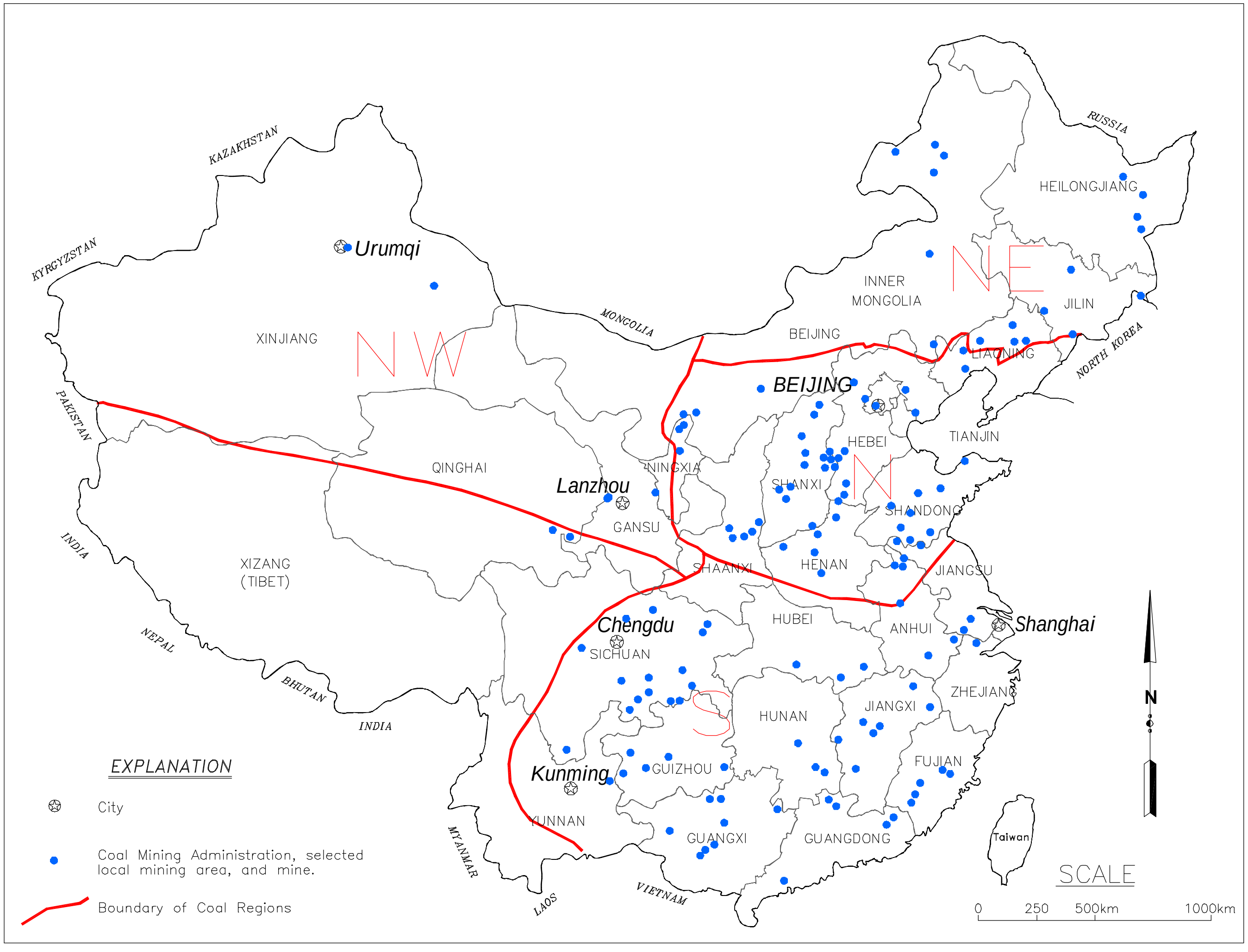


TABLE 6. SUMMARY OF 1993 COAL PRODUCTION FOR MAJOR CMAs

CMAs producing over 500,000 tons per annum, in descending order of production

(Locations of CMAs shown on Figures 17 - 20)

REGION	CMA	PROVINCE	COAL BASIN	SPECIFIC EMISSIONS	COAL PRODUCTION (10^3 T)
North	Datong	Shanxi	Daning	21.42	31,754.6
North	Kailuan	Hebei	Jingtang	15.82	17,604.8
North	Pingdingshan	Henan	Yuxi	NA	17,147.8
North	Huaibei	Anhui	Xuhuai	11.45	14,232.1
North	Xishan	Shanxi	Qinshui	12.35	14,127.7
Northeast	Hegang	Heilongjiang	Sanjiang-Mulinghe	16.17	13,130.7
North	Xuzhou	Jiangsu	Xuhuai	13.16	13,103.1
Northeast	Fuxin	Liaoning	Fuxin	29.08	12,698.7
North	Longkou	Shandong	Huangye		12,003.1
North	Yanzhuo	Shandong	Luxinan		12,003.1
Northeast	Jixi	Heilongjiang	Sanjiang-Mulinghe	29.84	11,644.2
North	Huainan	Anhui	Huainan	18.41	11,498.5
North	Yangquan	Shanxi	Qinshui	25.95	10,476.9
North	Fengfeng	Hebei	Taixing-Shandou	21.28	10,370.0
North	Jincheng	Shanxi	Qinshui	19.00	10,320.6
Northeast	Tiefa	Liaoning	Songliao	12.73	10,241.0
North	Xinwen	Shandong	Luzhong		10,089.0
Northeast	Qitaihe	Heilongjiang	Sanjiang-Mulinghe	19.18	10,060.1
Northeast	Shuangyashan	Heilongjiang	Sanjiang-Mulinghe	15.77	10,015.5
North	Lu'an	Shanxi	Qinshui		9,106.4
North	Yima	Henan	Yuxi	10.84	8,609.6
Northeast	Fushun	Liaoning	Donhua-Fushun	31.58	8,579.4
North	Pingzhuang	Inner Mongolia	Pingzhuang		6,993.3
North	Zaozhuang	Shandong	Luxinan		6,129.2
North	Shitanjing	Ningxia	Zhuohe	12.48	6,005.8
North	Beijing	Beijing	Jingtang		5,517.0
North	Zibo	Shandong	Guangfang	14.86	5,061.7
North	Zhengzhou	Henan	Qinshui		5,052.3
South	Panjiang	Guizhou	Liupanshui	20.42	5,014.0
North	Feicheng	Shandong	Luzhong		4,993.3
North	Fenxi	Shanxi	Qinshui		4,819.0
North	Xingtai	Hebei	Taixing Shandou		4,780.0
North	Tongchuan	Shaanxi	Ordos	17.08	4,721.6
North	Hebi	Henan	Taixing-Shandou	15.73	4,671.5
Northeast	Shenyang	Liaoning	Donhua-Fushun	26.18	4,410.5
North	Zhalainuoer	Inner Mongolia	Haila'er		4,305.1
South	Shuicheng	Guizhou	Liupanshui	33.74	4,122.2
North	Huozhou	Shanxi	Qinshui		4,016.8
Northeast	Liaoyuan	Jilin	Jiaohe-Liaoyuan	16.36	3,979.0
North	Datun Coal	Jiangsu	Luxinan		3,875.8
Northeast	Tonghua	Jilin	Hongyang-Hunjiang	18.25	3,809.3
Northeast	Shulan	Jilin	Yilin-Yitong	22.63	3,803.8
North	Jiaozuo	Henan	Qinshui	19.97	3,799.6
North	Wanbei	Anhui	Xuhuai		3,766.0
North	Huolinhe	Inner Mongolia	Shengli-Huolinhe		3,694.2
South	Panzhihua	Sichuan	Dukou-Chuxiong		3,527.2
North	Hancheng	Shaanxi	Hedong	16.48	3,462.8
Northwest	Jingyuan	Gansu	Jingyuan-Jingtai	11.25	3,350,8
North	Dayan	Inner Mongolia	Haila'er		3,311.9
North	Wuda	Inner Mongolia	Ordos		3,253.3
South	Pingxiang	Jiangxi	Jiyou	30.62	2,741.4
Northwest	Yaojie	Gansu	Zhongqilian	14.49	2,718.1
South	Songzao	Sichuan	Chuannon-Qianbei	47.99	2,696.4
North	Handian	Hebei	Taixing-Shandou		2,620.0
North	Shizuishan	Ningxia	Zhouhe	14.27	2,560.8

TABLE 6. SUMMARY OF 1993 COAL PRODUCTION FOR MAJOR CMAs

(Continued from previous page)

REGION	CMA	PROVINCE	COAL BASIN	SPECIFIC EMISSIONS	COAL PRODUCTION (10^3 T)
South	Furong	Sichuan	Chuannon-Qianbei	26.72	2,394.7
South	Lianshao	Hunan	Lianshao	37.88	2,360.1
South	Heshan	Guangxi	Guizhong		2,353.8
South	Nantong	Sichuan	Chuannon-Qianbei	36.83	2,208.6
Northeast	Beipiao	Liaoning	Nanpiao	24.57	2,177.6
Northwest	Urumqi	Xinjiang	Junggar	16.00	2,166.6
South	Zixing	Hunan	Chenzi	22.04	2,142.4
North	Xuangang	Shanxi	Daning	11.81	2,062.1
South	Fengcheng	Jiangxi	Pingdong	28.55	2,000.3
Northeast	Nanpiao	Liaoning	Nanpiao	12.29	1,954.2
North	Baotou	Inner Mongolia	Daqingshan	45.50	1,904.5
North	Haibowan	Inner Mongolia	Ordos		1,743.3
Northwest	Hami	Xinjiang	Tu'Ha		1,695.5
South	Baisha	Hunan	Chenzi	23.20	1,676.8
South	Guangwang	Sichuan	Guangwang	17.04	1,667.2
Northeast	Huichun	Jilin	Yanbian	15.52	1,610.1
South	Yongrong	Sichuan	Huayingshan-Yongrong	37.65	1,501.8
South	Liuzhi	Guizhou	Liapanshui	51.31	1,454.1
North	Pubai	Shaanxi	Hedong		1,401.1
South	Tianfu	Sichuan	Huayingshan-Yongrong	50.40	1,345.9
North	Yiminhe	Inner Mongolia	Haila'er		1,343.2
North	Yinying Mine	Shanxi	Qinshui	NA	1,203.1
North	Chenghe	Shaanxi	Hedong		1,180.1
North	Xiaoyu Mine	Shanxi	Daning		1,101.2
North	Jingxing	Hebei	Taixing-Shandou		1,100.0
South	Quren	Guangdong	Yuebei	16.33	1,084.2
South	Leping	Jiangxi	Pingdong	18.86	1,082.9
North	Dongshan Mine	Shanxi	Qinshui		1,060.9
North	Xinglong	Hebei	Chengde	14.65	1,050.0
South	Lindong	Guizhou	Liapanshui		1,041.6
South	Changguang	Zhejiang	Suzhe-Wanbian	27.64	1,027.6
South	Yong'an	Fujian	Yongmei		1,018.0
South	Dazhu	Sichuan	Huayingshan-Yongrong		1,012.9
South	Meitian	Guangdong	Yuebei	41.83	920.4
North	Cuijiagou Mine	Shaanxi	Ordos	10.32	863.1
South	Donglou	Guangxi	Nanning		818.2
South	Hongmao	Guangxi	Guizhong	24.48	810.1
North	Linyi	Shandong	Lunan		781.3
South	Youjiang	Guangxi	Baise		741.2
South	Yongding	Fujian	Yongmei		722.8
Northwest	Datong	Qinghai			707.0
South	Longyan	Fujian	Yongmei		670.1
South	Huayingshan	Sichuan	Huayingshan-Yongrong	26.07	669.8
North	Guzhuang Mine	Shanxi	Qinshui		667.2
South	Siwangzhang	Guangdong	Yongmei		665.4
North	Nanzhuang Mine	Shanxi	Taixing-Shandou		651.1
North	Xiahuayuan Mine	Hebei	Xuanwei	28.00	630.0
South	Songyi	Hubei	Chuanwu Xiangbian		625.4
South	Zhongliangshan	Sichuan	Chuannon-Qianbei	58.38	613.8
North	Yancheng City	Jiangsu	Lunan	13.97	609.4
South	Shangjing	Fujian	Yongmei		608.9
South	Luoshi	Jiangxi	Jiyou		604.6
South	Huangshi	Hubei	Wuganbian		586.5
North	Lingwu	Ningxia	Ordos		532.8
South	Yinggangling	Jiangxi	Pingdong		505.3

* Average specific emissions listed for high gas mines only (emissions greater that 10 m^3/ton)

Source: China Coal Industry Yearbook, 1994; and the CII

2.3.2 NORTHEAST REGION

The Northeast region contains coal-bearing sediments deposited predominantly during Late Jurassic time, with some deposited during Permo-Carboniferous and early Tertiary time. The region comprises Jilin and Heilongjiang Provinces, northern Liaoning Province and the eastern part of Inner Mongolia (Figure 17). The tectonics of the Mesozoic coalfields are relatively complex, due to the impact of the folding and faulting that occurred after the formation of the Mesozoic coal basins. A major subsidence zone, the Cathaysian rift system, developed in Northeast China after the late Mesozoic (Liu, 1986). Many extensional structures, such as horsts and grabens, formed in the rift system, and the coal-bearing formations are best developed in these fault-defined basins.

Coal seams are generally thick, although the lateral extent within individual coal basins may be relatively small. Coal rank ranges from lignite to high volatile bituminous coal with some occurrence of medium volatile bituminous coals. Late Jurassic coal-bearing sediments are well-developed in the eastern part of this region; the Sanjiang-Mulinghe Basin is located in this region. Grabens also formed during rifting events in the southern part of the region; the Songliao Basin contains late Jurassic coal-bearing sediments.

Most of the coal in this region is bituminous (much of it gassy), although there are some anthracite and lignite coals as well. Late Jurassic and early Cretaceous lignite deposits occur in Inner Mongolia, mainly in the area north of the Yinshan Mountains. The economic hard coal deposits comprise the Tertiary Fushun and Shulan Groups (Figure 15).

Deposits are grouped into four main basins, located in the provinces of Heilongjiang, Liaoning, and Jilin.

- The Sanjiang-Mulinghe Basin is the most economically important coal basin in Heilongjiang Province, with seams ranging in thickness from 2 to 20 meters. Major CMAs within this basin include Hegang and Shuangyashan. Coal measures in the Hegang CMA are shallow and gently dipping, and are structurally uncomplicated. These are high volatile bituminous coals, some of which are suitable for metallurgical coking. The Shuangyashan CMA, also located in Sanjiang-Mulinghe Basin, possesses high quality coals but is located far from major industrial centers.

- The Songliao Basin has an area of 513 km^2. The basin contains the large Tiefa CMA, which has eight active underground mines, all of which are gassy. Seam depth ranges from 600 to 800 m. There are 20 coal seams, of which 12 seams are mineable. The basin's major mineable coal seam, No. 8, has an average thickness of 2-4 m. Coal rank is high volatile bituminous.

- The Donhua-Fushun Basin is a major coal-producing basin in Liaoning Province. The coal basin has three workable Eocene seams whose total thickness ranges from 20 to 134 meters. Structurally, this basin is relatively simple, with laterally continuous high volatile bituminous coal seams that are low in ash and sulfur. The Fushun CMA, located in the Donhuan-Fushun Basin, recovers and uses coalbed methane. In 1993, Fushun CMA had an annual gas drainage of 113.36 million cubic meters (Huang L., 1995).

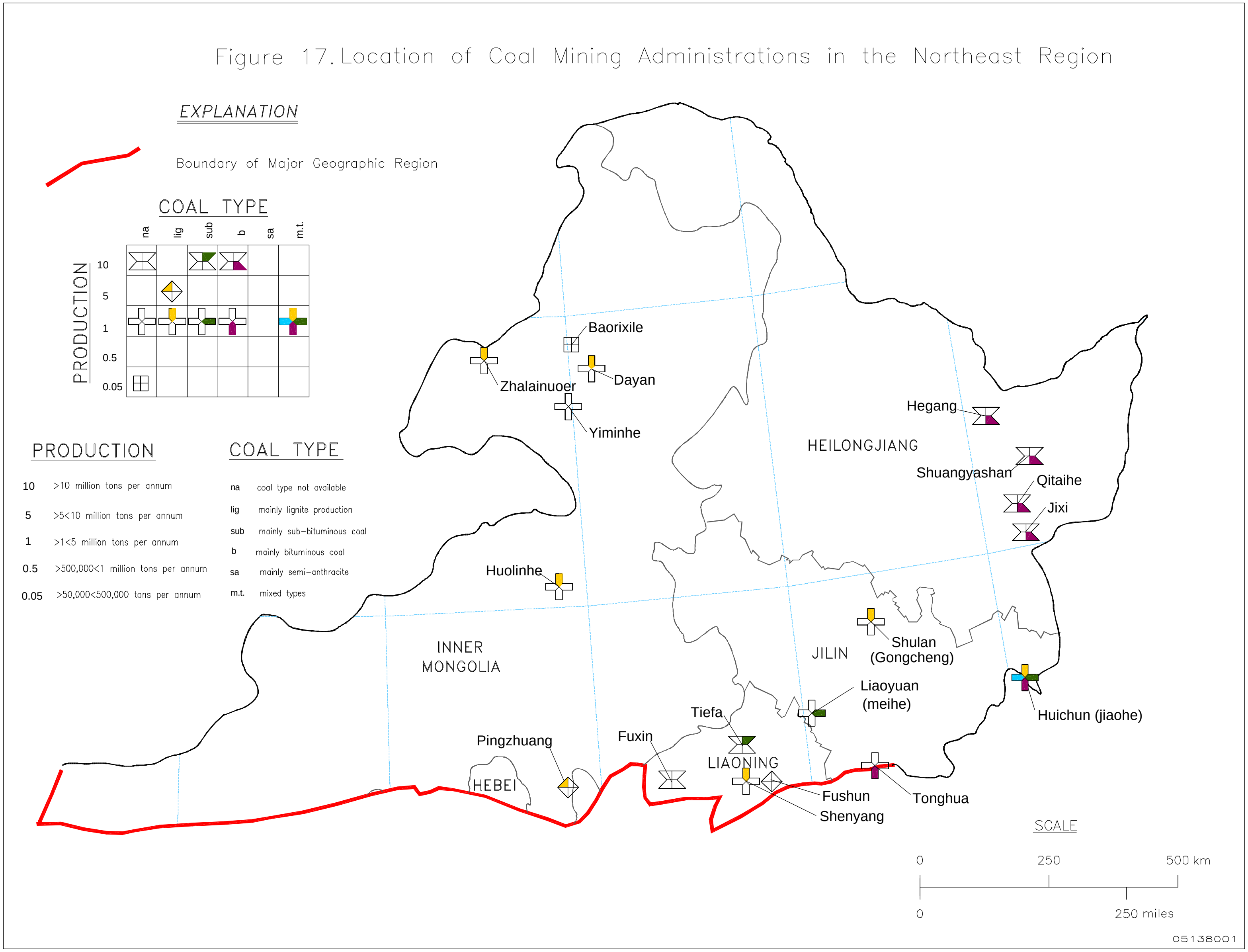


Figure 17. Location of Coal Mining Administrations in the Northeast Region
EXPLANATION
Boundary of Major Geographic Region
COAL TYPE
na
lig
sub
b
sa
m.t.
PRODUCTION
10
5
1
0.5
0.05
PRODUCTION
10 >10 million tons per annum
5 >5<10 million tons per annum
1 >1<5 million tons per annum
0.5 >500,000<1 million tons per annum
0.05 >50,000<500,000 tons per annum
COAL TYPE
na coal type not available
lig mainly lignite production
sub mainly sub-bituminous coal
b mainly bituminous coal
sa mainly semi-anthracite
m.t. mixed types
Baorixile
Zhalainuoer
Dayan
Yiminhe
Hegang
HEILONGJIANG
Shuangyashan
Qitaihe
Jixi
Huolinhe
INNER MONGOLIA
Shulan (Gongcheng)
JILIN
Liaoyuan (meihe)
Huichun (jiaohe)
Tiefa
Fuxin
Pingzhuang
LIAONING
HEBEI
Fushun
Shenyang
Tonghua
SCALE
0
250
500 km
0
250 miles
05138001

- The Hongyang-Hunjiang Basin is located in Jilin Province. Within this basin, the Tonghua CMA has numerous mineable bituminous coal seams. Some of these Jurassic coal seams are mined for coking coal.

2.3.3 NORTH REGION

The North Region contains the largest quantity of proven coal reserves in the country. It is an important coal-producing region of China, possessing high quality coal and nearby markets. Flat-lying Paleozoic and Mesozoic strata occur in a series of basins comprising 800 km^2 and extending through Shanxi Province north to Hebei Province and southwest Inner Mongolia. All twelve of the provinces in this region produce coal, making an important contribution to national coal production. Rank of these coals is principally bituminous, with occurrences of small amounts of semi-anthracite and anthracite. Coal basins in the northern region are generally linked by rail to the domestic markets and ports from which coal is exported. The rail system to coastal markets has recently been upgraded. The area has been extensively explored, and numerous large underground mines are in operation. Abundant hard coal reserves occur in Inner Mongolia, which lie in remote areas with access to markets via railway.

The North Region consists of predominately Upper Carboniferous-Permian coal basins, with lesser amounts of coal reserves contained in Lower and Middle Jurassic sediments (Figure 15). Major CMAs and coal basins in this region include Kailuan, Fengfeng, Tonghua, Datong, Jiaozuo, Zibo, Yangquan, Huainan, Huaibei, Yuxi, and Hebi (Figure 18). Quality of the Paleozoic coal produced in this region is relatively consistent. With the exception of the anthracite deposits of the West Beijing coalfield, all other coalfields contain high volatile bituminous coal. In the central part of this region near Taihang Mountain, coal deposits range in rank from low volatile bituminous coal to anthracite coal. Key coal basins in the North Region are:

- The economically important coal basin in Hebei Province is Taixing-Shandou, with bituminous coals of Permo-Carboniferous age. In this basin, there are up to 21 mineable coal seams, some of which are coking quality, whose maximum thickness is 30 m. In general, coal measures are gently dipping with some local faulting. Major CMAs in the Taixing-Shandou Basin include Hebi, Jingxing, and Xingtai.

- The Qinshui Basin, located in Shanxi Province, is a major coal-producing basin containing Carboniferous, Permian, and Jurassic coals (Walker, 1993). Major CMAs in the Qinshui Basin include Yangquan, Xishan, Jincheng, and Jiaozuo; these CMAs produce bituminous and semianthracitic coals. Methane recovery systems are used at the Yangquan CMA, and gas drainage in 1992 averaged 90 million cubic meters per annum.

- The Daning Basin, located in northern Shanxi Province, comprises Carboniferous, Permian, and Jurassic coals (Walker, 1993). It contains the largest CMA in China, the Datong CMA. In 1994, the coal mines of Datong CMA produced over 31 million tons of coal, primarily subbituminous in rank.

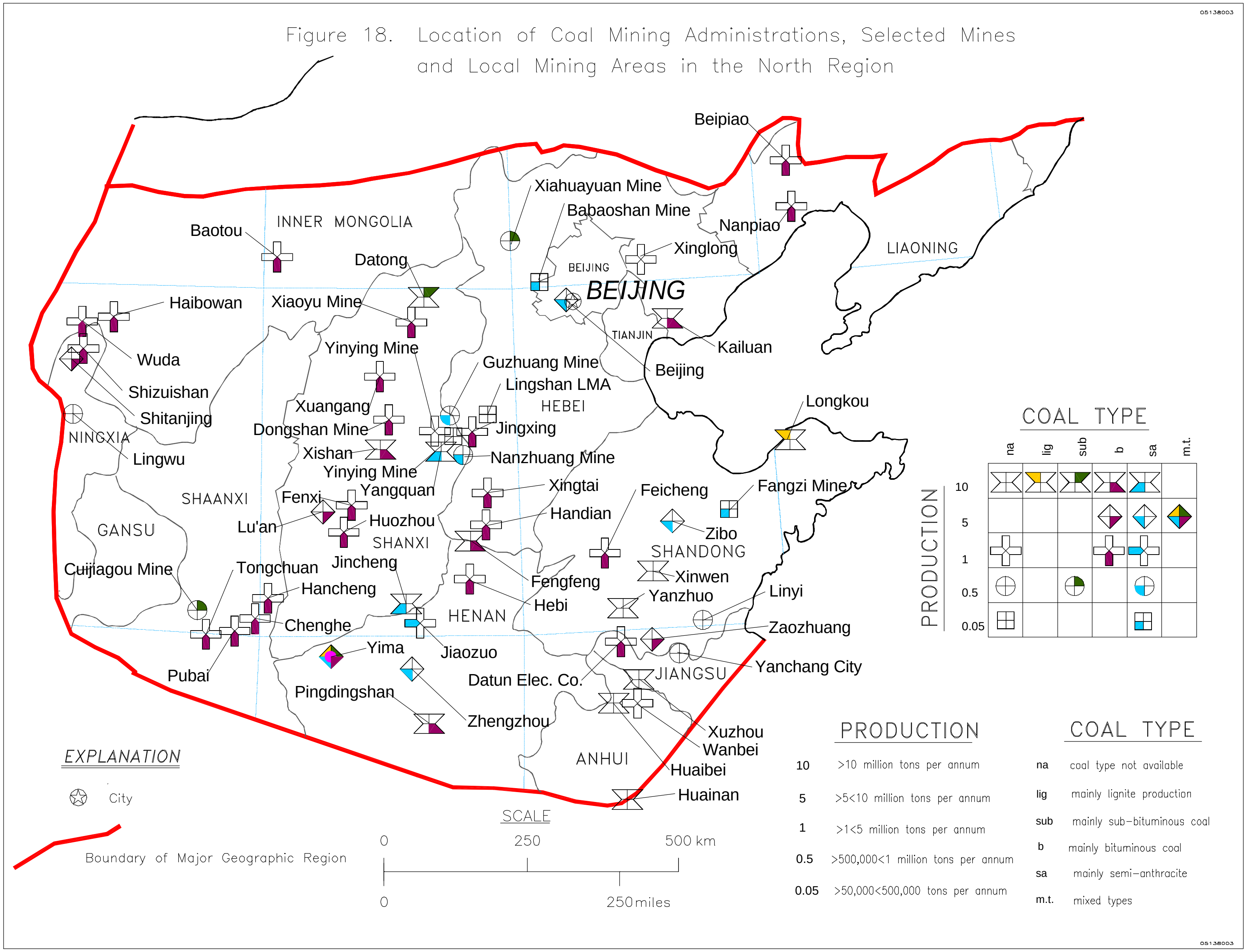


Figure 18. Location of Coal Mining Administrations, Selected Mines and Local Mining Areas in the North Region
Beipiao
Xiahuayuan Mine
Babaoshan Mine
Nanpiao
Xinglong
INNER MONGOLIA
Baotou
Datong
LIAONING
BEIJING
BEIJING
Xiaoyu Mine
Haibowan
TIANJIN
Kailuan
Wuda
Yinying Mine
Guzhuang Mine
Beijing
Shizuishan
Lingshan LMA
HEBEI
Longkou
Shitanjing
Xuangang
Dongshan Mine
Jingxing
NINGXIA
Lingwu
Xishan
Nanzhuang Mine
Yinying Mine
Yangquan
Xingtai
Feicheng
Fangzi Mine
SHAANXI
Fenxi
Huozhou
Handian
Zibo
GANSU
Lu'an
SHANXI
SHANDONG
Jincheng
Cuijiagou Mine
Tongchuan
Fengfeng
Xinwen
Hancheng
Yanzhuo
Linyi
Hebi
Chenghe
HENAN
Zaozhuang
Yima
Jiaozuo
Yanchang City
Pubai
JIANGSU
Datun Elec. Co.
Pingdingshan
Zhengzhou
Xuzhou
Wanbei
ANHUI
Huaibei
Huainan
COAL TYPE
na
lig
sub
b
sa
m.t.
PRODUCTION
10
5
1
0.5
0.05
EXPLANATION
City
Boundary of Major Geographic Region
SCALE
0
250
500 km
0
250 miles
PRODUCTION
10 >10 million tons per annum
5 >5<10 million tons per annum
1 >1<5 million tons per annum
0.5 >500,000<1 million tons per annum
0.05 >50,000<500,000 tons per annum
COAL TYPE
na coal type not available
lig mainly lignite production
sub mainly sub-bituminous coal
b mainly bituminous coal
sa mainly semi-anthracite
m.t. mixed types

- The Ordos Basin is an extensive coal basin, spanning the provinces of Shaanxi, Gansu, Ningxia, and Inner Mongolia. It contains Carboniferous, Permian, and Jurassic coals (Walker, 1993). Major CMAs contained within the Ordos Basin include Tongchuan, Wuda, and Cuijiagou, which produce subbituminous and bituminous coals.

- Most of the coal seams in Henan Province are relatively deep, and were deposited in Permo-Carboniferous time. The Yuxi Basin contains the Pingdingshan and Yima CMAs.

- The Xuhuai Basin, located in northern Anhui Province, contains substantial anthracite and bituminous deposits of coking coal. It is a large basin, covering 4,000 km^2 and containing 12 coal mines, 10 of which are considered highly gassy mines. Seam depth ranges from 400 to 1,000 m, with 13 to 46 seams, 4 to 13 of which are mineable in various parts of the basin. The basin contains the large Huaibei CMA. At these mines, seam thickness ranges from 1 to 19 m. The coal-bearing strata are predominately steeply dipping, but free of intense structural deformation.

- The Huainan Basin is an important coal basin in southern Anhui and Jiangsu Provinces, covering an area of 2,500 to 3,000 km^2 (Yang et al, 1995). Depth to the coal seams is generally less than 1,000 m, with a maximum depth of 1,700 m. There are 10 to 18 seams considered mineable; four to five major seams are 2 to 6 m thick. Permo-Carboniferous coal seams range in rank from low to high volatile bituminous, much of which becomes coking quality with depth. The Huainan Basin is linked by railroad to the ports of Suzhou and Shanghai.

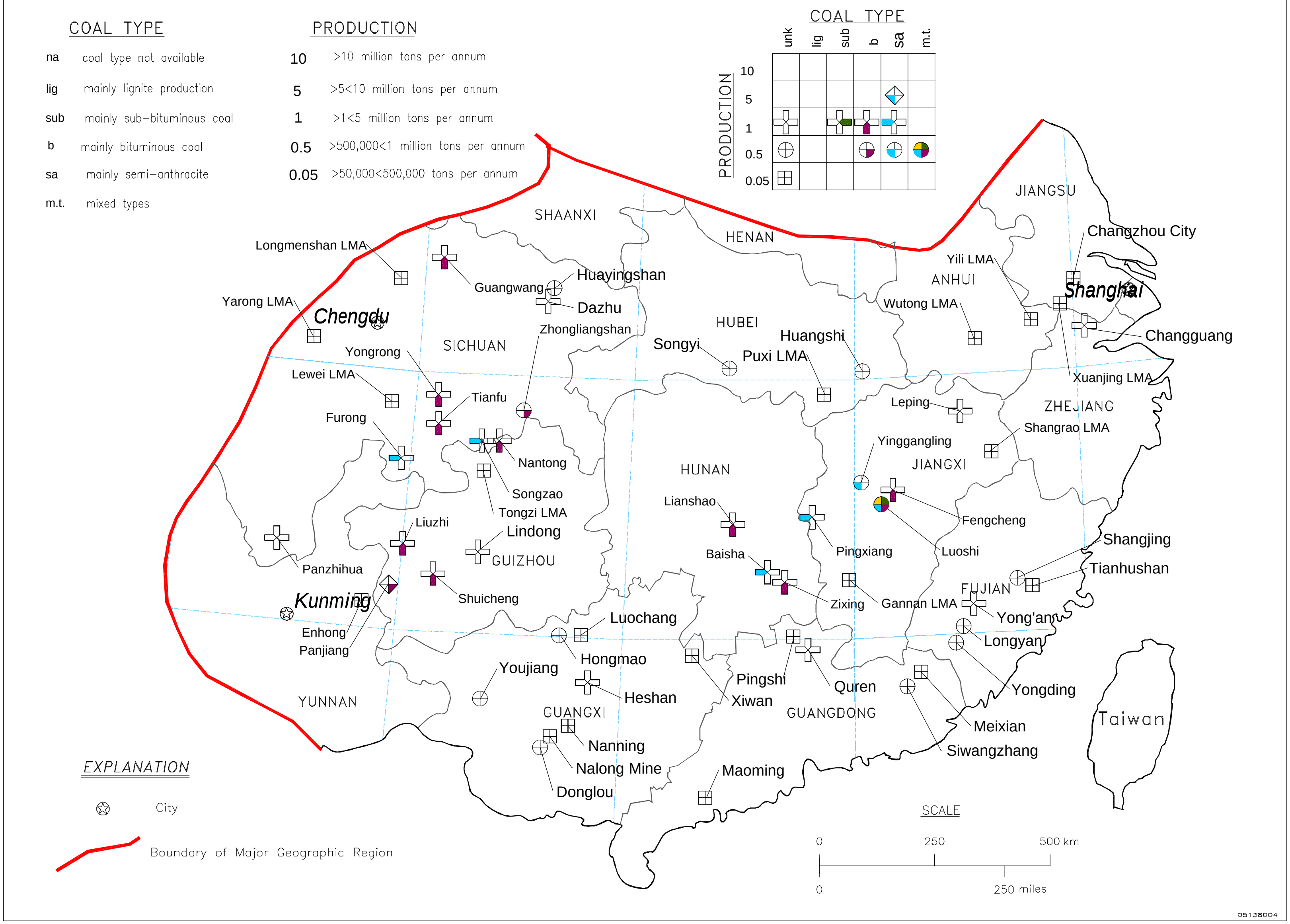
2.3.4 SOUTH REGION

The South Region comprises of Paleozoic and Mesozoic bituminous and anthracite coals, of Paleozoic and Mesozoic age, with less important coal seams deposited during the late Tertiary. Most of the coal deposits in the region were deposited in the Permian and late Triassic-early Jurassic (Figure 15). Important deposits of extractable coal deposits in the eastern part of this region are limited to complex tectonics and thinner seams. These deposits are scattered throughout the provinces of Hubei, Hunan, Guangxi, Guangdong, Fujian, Zhejiang, Jiangxi, and South Anhui (Figure 19). Numerous medium and small coal mines are currently operating in this area.

Permian coal deposits in Guizhou, Sichuan, and Yunnan Provinces are more substantial, accounting for about 75 percent of the total coal resources in the South Region. Although the southwestern part of this region lacks the infrastructure of the North Region, the government is committed to aggressively developing these coal resources. Some of the key coal basins in the South Region are:

- The Chuannon-Qianbei Basin is located in Sichuan and Guizhou Provinces. It contains thick, bituminous coals good for coking. There are both semi-anthracite and lignite deposits in Sichuan Province. Major CMAs in this basin include Songzao, Furong, Nantong, and Zhongliangshan. The Songzao CMA, between Sichuan and Guizhou Province, recovers and uses coalbed methane from underground methane drainage systems. In 1992, Songzao drained 67 million cubic meters, or 33 percent of the mine gas liberated.

Figure 19. Location of Coal Mining Administrations, Selected Mines and Local Mining Areas in the South Region



- Huayingshan-Yongrong Basin is located in northern Sichuan Province. The basin contains two large CMAs with high gas mines, the Yongrong and Huayingshan CMAs.

- Guizhou Province contains large coal reserves which have only been recently explored. They consist mainly of Permian bituminous and anthracite deposits. The Liapanshui coal basin is the most extensively developed coal basin in the province. The Panjiang, Shuicheng, and Luizhi CMAs are located in this basin.

- There are six gassy mines in Yunnan Province, however, none of these are part of large, state-run CMAs. They are the Yipinglang, Yangchang, Laibin, Tianba, Houshou, and Enhong mines. Neither coal gas content nor specific emissions data are available for these mines.

2.3.5 NORTHWEST REGION

The Northwest Region is geologically similar to the North region, containing large resources of mainly Jurassic and some Permo-Carboniferous deposits of bituminous coal. The deposits are located in the provinces of Xinjiang, Gansu, and Qinghai (Figure 20). Despite large reserves, coal production is low due to the lack of infrastructure and the region's distance from heavy industry and population centers.

Xinjiang Province, located in extreme northwest China, contains the largest estimated coal resources of any province. Jurassic coal deposits range from lignite to bituminous in rank, and are mostly is high volatile bituminous. Three large basins, the Junggar, Tu-Ha, and Yili Basins, contain numerous thick coal seams, ranging to a maximum thickness of 200 m. Although current production in this region is limited, it is an area with a great potential for future coal development.

2.4 COALBED METHANE RESOURCES AND EMISSIONS ESTIMATES

The Xi'an Branch Institute of the Central Coal Mining Research Institute (CCMRI) estimates that China's coalbed methane resources, at depths less than 2000 meters, total 30 to 35 trillion cubic meters (Sun and Huang, 1995). This estimate is the product of a special study entitled "Evaluation of Coalbed Methane Resources in China".

High gas or outburst-prone coal mines account for almost half of the key state run mines in China. Table 7 summarizes 1994 methane emission data for high methane mines, low methane mines and open pits. Based on data from 334 major coal mining areas in China, there are 149 areas with high gas content, and 185 mining areas with low methane content.

Appendix C lists the 1992 and 1994 emissions data by province for these mines (Tables C-1 and C-2, respectively). Table C-3 lists 12 local mine areas (LMAs) that are considered by MOCI to be high gas.

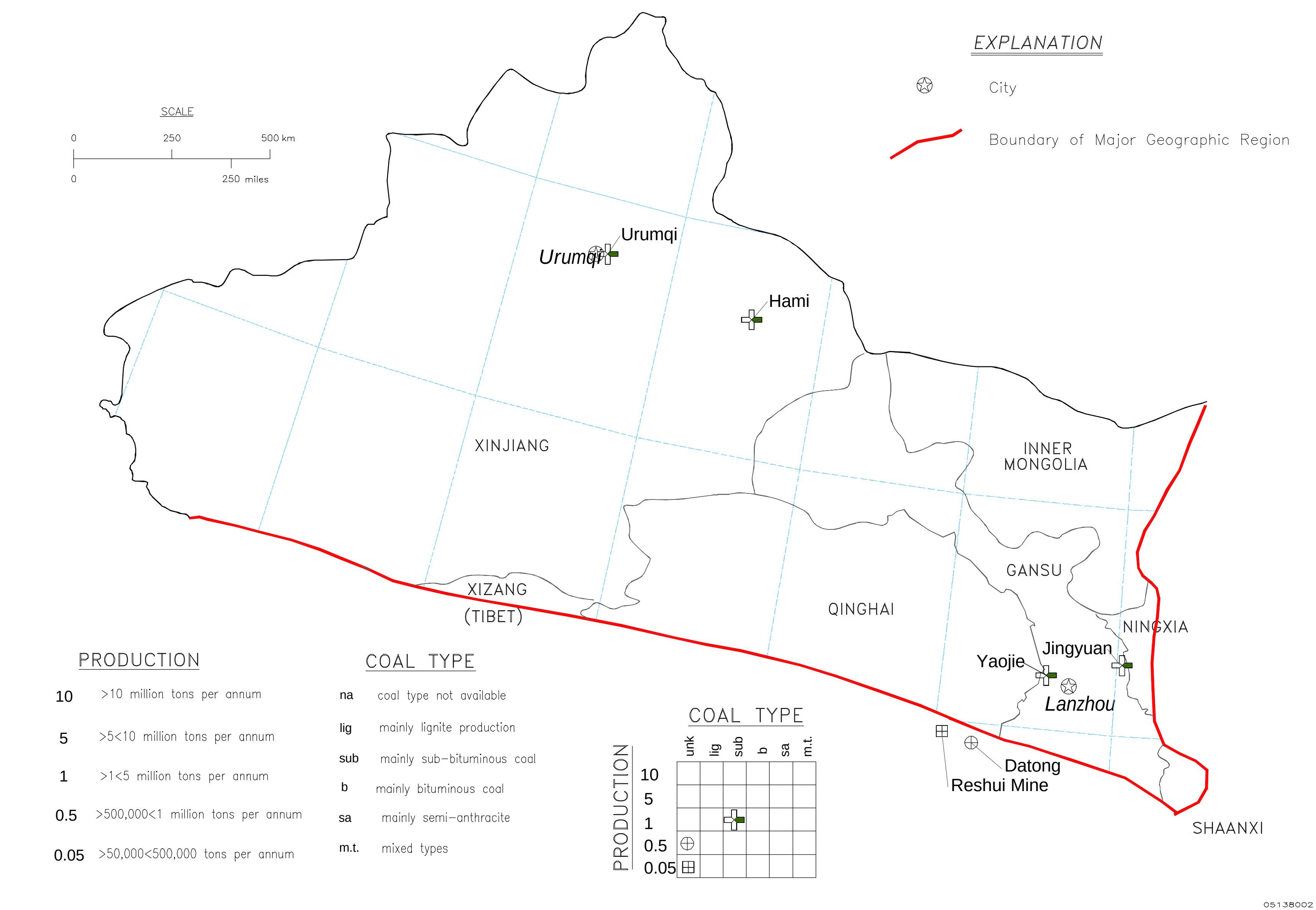


Figure 20. Location of Coal Mining Administrations and Selected Mines in the Northwest Region

According to the CII, the CMAs whose average specific emissions exceed 20 cubic meters per ton are as follows:

- Northeast China: Fuxin, Yingcheng, Liaoyuan, Qitaihe;
- North China: Xiahuayuan, Beipiao, Baotou, Yangquan; and
- South China: Tianfu, Huayingshan, Nantong, Yongrong, Furong, Liuzhi, Shuicheng, and Songzao.

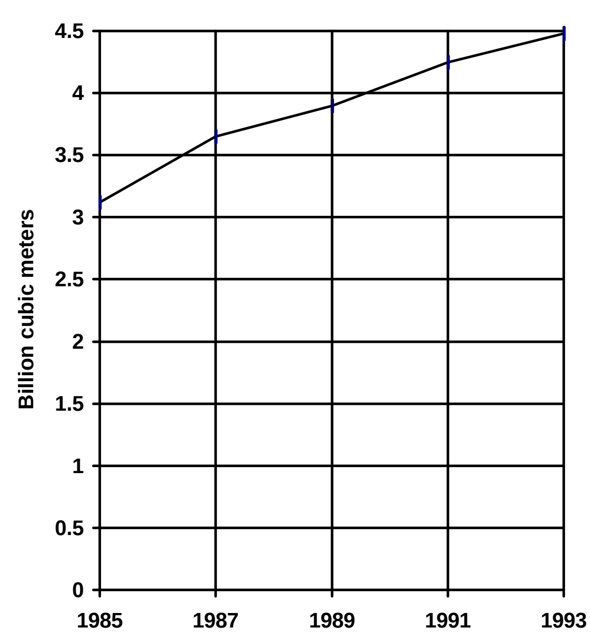
TABLE 7 - SUMMARY OF 1994 METHANE EMISSION DATA CHINA'S KEY STATE-RUN MINES

	LOW METHANE MINES	HIGH METHANE MINES	OPEN PITS	TOTAL
NUMBER OF MINES: Total	351	318	14	683
With Drainage	0	131	0	131
METHANE VENTED (10^6 m^3)	798.6	3,863.5	106.1	4,768.3
METHANE DRAINED (10^6 m^3)	0.0	561.3	0.0	561.3
TOTAL LIBERATED (10^6 m^3)	798.6	4,424.8	106.1	5,329.5
DRAINED & USED (10^6 m^3)	0.0	395.2	0.0	395.2
DRAINED & VENTED (10^6 m^3)	0.0	166.1	0.0	166.1
TOTAL EMITTED (10^6 m^3)	798.6	4,029.6	106.1	4,934.3
COAL PRODUCTION (10^6 tons)	248.1	190.5	30.1	468.7
ABSOLUTE EMISSIONS (m^3/min)	1519.4	8418.6	201.9	10139.9
SPECIFIC EMISSIONS (m^3/t)	3.22	23.23	3.52	11.37

Source: Fushun CCMRI, 1995

In 1994, 318 of the 683 state-run mines listed, or 46.5 percent, were classified as high gas or outburst mines. High gas mines are defined as those mines with specific emission greater than 10 cubic meters per ton, and low gas mines are those with specific emissions less than 10 cubic meters per ton. As shown in Figure 21, total emissions of coalbed methane increased steadily, from 3.12 billion cubic meters in 1985 to 4.48 billion cubic meters in 1993. Over this 8-year period (from 1985 to 1993), total emissions increased by an average of 170 million cubic meters per annum.

FIGURE 21. INCREASE IN METHANE EMISSIONS AT STATE RUN COAL MINES



Underground gas drainage is practiced in many mines to improve mine safety. In 1994, 131 mines had methane drainage systems. A total of 4.425 billion cubic meters of methane was emitted from all mines in 1994. Of this, 561 million cubic meters of methane were recovered. A total of 395 million cubic meters, or 70 percent, of the recovered methane was used. This represents less than 10 percent of the total methane liberated from Chinese mines.

Table 8 is a summary of emissions data by province, and indicates the amount of methane recovered and used by the key state-run mines whose specific emissions are greater than 10 cubic meters per ton of coal mined. Appendix C (Table C-4) lists detailed information on individual high gas CMAs.

Current methane recovery and methods are discussed in greater detail in Chapter 3. Figure 22 shows the location of these high gas mines. Many of these mines, which are currently recovering methane, are discussed in detail in Chapters 3 and 4.

Figure 23 shows China's coal basins, along with the coalbed methane generation potential and storage capacity. The Xi'an branch of CCMRI classifies these prospects as follows:

- Low generation potential and medium storage capacity
- High generation potential and low storage capacity
- High generation potential and high storage capacity
- Variable generation and low storage capacity

These four categories give an indication of the coalbed methane potential for selected Chinese coal basins; the optimal category for coalbed methane production is high generation potential and high storage capacity. As Figure 23 shows, the North, Northeast and South regions contain several coal basins with these characteristics, and many key state-run mines are located in these basins. One basin in the Northwest Region (the Tarim Basin) is also in this category.

2.5 OVERVIEW OF FACTORS AFFECTING RESOURCE RECOVERABILITY IN CHINA

China has abundant coalbed methane, but the development of this resource is limited by many factors. Regional variations in tectonics can result in over- or underpressured zones, low permeability, or erratic methane content, adversely affecting development of coalbed methane. The permeability of many coal seams in China, particularly those that have not undergone relaxation due to mining, is generally low, often less than 0.1 md; Sun and Huang (1995) cite low permeability as the single most unfavorable factor affecting the development of coalbed methane in China. Experience in the US indicates that the optimal permeability for coalbed methane development is about 3 to 4 md, and that it should be no lower than 1 md.

Underpressured reservoirs are another relatively common problem in China. Based on analysis of available data and ongoing testing for coalbed methane development, most coal seams in China have low reservoir pressures, ranging from 0.5 to 3.0 MPa. A small number of mines operating at depths of 800 to 1000 m have reservoir pressures as high as 5 to 8 MPa. In the US, by comparison, the Blue Creek Seam of the Warrior Basin has reservoir pressures of 5.6 MPa at a depth of only 600 to 800 m. Coal seams with low permeability or those that are underpressured may not be effectively stimulated by hydraulic fracturing, and may ultimately yield low production.

Table 8: KEY DATA PERTAINING TO METHANE LIBERATION FROM HIGH GAS MINES BY PROVINCE

PROVINCE	REGION	NO. MINES (1994)	AVERAGE SPECIFIC EMISSIONS (m^3/T)	TOTAL METHANE LIBERATED (Mm^3)		% CHANGE	TOTAL METHANE DRAINED (Mm^3)		% CHANGE	TOTAL METHANE USED (Mm^3)		% CHANGE
				1992	1994		1992	1994		1992	1994	
Heilongjiang	NE	32	29.5	390.1	450.1	15%	16.3	13.5	-18%	0.0	0.0	
Jilin	NE	18	19.1	101.2	112.9	12%	0.3	1.6	420%	0.0	0.0	
Liaoning	NE	30	22.5	549.7	536.0	-2%	132.9	142.2	7%	114.9	126.7	10%
TOTAL		**80**	**24.6**	**1040.9**	**1099.0**	**6%**	**149.5**	**157.2**	**5%**	**114.9**	**126.7**	**10%**
Hebei	N	15	15.9	231.1	196.2	-15%	20.7	19.3	-7%	10.4	14.2	37%
Shandong	N	3	17.9	28.1	32.6	16%	0.0	0.0		0.0	0.0	
Jiangsu	N	2	11.0	13.8	12.1	-12%	0.0	0.0		0.0	0.0	
Anhui	N	17	13.6	248.7	303.5	22%	9.5	9.8	3%	6.1	7.4	21%
Henan	N	29	16.2	302.1	314.6	4%	19.5	23.5	21%	10.6	13.8	30%
Shanxi	N	24	21.2	806.8	795.5	-1%	114.5	115.2	1%	95.6	101.9	7%
Shaanxi	N	10	25.8	122.0	161.3	32%	3.5	4.7	35%	0.0	0.0	
Inner Mongolia	N	4	19.4	26.4	71.0	169%	1.4	0.0	-100%	0.0	0.0	
Ningxia	N	6	14.7	73.7	92.6	26%	8.0	13.1	63%	3.4	5.6	65%
TOTAL		**110**	**17.7**	**1852.8**	**1979.4**	**7%**	**177.1**	**185.6**	**5%**	**126.1**	**142.9**	**13%**
Zheijiang	S	11	30.9	31.1	28.0	-10%	0.0	0.0		0.0	0.0	
Jiangxi	S	15	29.3	123.5	111.6	-10%	9.3	11.5	24%	5.1	8.0	57%
Hunan	S	31	30.9	104.9	103.2	-2%	1.8	2.4	33%	1.1	1.9	73%
Sichuan	S	43	48.3	644.4	618.7	-4%	154.1	153.0	-1%	90.9	101.8	12%
Guizhou	S	19	37.1	389.1	416.6	7%	40.6	48.5	19%	8.1	13.9	72%
Yunnan	S	5	19.7	20.2	35.3	75%	0.0	0.0		0.0	0.0	
Guangxi	S		N/A									
Guangdong	S		N/A									
TOTAL		**124**	**37.2**	**1313.2**	**1313.3**	**0%**	**205.9**	**215.4**	**5%**	**105.2**	**125.6**	**19%**
Gansu	NW	4	37.2	23.5	33.2	41%	0.0	3.1		0.0	0.0	
Xinjiang	NW	0	N/A	N/A	N/A		0.0	0.0		0.0	0.0	
TOTAL		**4**	**37.2**	**23.5**	**33.2**	**41%**	**0.0**	**3.1**		**0.0**	**0.0**	
GRAND TOTAL		**318**		**4230.4**	**4424.9**	**5%**	**532.5**	**561.3**	**5%**	346.2	395.2	

SOURCE: FUSHUN CCMRI (1995); CII (1995); JP International (1990)

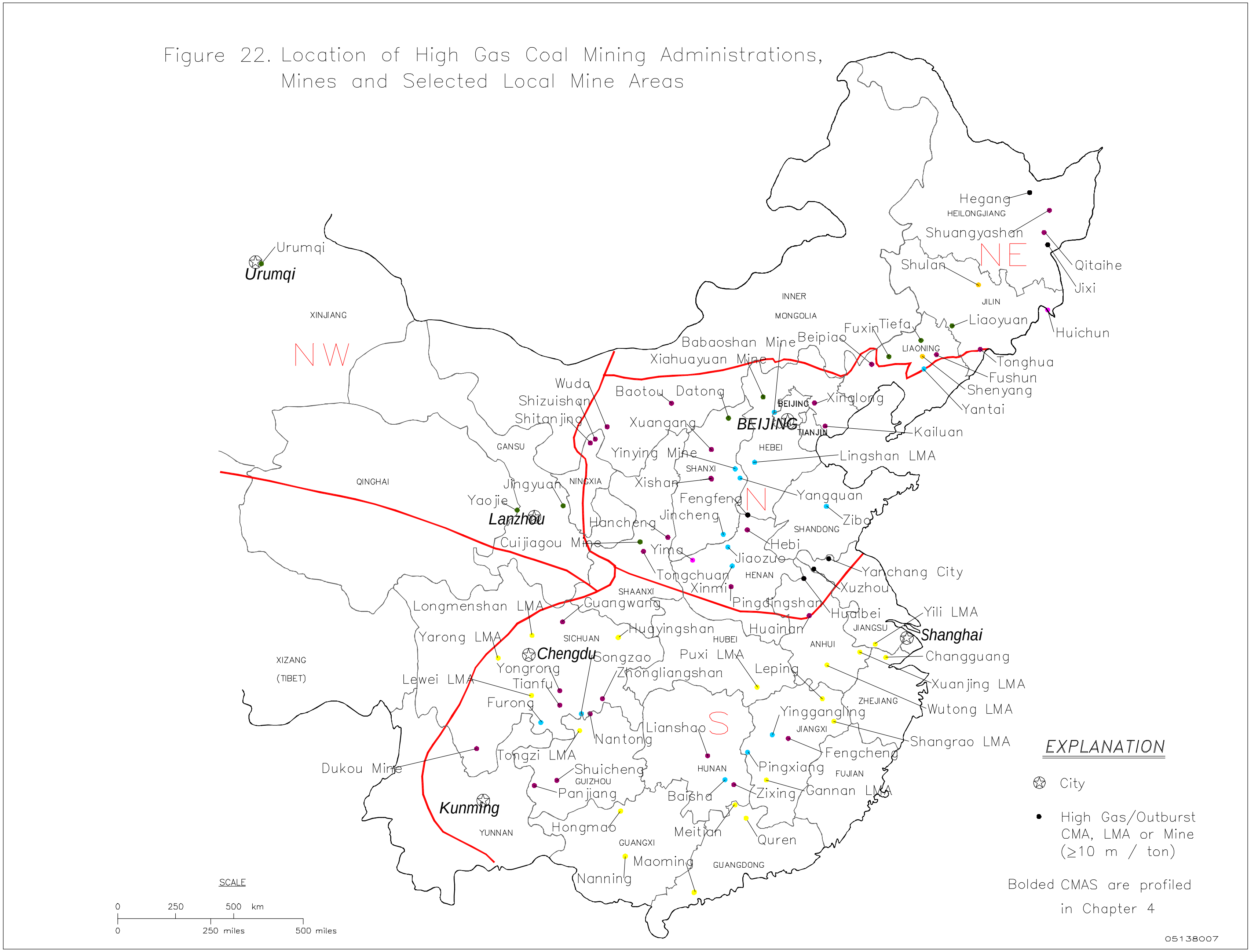


Figure 22. Location of High Gas Coal Mining Administrations, Mines and Selected Local Mine Areas

Figure 23. Coalbed Methane Generation Potential and Storage Capacity

Source: CII, 1995

05138012

One key to successful coalbed methane exploitation in China will be identification of localized areas with enhanced permeability. These enhanced zones are caused by either faulting and folding of the coal bearing strata, or simply by the mining out of adjacent seams, causing relaxation of the beds. In addition, coalbed methane research work in China should focus on the development of technologies for producing methane from coalbeds with low permeability and/or low reservoir pressures (Sun and Huang, 1995).

Underground gas drainage will continue to play an important role in China's coalbed methane development program. Many Chinese mines are also interested in recovering methane via surface wells, but currently lack experience in this technology (Sun et al, 1995). Chapter 3 discusses the gas drainage techniques currently used in China, including several ongoing projects demonstrating state-of-the-art technologies.

CHAPTER 3

THE POTENTIAL FOR INCREASING COALBED METHANE RECOVERY AND USE IN CHINA

3.1 INTRODUCTION

While methane drainage has been practiced in China for several decades, tremendous opportunities exist for increased recovery and use of methane from coal mines. Currently, the drainage efficiency of existing degasification systems is relatively low, averaging 20 percent (Sun and Huang, 1995). Significantly more gas could be available for use with an integrated approach to methane recovery in conjunction with mining operations.

Chinese mines vent to the atmosphere most of the gas they produce. Based on methane emissions data from 1994, mines in China drained about 564 million cubic meters, which represents about 10 percent of the total methane liberated. A total of 110 government-run mines currently have methane drainage systems. Less than one-half of these mines, however, are set up to distribute and use recovered methane. China's mines use about 73 percent of the methane they drain, and only about 14 percent of the total methane they liberate. With an integrated approach to methane recovery in conjunction with mining operations, these mines could make available significantly more gas that could be used, rather than vented.

Gassy coal mines throughout the world are concerned, for safety reasons, with reducing the methane concentration in mine ventilation air. As discussed in Section 3.2 below, safety is of prime concern at Chinese coal mines due to a high number of methane related accidents. Mines can reduce methane concentrations by increasing ventilation, or by decreasing the amount of methane liberated into the mine workings from the coal and surrounding strata. They can increase ventilation by increasing the size of the fans, or adding additional ventilation shafts. Alternatively, they can reduce the methane concentration in ventilation air by expanding methane drainage, ultimately reducing ventilation requirements. Methane drainage can increase profits by improving mining productivity and reducing ventilation requirements. In addition, mines can often sell the gas they recover.

3.2 METHANE ACCIDENTS IN CHINA'S COAL MINES

Gas explosions and outbursts are a severe threat to Chinese mines, causing numerous fatalities and economic loss. MOCI thus gives high priority to efforts related to controlling gas hazards. Gas and coal dust explosions account for the largest percentage of accidents in China's mines. Table 9 shows fatalities caused by gas and coal dust explosions in key state-run mines from 1981 to 1993.

TABLE 9. GAS EXPLOSIONS AND OUTBURST FATALITIES IN KEY STATE-RUN COAL MINES

	EXPLOSIONS		OUTBURSTS		TOTAL	
	Accidents	**Fatalities**	**Accidents**	**Fatalities**	**Accidents**	**Fatalities**
1981	11	270	4	7	15	227
1982	6	35	6	17	12	52
1983	11	219	4	15	15	234
1984	11	65	8	18	19	83
1985	8	161	7	41	15	202
1986	6	58	7	16	13	74
1987	9	81	5	20	14	101
1988	7	121	10	42	17	163
1989	4	30	10	42	14	72
1990	10	149	7	41	17	190
1991	5	40	6	16	11	56
1992	3	24	2	12	5	36
1993	7	108	12	47	19	155
TOTAL	**98**	**1361**	**88**	**334**	**186**	**1695**

Local mines face more severe conditions. Between 1983 and 1993, there were 50 accidents at local mines with more than ten fatalities each, of which 40 accidents were caused by gas explosions, killing 835 people. The remaining 10 accidents were caused by gas outbursts, killing 184 people.

Methane drainage is a highly effective means of reducing emissions and preventing gas explosions and outbursts. The following section describes historical and current trends in methane drainage in China, as well as the potential for increasing methane recovery.

3.3 COALBED METHANE RECOVERY

3.3.1 TRENDS IN METHANE DRAINAGE IN CHINA

Nationwide, coalbed methane drainage nearly doubled in 14 years, increasing from 294 million cubic meters in 1980 to 564 million cubic meters in 1994 (Table 10). In 1980, there were five coal mining administrations (CMAs) whose coalbed methane output exceeded 10 million cubic meters; in 1993, 13 CMAs met this criteria. Much of the progress during this period can be attributed to improved technology and the acquisition of additional equipment.

TABLE 10. METHANE DRAINAGE AT COAL MINING ADMINISTRATIONS (Million Cubic Meters, in descending order of 1993 volume recovered)

CMA	PROVINCE	1980	1985	1990	1992	1993
Fushun	Liaoning	99.88	102.12	108.63	109.73	113.36
Yangquan	Shanxi	85.78	89.52	76.91	106.11	90.53
Songzao	Sichuan	10.70	34.09	59.23	60.70	76.31
Tianfu	Sichuan	5.44	12.91	22.59	26.59	25.10
Zhonglangshan	Sichuan	18.56	18.83	21.50	24.31	22.07
Nantong	Sichuan	1.70	7.18	22.00	26.03	20.27
Liuzhi	Guizhou	1.94	4.66	11.00	18.35	18.41
Tiefa	Liaoning	2.52	1.80	10.17	16.80	16.26
Panjiang	Guizhou	0.08	0.01	5.64	8.16	15.00
Furong	Sichuan	0.58	1.24	12.43	13.87	14.10
Shuicheng	Guizhou	1.93	1.64	5.35	14.11	12.75
Jiaozuo	Henan	2.27	3.86	10.26	11.66	12.27
Shitanjing	Ningxia	0.00	0.00	0.15	7.99	11.04
Fengfeng	Hebei	4.49	6.25	7.62	11.97	9.89
Hegang	Heilongjiang	3.22	1.10	3.95	9.04	9.88
Fengcheng	Jiangxi	9.77	4.67	8.01	7.90	8.27
Kailuan	Hebei	3.08	4.44	8.35	8.69	8.07
Nanzhuang	Shanxi	0.00	0.00	0.00	3.24	7.83
Beipiao	Liaoning	3.59	2.09	5.93	6.21	6.57
Hebi	Henan	5.21	6.91	7.12	8.02	6.48
Tongchuan	Shaanxi	0.00	0.00	0.00	3.50	5.05
Huaibei	Anhui	1.69	4.25	3.16	4.72	4.66
Huainan	Anhui	2.47	4.74	4.06	4.78	4.20
Guzhuang	Shanxi	0.00	1.28	3.68	3.77	3.75
Guangwang	Sichuan	0.00	0.00	0.00	1.17	3.70
Yinying Mine*	Shanxi	3.48	1.16	3.54	3.60	3.70
Jixi	Heilongjiang	2.47	7.34	5.42	7.30	3.37
Jingyuan	Gansu	0.00	0.00	0.00	1.41	2.00
Lianshao	Hunan	0.31	1.60	1.40	1.70	1.67
Xishan	Shanxi	0.86	NA	1.50	1.05	1.47
Yongrong	Sichuan	0.00	0.00	0.00	0.79	1.44
Pingxiang	Jiangxi	0.18	0.89	0.44	1.20	1.28
Hangcheng	Shaanxi	0.00	0.00	0.00	1.00	1.09
Pingdingshan	Henan	0.00	0.00	0.00	0.13	0.65
Shenyang	Liaoning	0.00	0.04	0.17	0.11	0.22
Yaojie	Gansu	0.00	0.00	0.00	NA	0.20
Yinggangling	Jiangxi	0.00	0.20	0.06	0.16	0.13
Baisha	Hunan	0.25	NA	0.04	0.13	0.00
Benxi	Liaoning	0.39	NA	NA	0.00	0.00
Jingjing	Hebei	0.57	NA	NA	0.00	0.00
Leping	Jiangxi	0.35	NA	NA	0.00	0.00
Xuangang	Shanxi	0.01	0.00	0.00	0.00	0.00
Baotou	Inner Mongolia	16.44	4.20	4.66	NA	NA
Fuxin	Liaoning	1.17	NA	NA	NA	NA
Liaoyuan	Jilin	2.39	1.25	0.37	0.33	NA
Shizuishan	Ningxia	0.00	0.00	0.00	0.02	NA
TOTAL		**293.77**	**330.27**	**435.34**	**536.35**	**543.04**

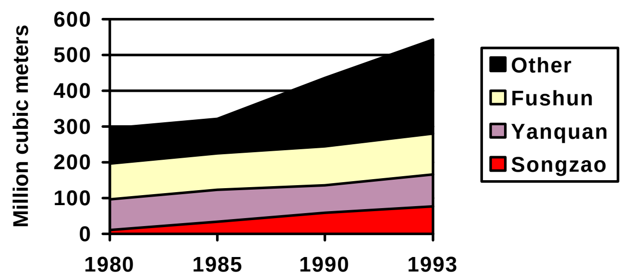
Note: 1994 drainage totaled 564 million m^3; a breakdown by CMA was not available

*** Yinying Mine is not associated with a CMA; it is under the jurisdiction of the Shanxi Province Coal Administration**

Shaded CMA's are profiled in Chapter 4 **SOURCE: CII, 1995 and Huang, 1995**

Figure 24 shows the annual methane drainage from CMAs. During the period 1980-1993, the Fushun and Yangquan CMAs consistently recovered more methane than all of the remaining CMAs combined. In 1993, the Fushun, Yangquan, and Songzao mines accounted for 52 percent of the total methane drainage from Chinese mines. Figure 25 shows the locations of the 46 CMAs[1] that drain methane. The greatest increase in methane drainage since 1980 occurred at the following CMAs: Songzao, Nantong, Zhongliangshan and Furong in Sichuan Province; Tiefa in Liaoning Province; Liuzhi in Guizhou Province; Jiaozuo in Henan Province; and Hegang in Helongjiang Province. The CII considers these CMA's as key areas for future coalbed methane development.

FIGURE 24. ANNUAL METHANE DRAINAGE FROM CMAs



3.3.2 METHANE DRAINAGE METHODS

Underground coal mines can employ several different techniques to recover methane. The most attractive option for a specific mine depends on site specific conditions, including:

- development and topography of the surface;
- the thickness and depth of the targeted seam;
- the amount of methane contained in the coals;
- the mining method used;
- the number of mined seams;
- the efficiency of the ventilation system;
- equipment availability; and,
- local experience.

The principal drainage methods used worldwide are pre-mining and in-mine degasification, enhanced gob well drainage, and, in some instances, an integrated approach that combines these techniques. Table 11 lists methane recovery and use options along with support technologies needed to apply these methods.

Drainage efficiencies and the amount of methane drained per ton of coal mined indicate the effectiveness of a drainage system. Table 12 summarizes these data for 98 Chinese mines.

[1] One of these, the Yingying Mine, is not associated with any CMA; it is under the jurisdiction of the Shanxi Province Coal Administration

Figure 25. Location of Coal Mining Administrations that Drain Methane

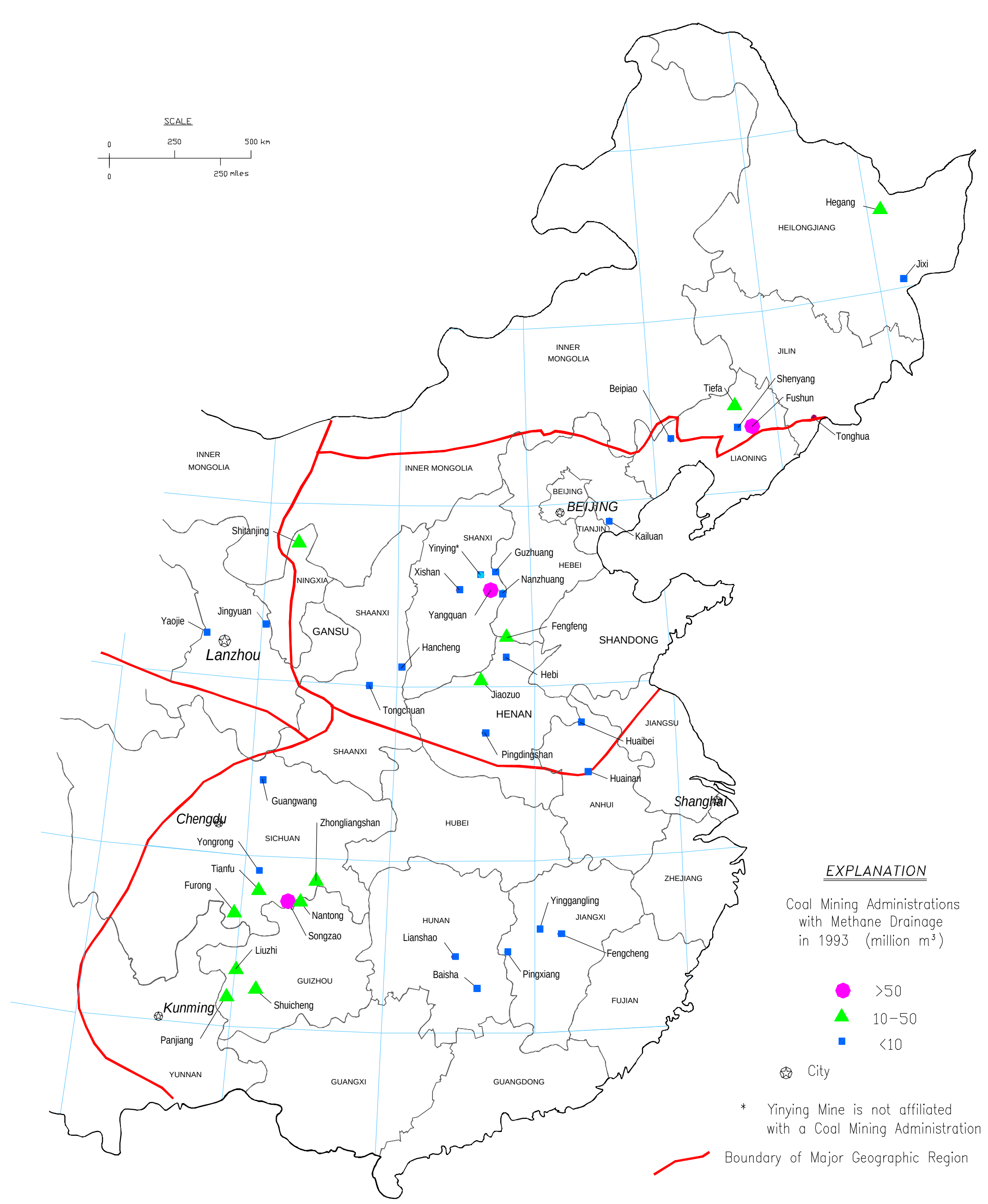


TABLE 11. SUMMARY OF OPTIONS FOR REDUCING METHANE EMISSIONS FROM COAL MINING

Technology or Parameter	Gas Recovered from Gob Wells	Gas Recovered in Advance of Mining	Gas Recovered from Ventilation Air	Gas Recovered from All Sources
Recovery Techniques	• In-Mine Boreholes • Vertical Gob Wells	• Vertical Wells • In-Mine Boreholes	• Fans	• All Techniques
Support Technologies	• In-Mine Drills and/or Basic Surface Rigs • Compressors, Pumps, and other support facilities	• In-Mine Drills and/or Advanced Surface Rigs • Compressors, Pumps, and other support facilities	• Surface Fans and Ducting	• All Technologies • Ability to Optimize Degasification using Combined Strategies
Gas Quality	• Medium Quality (11-29 MJ/m^3) (300-800 Btu/cf) (approx. 30-80% CH_4)	• High Quality (32-37 MJ/m^3) (900-1000 Btu/cf) (above 90% CH_4)	• Low Quality (<1% CH_4; usually below 0.5%)	• All Qualities
Use Options	• On-Site Power Generation • Gas Distribution Systems • Industrial Use	• Chemical Feedstocks *in addition to those uses listed for medium quality gas*	• Combustion Air for On-Site / Nearby Turbines and Boilers	• All Uses
Availability	• Currently Available	• Currently Available	• Requires Demonstration	• Currently Available
Capital Requirements	• Low	• Medium/High	• Low/Medium	• Medium/High
Technical Complexity	• Low	• Medium/High	• Medium/High	• High
Applicability	• Widely Applicable • Site Dependent	• Technology, Finance, and Site Dependent	• Nearby Utilization • Site Dependent	• Technology, Finance, and Site Dependent
Methane Reduction*	• Up to 50%	• Up to 70%	• 10-90% recovery	• 80-90% recovery

* These reductions are achievable at specific sites or systems

After USEPA, 1993

TABLE 12. DRAINAGE EFFICIENCIES AT CHINESE MINES

Number of Mines	Drainage Efficiency	Amount Drained (m^3/ton)
59	<10 %	
15	>15%	>20
24	>20	>10
TOTAL 98		

The following portions of this section describes methane drainage methods typically used in China.

Drainage from Working Seams

In the case of a single seam, boreholes are drilled from the haulage roadway into the seam, in a parallel or fan-shaped pattern (Figure 26). Quality of gas will vary greatly depending on local geology, coal rank, and the efficiency of the drainage system. Typically, medium quality gas (11-30 MJ/m^3) will be recovered. The advantage of this method is that it is inexpensive and can be implemented out relatively quickly. The drainage efficiency is low, however, usually about 20 percent. In general, the drainage efficiency can be increased by using longer parallel holes with larger diameter (up to 300 mm), and lengths ranging from 70 to 80 percent of face length.

FIGURE 26. PLACEMENT OF BOREHOLES WITHIN COAL SEAM, XIE NO. 2 MINE(Plan View)

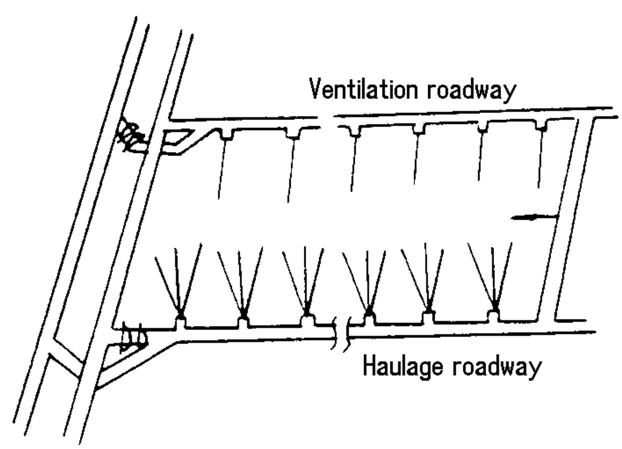
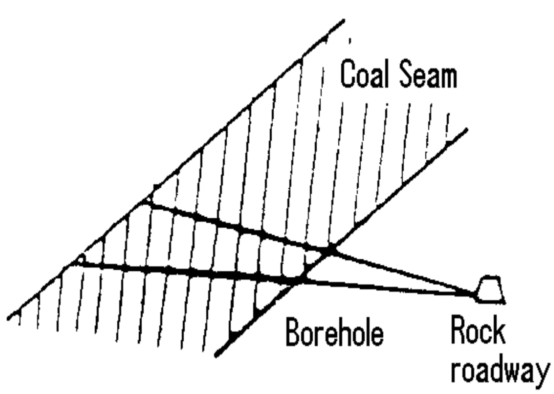


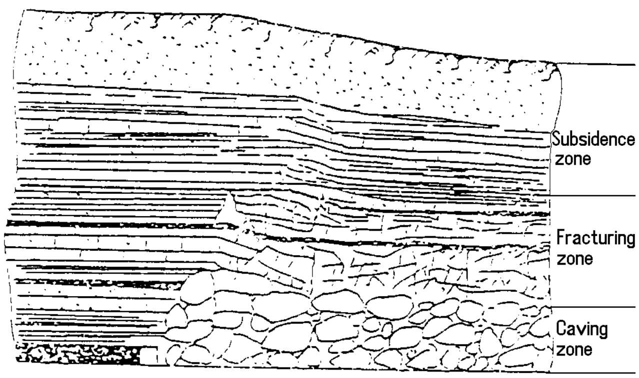
FIGURE 27. PLACEMENT OF CROSS-MEASURE BOREHOLE FOR METHANE DRAINAGE (Side View)



In the case of very thick, dipping seams or multiple seams, cross-measure boreholes are drilled for pre-drainage (Figure 27). The drilling station is set up in a rock heading beneath the seam. Boreholes cross the seams and adjacent strata, intercepting the bedding planes and cross-cutting features through which liberated methane flows into boreholes. Therefore, with cross-measure boreholes the drainage efficiency is much higher than with parallel boreholes drilled within seams.

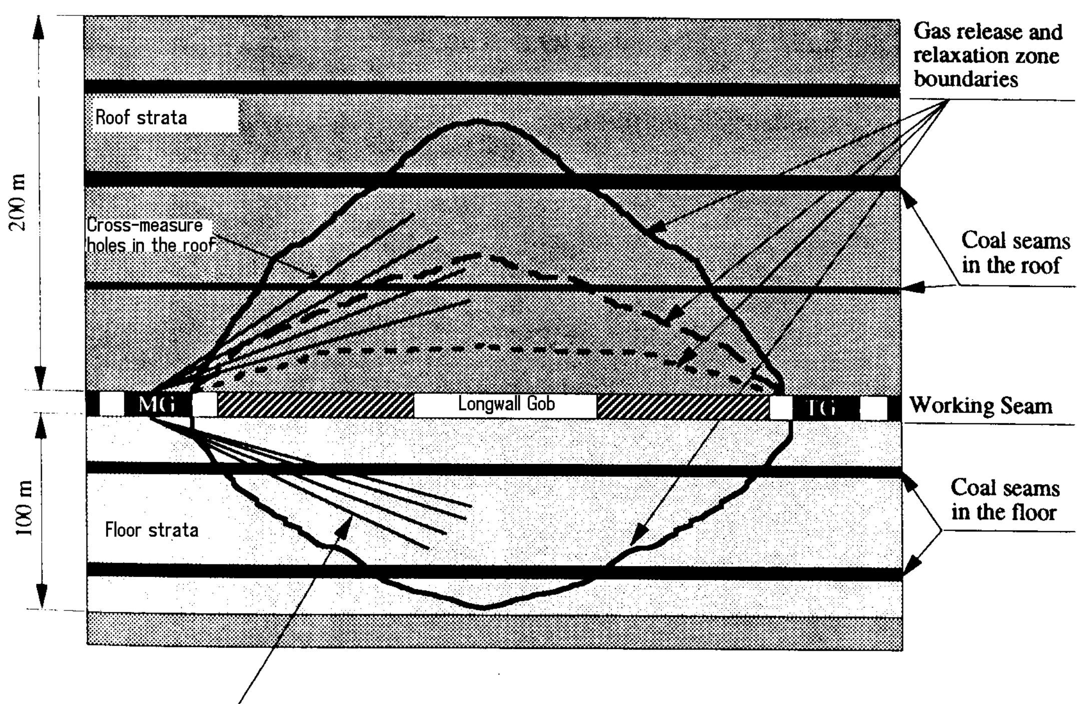
Drainage From Adjacent Seams

FIGURE 28. IMPACT OF MINING ON OVERLYING STRATA



After a seam is mined, the overlying or underlying strata will be relaxed, deformed and fractured, liberating methane into the working face through these fractures (Figure 28). In order to reduce these methane emissions, it is necessary to drain gas from these strata during mining. The degree of relaxation, and consequent volume of methane liberated, depends on the competence of the adjacent strata. Figure 29 shows the gas release and relaxation zone boundaries. It also shows where to place boreholes within these relaxation zones so as to optimize methane drainage.

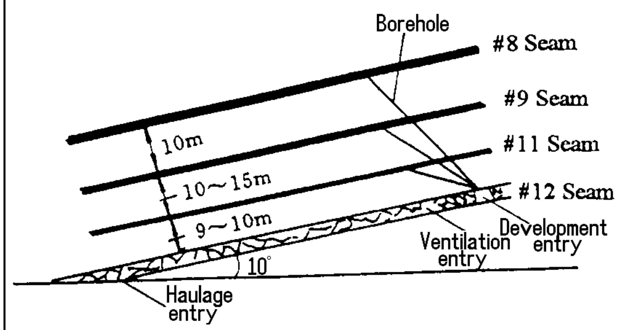
FIGURE 29. CROSS-SECTION OF LONGWALL ROOF AND FLOOR STRATA



After Lunarzewski et al, 1995

In most cases, drilling sites are set up in a development entry (Figure 30). Boreholes are drilled into adjacent seams, and should be located within the fracture zones that open during mining, and accompanying strata relaxation. Boreholes may be 20-50 m apart, with a diameter of 70-150 mm. Methane drainage begins after the working face advances about 10-30 m past the drainage borehole, and stops when the working face is 100-200 m past the borehole. The gas is generally of medium quality, similar to that recovered from working seams, as described previously.

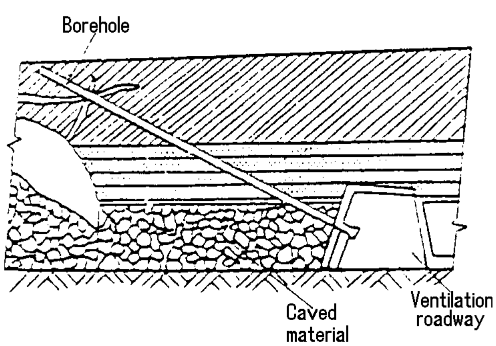
FIGURE 30. BOREHOLE PLACEMENT FOR DRAINAGE FROM ADJACENT SEAMS



Drainage From Gob Areas

According to information from about 60 mines, methane liberated from gob areas typically accounts for 25-30 percent of total emissions from a given mine, and can be as high as 50 percent in some mines. In order to reduce methane emissions from gob areas into ventilation roadways, gob gas drainage has been implemented in some mines. Since the 1950's, mines of the Fushun CMA have recovered 600 million cubic meters of methane from gob areas.

FIGURE 31. BOREHOLE PLACEMENT FOR DRAINAGE FROM GOB AREAS



In general, gob gas is accumulated at the upper area of the roof cavity. Therefore, an effective approach is to drill boreholes from the ventilation roadway into the upper area of the cavity (Figure 31). The most efficient number and spacing of vertical gob boreholes per panel depends on underground conditions. The concentration of methane drained gob areas can be as high as 60-80 percent, and flow rates can reach 3-4 cubic meters per minute.

Drainage Using Surface Wells

Methane drainage using surface wells is new to China's coal mines. Compared with conventional natural gas production in China, coalbed methane reservoirs have poor permeability and furthermore tend to be underpressured. Therefore, it may be necessary to fracture or otherwise stimulate coal seams. Surface wells are used in order to increase methane production.

The State Science and Technology Commission approved China's first surface well methane drainage demonstration project in 1989. The project, located at the Kailuan mine, set out to develop key technologies for well-drilling, fracturing and production of coalbed methane from surface wells. Participation of US coalbed methane consulting firms provided the introduction of modern equipment. In 1992, the Kailuan project was included in a Global Environmental Facility (GEF) project, executed by the United Nations Development Programme (UNDP), titled "Development of Coalbed Methane Resources in China". Now, more than 20 projects involving surface drainage from vertical surface wells are underway in China. Of these, several CMAs have surface wells that are now producing methane, including: Fengcheng in Jiangxi Province; Dacheng in Hebei Province; Jincheng in Shanxi Province; and Tiefa in Liaoning Province. Production rates from the No. 1 test well of the Dacheng project reached 6,000 cubic meters per day. MOCI plans to select several coal basins for intensive development based on a nationwide evaluation of coalbed methane resources. As noted in Section 3.5, the Xi'An branch of the CCMRI is conducting this resource evaluation, which is funded by the GEF project. MOCI expects to build two to four coalbed methane production centers by year 2000.

3.3.3 OPTIONS FOR INCREASED RECOVERY

Significant opportunities exist to increase the quality and quantity of gas recovered in China. Chinese mines currently rely on in-mine degasification from the working and adjacent seams, and in-mine gob drainage. Drainage efficiencies could increase significantly with updated technologies, including: vertical pre-mine drainage from surface wells; in-mine pre-mine drainage employing hydraulic fracturing and possibly horizontal longhole drilling, techniques; and drainage of methane from gob areas using surface boreholes.

The effectiveness of degasification systems at all mines must be assessed on a site-specific basis, and will depend on factors such as:

- methane content of the coal;
- volume and rate of methane liberated;
- type and age of the mine;
- time available for degasification before the coal is mined; and,
- geologic conditions such as faulting, fracturing, and characteristics of adjacent strata.

Commonly, recovered methane is vented during periods of low gas demand, such as during the night (when few people are cooking) and during the summer months. Due to recent reform of China's energy policy, however, there is newly found interest in expanding methane use, both regionally and locally. Many regions face serious coal shortages, and need additional local sources of energy. Coal used for cooking and heating is a major source of local air pollution and has contributed to a greater interest in developing clean-burning natural gas resources. For this reason, municipalities often pursue coalbed methane projects most aggressively.

In the near term, basic improvements to existing technology could increase the quality and quantity of gas recovered. Typically, Chinese mines now drain gas with methane concentrations from 40 to 60 percent. Mines could improve their recovery systems by monitoring gas quality; regulating quality by stopping leaks in the in-mine and surface gas gathering systems; and modifying drilling and completion techniques (such as hydraulic fracturing and more optimal placement of drainage wells). In the longer term, an integrated approach to mine drainage could maximize the recovery of methane and improve mine profitability and safety. This could include recovery of methane before, during, and after mining, both from the surface and within the mine.

Methane drainage efficiency at China's coal mines averages less than 20 percent. A primary cause of this low efficiency is the low permeability of coal seams in many mines. Outdated drilling and drainage equipment is also a problem at least 30 percent of the coal mines with existing drainage systems. As discussed below, drainage efficiencies could increase significantly with modern equipment and updated technologies, including fracturing seams to enhance permeability, and using integrated drainage methods.

<u>Enhancing Fracture Conductivity</u>

Enhancing fracture conductivity would lead to significant increases in methane recovery during single-seam pre-drainage efforts. Several mines have tested methods for enhancing fracture conductivity. The No. 2 mine at the Hebi CMA (see Chapter 4 for details) and the Liwangmiao Mine in Hunan Province tested the use of high-pressure water jets to cut slots in their coal seams. The No. 1 Mine at the Yangquan CMA, Longfeng Mine at the Fushun CMA, and Zhongmacun Mine at the Jiaozuo CMA tested hydraulic fracturing using clear water and sand. The tests showed that the fracture lengths reached 100 m with water pressures of 10 to 20 MPa and flow rates of 0.5 to 2 m^3/min. As a result, methane flow from a borehole increased to 0.5 to 2 m^3/min., about 100 times the rate prior to fracturing.

<u>Integrated Recovery Methods</u>

At some sites, drainage efficiencies can increase to over 75 percent using a combination of pre-mining, during mining, and post-mining techniques. Experience from many mines shows that the drainage rate could increase significantly by taking advantage of strata relaxation, enhancing permeability; this holds true for both single-seam and multiple-seam mining. In addition, more and more mines in China are recognizing the importance of methane recovery from gob areas, now that the significance of coalbed methane as an economic resource is being recognized.

<u>Use of Updated Technology</u>

In order to achieve high drainage efficiencies, it can be effective to drill horizontal longholes from an adjacent haulage way into the fractured zone above the gob. In this case, in-mine directional drilling may be the best option. Recently, the Tiefa Coal Mining Administration imported directional drills for a methane drainage project that is part of the GEF-funded project mentioned in Section 3.3.2. Other improvements that would increase methane recovery include:

- improvement of gas collection systems, including more efficient moisture separation;
- equipment for grouting standpipes under pressure to ensure a bond to the rock;
- effective use of modern drilling and monitoring equipment; and,
- enforcement of safety standards and practices.

Methane Drainage Using Surface Wells

Experiences with methane production in the US show that surface wells can recover up to 70 percent of the methane in place. Surface well demonstration projects are currently underway in the Kailuan, Huainan, Jincheng and Tiefa CMAs, and in unmined areas of the Dacheng Basin in the Tianjin region southeast of Beijing. The preliminary results of these projects are promising. Recent testing of three vertical gob wells at Tiefa has been encouraging, as noted in Section 3.5.

3.4 COALBED METHANE USE

Increased methane recovery will only be economically and environmentally feasible if it is accompanied by increased use. Because most of China's coal mining areas are distant from integrated pipeline networks, opportunities for large-scale, off-site use of methane are limited. In contrast, many opportunities exist for on-site uses for the gas, because of the large volume and close proximity of potential industrial and residential users.

Based on 1993 data, China already uses about 395 million cubic meters (approximately 73 percent) of the 543 million cubic meters of methane recovered from its coal mines annually, mainly in the residential and industrial energy sectors. Forty of China's 110 coal mines recovered their methane. While this is a commendable use rate compared to many countries, the remaining 148 million cubic meters that they vented to the atmosphere presents a large volume of wasted methane that can be recovered and used. Less that one-half of the mines with drainage systems use any of the drained methane. China's recent reforms in the coal industry have increased the focus on coalbed methane use, as exemplified in Box 2.

The best options for the use of mine methane will vary regionally, depending on the quality and quantity of gas, and local energy markets. Any additional use of coalbed methane for commercial and residential heating that would displace the current dependence on coal could significantly improve local and regional air quality. In addition, mines can be potentially increase profitability by expanding their use of methane on site, and/or by selling it to nearby industries.

BOX 2. CHINA'S INCREASED FOCUS ON COALBED METHANE RECOVERY AND USE

Since 1982, MOCI's Department of Coal Processing and Utilization (DCPU) has included gas use in its energy strategy. Using state allocated funds, such as the coal-substitute-oil fund, and various preferential loans, DCPU has completed over 50 gas use projects. These include installation of gas storage facilities with a volume capacity of 650,000 cubic meters, and construction of 620 km of gas pipelines to provide 220,000 households with coalbed methane (Sun and Huang, 1995).

The following sections discuss various options for using methane recovered from coal mines. The most viable options include on-site heating of water and air; cofiring methane with coal in mine boilers; use in gas turbines; and domestic (residential) uses, such as heating and cooking.

3.4.1 DIRECT INDUSTRIAL AND RESIDENTIAL USE OPTIONS

As discussed in Chapter 1, industry consumes two-thirds of the total energy produced in China. One of the key opportunities for expanded coalbed methane use is substitution for coal at mines and in nearby industries. Specific uses depend on conditions at specific mines, but include:

- on-site heating of water and air;
- thermal coal drying;
- heating of ventilation air; and,
- substitution for coke gas, coal or gas in local industries.

Combined heat and power generation facilities located at mine sites often use low-quality coal as the main fuel source. Often this coal has low heating values, and a high ash and sulfur content, resulting in low energy efficiency and decreased air quality. During winter months, when heat and electrical requirements are high and atmospheric inversions occur, air pollution generated by these facilities severely impacts the local communities. Coalbed methane could readily displace the use of coal at mine sites, providing increased energy efficiency while improving the local environment. Availability of coalbed methane may permit conversion of existing coal-fired boilers to co-fire with gas.

As an alternative fuel, coalbed methane can replace lignite, hard coal and coke oven gas, and conventional natural gas. Coalbed methane is an environmentally sound fuel and has high thermal efficiency. The heating value of methane is 8000-9000 calories per cubic meter; 1000 cubic meters of methane is equal to about 1 ton of coal equivalent. Currently, the use of coalbed methane in China includes on-site heating of water and air, heating of ventilation air, and on-site coal drying. In addition, relatively small amounts of coalbed methane are used for production of chemical products. For example, the Songzao Coal Mining Administration has built a chemical plant with a capacity of 600 tons of carbon black annually.

Box 3 describes several uses of coalbed methane in China by industries that would otherwise employ coal.

BOX 3. INDUSTRIAL USE OF COALBED METHANE IN CHINA

In China, coalbed methane has numerous applications in industry. Potential users of CBM are the many on-site or nearby industries operated by the coal mines. China already uses coalbed methane locally, and the potential to expand use is significant. Examples of local use opportunities include the carbon black plants near the large state-run mines.[2] The first factory producing carbon black was built in 1952 at the Longfeng Coal Mine in the Fushun CMA (see the Fushun profile in Chapter 4 for additional details). Now there are carbon black plants at several of the larger CMAs. In 1970, a formaldehyde factory with an annual production of 500t was built at West Opencast Mine at the Fushun CMA, although due to decreased demand for formaldehyde it is not longer in operation. Other users include powder, plastic, and glass factories at the Fushun CMA (Huang L., 1995). In Hebei Province, there is a ceramics operation at the Kailuan CMA, which could readily use CBM for its daily operations.

[2] Carbon black is an amorphous form of carbon produced commercially by thermal or oxidative decomposition of hydrocarbons. It is used primarily in rubber goods, pigments, and printer’s ink.

There are also many opportunities for increasing use of coalbed methane in the residential sector. These residential uses include cooking and heating at mine residences as well as dining, child care, and school facilities. Town gas (gas manufactured from coal) is sometimes employed for these purposes, but coalbed methane requires less investment and provides higher benefits, because it does not require construction of a gas supply plant. Coal mine gas supplied for residential use normally contains 35-40 percent methane, but no harmful impurities arise from the distillation process, therefore a complex cleaning system is not required. As a result, residential use of coalbed methane is becoming widespread throughout the mining regions.

3.4.2 NATURAL GAS PIPELINE SYSTEMS

Recovered coal mine gas can be compressed and transported by natural gas pipeline systems. According to the CII, the gas must meet the following requirements: (1) Methane content of the gas transported in the pipelines must be greater than 95%; and (2) pressure must be between 23.8 and 37.4 atm.

In 1993, China produced nearly 17 billion cubic meters of gas from 79 fields. Currently, there are only 5,902 km of pipelines in China, mainly in Sichuan, Guangdong, and Hebei Provinces (the main gas pipeline system is shown in Figure 8 of Chapter 2). In addition, a 900 km pipeline channeling natural gas from Yan'an (in Shaanxi Province) to Beijing is under construction. For the purpose of coalbed methane development, the pipeline diameter has been redesigned from 500 mm to 600 mm. There currently exists no large, integrated pipeline infrastructure in China, and additional capital costs are required in order to upgrade and increase China’s pipeline system.

In general, most of the high-gas mining areas lack complete natural gas pipeline systems. At present, a short-distance gas pipeline can be used to supply coalbed methane to nearby users; currently, the Tangshan Mine of the Kailuan CMA injects coalbed methane into its city gas system. Because of the proximity of many of China’s CMAs to residential and industrial areas, they are ideally suited for construction of a local pipeline network to these users. Before initiating pipeline projects however, several issues must be carefully considered, including transmission costs, distances from production sites to gas markets, and the productive life of the resource.

3.4.3 POWER GENERATION OPTIONS

Electricity used by China’s coal mines is provided mostly by coal-fired power stations, with waste-fired stations providing only small amounts of power. Coal is also the dominant fuel used for heat at mine facilities. Replacing coal with coalbed methane for power generation and heating would not only reduce environmental pollution, but would likely increase thermal efficiency. Numerous opportunities exist for the generation of electricity and steam at mine power plants, since all coal mines consume electric power. Mines currently generate most of their electricity and steam from coal. Coalbed methane could displace the use of coal in power generation, which causes severe air pollution and is in short supply. Following is a discussion of several power generation options that may apply well to China.

Cofiring With Natural Gas

Cofiring is the combustion of natural gas with coal in the primary combustion zone of a coal-fired boiler. The gas input may vary from less than 10 percent to up to 100 percent of total fuel input depending on boiler design and the needs of the boiler operator. Intermittent gas use may be attractive to larger power plants in the event that there is insufficient coalbed methane to meet year-round needs. This would allow the power plant to take advantage of low summer prices for methane, while maintaining the flexibility of burning coal when gas is either unavailable or more expensive. Box 4 describes seasonal use of methane at mines in Ukraine.

BOX 4. GENERATION OF ELECTRICAL AND THERMAL ENERGY FOR MINE USE: UKRAINE

The Donetskugol Production Association in the Donetsk Coal Basin of southern Ukraine contains several mines that use coalbed methane as fuel in their boiler plants. The boilers use methane when it is available and switch to low quality coal when the quantity or quality of the gas is insufficient. There are, however, other mines in the Coal Production Association that do not use the methane they recover, due primarily to lack of capital for investment in the required surface facilities to collect, process, and transport the gas to the boiler (USEPA, 1994a).

Similar situations exist at Chinese coal mines. There is a need for on-site water heating for space heating and bathhouses. In addition, it is necessary to heat mine ventilation air during the winter months in many northern and northeastern mines. Installation of improved methane drainage systems to recover gas of reliable quantity and quality, and availability of capital necessary to invest in surface equipment, would allow increased methane use.

Cofiring can yield a broad range of operational, economic, and environmental benefits, including reduced sulfur, particulate, carbon, and NOx emissions, lower maintenance costs, greater fuel flexibility, improved plant capacity factor, and production of salable fly ash. While many of these benefits are site-specific, most plants will achieve at least some of them. Cofiring can be accomplished at very low capital costs and with no technological risk; if for any reason natural gas is no longer available, the boiler could continue to operate entirely on coal. At some power plants in the U.S., cofiring has reduced operating costs by millions of dollars per year (Vejtasa et al, 1991; CNG, 1987).

The only modifications required to the boiler are the addition of gas supply piping, gas ignitors, and warmup guns. In the US, the costs for minor modifications such as replacing ignitors is on the order of $US 3-7 per kW. The cost to modify burners to add dual firing capacity is on the order of $US 10-20 per kW (GRI, 1995).

Equipping a unit to fire 100 percent gas or cofire high percentages of gas commonly includes installation of a side-wall mounted gas burner equipped with a combustion air fan. Based on the large diameter of such a burner, tube wall modifications are required. A conventional side-wall mounted ring-type gas burner capable of firing the average available methane should be rated at about 4.8 Gcal/hr.

An alternative to the side-wall mounted gas burner is to insert gas injectors between boiler tubes along the side walls. This approach could be used to fire at least 25-35 percent of the boiler heat input without the need for an additional combustion air supply. Greater heat input using this approach may be possible, but would require further evaluation.

Box 5 describes a power plant in Poland that cofires methane along with pulverized coal; the plant operates more efficiently and cost effectively.

BOX 5. COFIRING OF METHANE AT THE ZOFIOWKA CHP PLANT, POLAND

The Zofiowka mine in the Rybnik-Jastrzebie area of the Upper Silesian Basin of Poland cofires methane and pulverized coal at its CHP plant, whose capacity is 64 MW_{el} + 320 Mw_{th}. The plant supplies heat and power to the mine and the town of Jastrzebie. About 10 percent of the fuel energy consumed by the power plant is delivered in gas. During the first half of 1994, 20.8 million cubic meters of gas, with a methane concentration of 46.5 percent, were consumed by the plant.

Methane is combusted in the startup burners and the backup combustion supporting burners. Each 1000 cubic meters of methane yields 12.9 MWh of steam, which produces 3.1 MWh of electricity, 4.7 MWh of heat energy, and 5.1 MWh of regeneration feedwater. Use of coalbed methane in the CHP plant is cost effective, due largely to the low price of coalbed methane (each cubic meter of methane produces $0.08 US worth of electricity and $0.03 US worth of heat). Using conventional natural gas to cofire with the coal would cost four to five times as much (USEPA, 1995c).

Internal Combustion Engines

Internal combustion (IC) engines include spark-ignited four-stroke and diesel dual-fuel engines. They can generate electrical power with medium to high-quality coalbed methane. Typical capacities of IC engines range from several kilowatts (kW) to several megawatts (MW). These sizes are much smaller than gas turbines and would be more compatible with the production of coalbed methane from a single well. As an example, a 1 MW IC engine would require approximately 10,000 cubic meters of methane per day. IC engines can use medium quality gas (30 - 80 percent methane) such as that produced by surface gob drainage.

IC engines are modular in design and require little specialized expertise to install and maintain. Due to their small sizes, they can be relocated easily if the gas supply is depleted. They tend, however, to require high capital investment and maintenance costs. Previously, variations in gas quality caused some problems with the use of mine gas in IC engines, but with modern integrated control systems it now appears possible to accommodate these fluctuations.

Gas Turbines

Gas turbines are more efficient than coal-fired generators, cost less to install, and are available in a wide range of sizes. This allows utilities to add smaller increments of capacity to handle peak consumption, rather than investing in larger, capital intensive coal-fired units that would be underutilized. In addition, gas turbine exhaust is a source of waste heat, which can be used to generate steam in a heat recovery boiler. Three systems which improve the thermal efficiency of the system are: 1) Use of steam for process or district heating, known as **cogeneration**; 2) Use of steam in a turbine generator for additional electrical power production, known as a **combined cycle,** and 3) Use of steam injected into the hot gases flowing to the thermal turbine, known as a **steam injected turbine (STIG).**

Gas turbines can use coalbed methane directly from a high pressure pipeline, or from an external coalbed methane compressor. Box 6 describes a gas turbine at the Fushun CMA. In most of these cases, waste heat is recovered from the turbine stack for use in an auxiliary thermal process. These turbines, which range in size from 3 to 20 MW, can frequently supply a significant portion of a mine's electrical needs.

BOX 6. GAS TURBINE AT THE FUSHUN CMA

In 1990, the Laohutai Mine of the Fushun CMA built a coalbed methane-fired power plant that utilizes surplus methane saved during low periods of methane use in the summer months. The rated capacity of the generating unit is 1,500 kW. Research indicates that when the methane concentration reaches 40 percent, the gas flow rate needed for generating 1,200 kWh electricity is 35 m3/minute, and the efficiency of the unit can exceed 80 percent.

The success achieved in using methane to generate electricity has created additional use and conversion opportunities. The coalbed methane-fired power plant has an annual generating capacity of 2.8 MWh, and can supply 1.8 MWh electricity into the electric network (Huang L., 1995). It runs only during the summer, however (May to September).

The working efficiency of a gas turbine is about 30 percent. The Raston TB5000 gas turbine, manufactured in the UK, provides nearly complete combustion of coalbed methane. The large amount of waste heat in gas turbine exhaust can be recovered by waste heat boilers and used for heating. Gas turbines requires high-pressure fuel input (above 18 atm), and the methane concentration of the gas must be greater than 40 percent.

Compared with other power generating technology options, steam turbines have low thermal efficiency, but they operate reliably and have a long service life. Under normal conditions, where a standard boiler is used to combust coalbed methane for steam generation, boilers can use medium- to high-quality gas.

The combined cycle method is one of the most efficient methods to convert gas energy into thermal power. Gas turbine exhaust has a high temperature and rich oxygen content, and can be transported to waste heat boilers to generate steam for driving a turbine. Thermal efficiency of the system can reach 45 percent.

In 1990, the Laohutai Mine of the Fushun CMA built the first coalbed methane-fired power station in China. The power station has an installed capacity of 1200 kW, and the methane concentration of the gas exceeds 40 percent.

3.4.4 VENTILATION AIR USE OPTIONS

Because nearly five billion cubic meters of methane are emitted annually from ventilation systems at China's key state-owned mines alone, use of this ventilation air, if feasible, would be highly desirable. Numerous studies have examined options for purifying this gas, but the expense is prohibitive using existing available technology. However, as technology progresses, it may become economically feasible to enrich the gas contained in mine ventilation air using some of the methods discussed in Section 3.4.5 below.

At present, the best option for use of ventilation air is as part of the fuel mixture in steam boilers, gas turbine generators, or gas engines. This has been successfully achieved at the Appin and Tower Collieries in Australia, where ventilation air is used to help fuel a set of gas engines, increasing overall output of the plant by 7-10 percent (IEA, 1996). Where feasible, the use of ventilation air should be part of an integrated methane drainage program. In general, the targeted generation facility should be within approximately 2 km of the ventilation air source for this option to be economic.

3.4.5 IMPROVING GAS QUALITY

Much of the 1.7 billion cubic meters of gas that mine drainage systems recover but vent to the atmosphere each year have methane concentrations ranging from 30 to 50 percent. Developing uses for this methane would be aided by producing the highest quality gas possible and by ensuring that quality (concentration) variations are minimized.

In the short term, there are several relatively inexpensive, low technology methods of improving the quality of recovered mine gas in China. These include shutting in old wells (in-mine); reducing leaks in the in-mine and surface gas gathering systems (pipelines); and improving grouting of standpipes. In the longer term, there are several methods for improving gas quality which require some investment and higher technology. The three primary means of improving the quality of gas recovered from coal mines are improved monitoring and control, increased pre-mining drainage, and gas enrichment.

Improved Monitoring and Control

One of the most economical methods to improve the quality of gas is to reduce air entrapment in the gas stream during the production process. This can only be accomplished by finding the equilibrium production rate of the well, i.e., the rate at which the ratio of methane liberation in the coal equals the rate of production at the well head.

Since the rate of methane liberation generally declines with time it is necessary to adjust critical production parameters frequently in order to control the bottom hole pressure (BHP) and maintain a high methane concentration in the product gas. Continuous monitoring of the oxygen content at the well head in conjunction with adjusting the production rate to maintain a desired gas quality is a production control technique that automatically maintains the BHP at the required level without needing to determine its actual value. Since the mine ventilation system and the wellbore are in communication, it is customary (and advisable for safety reasons) to also monitor the mine ventilation system at appropriate check points.

Increased Pre-Mining Drainage

Gas drained in advance of mining usually has a higher methane content than that drained from working faces or gob areas. Advanced pre-mining drainage techniques include:

- Use of vertical wells drilled from the surface. Chinese mines do not widely employ this technique at present, but it has been highly successful in the US (Diamond et al, 1989).

- Use of more numerous, and more strategically placed, cross-measure boreholes drilled in advance of mining. Predictive techniques can be used to maximize recovery (Lunarzewski, 1994).

Gas Enrichment

Gas quality can be improved by enriching gas through removal of one or more of the following contaminants: nitrogen, oxygen, carbon dioxide, and moisture. Cryogenic processes for separating nitrogen and air for methane have been successful for large-scale conventional natural gas operations, but require high capital investment and are economic only for very large gas flows (millions of cubic meters per day). At present, this method would not be economical for coal mines, which produce smaller volumes of gas.

There are a number of enrichment processes that are at various stages of research and development, and that may in the near future be economic for small-scale plants processing gas volumes under 300 thousand cubic meters per day, such as would be produced by the typical coal mine.

Nitrotec Engineering, UOP, and BOC Group have each developed pressure swing adsorption (PSA) processes that use carbon molecular sieves to adsorb methane from nitrogen and oxygen. This type of PSA process has been proven in the laboratory and appears to be ready for full-scale commercial operation. Costs of this process are reportedly in the range of $US 26 to $US 48 per thousand cubic meters for gas volumes between 57 and 283 thousand cubic meters per day, and mixtures ranging from 75 to 92 percent methane (D'Amico and Reinhold, 1993).

Gas Separation Technology uses natural zeolites in a PSA process to adsorb nitrogen and oxygen from methane mixtures. They report costs, based on laboratory tests, in the range of $US 4 to $US 16 per thousand cubic meters for mixtures ranging from 40 to 90 percent methane and volumes between 28 and 142 thousand cubic meters per day. This process has not been tested in the field (Gas Separation Technology, 1995).

The Mehra process uses hydrocarbon solvents for nitrogen rejection. It has been successfully demonstrated in the field with respect to nitrogen and moisture removal. If the process can be proven to handle oxygen, it may be economic for volumes of 4,200 to 8,500 cubic meters per day of mildly diluted methane (Mehra and Wood, 1993).

Bend Research uses a transition metal-based liquid adsorbent to remove nitrogen from methane. Based on laboratory research they report costs of $US 19 per thousand cubic meters for an unspecified mixture and volume, and expect to lower the cost to $US 11 per thousand cubic meters (Shoemaker, 1994). This process is still in the laboratory research phase.

Membrane Technology and Research, along with several other firms, has extensively researched membrane separation of nitrogen and methane, which would be very attractive because of the simplicity of membrane separations and their applicability in small plants. To date, however, this is process is only conceptual, and there have been no reports of success in developing a membrane of sufficient selectivity between nitrogen and methane that will enable an efficient separation (Baker, Pinnau, and Wijmans, 1993).

None of the above methods can be said to be both proven and commercially available. It seems likely, however, that in the near future one or more processes will prove to be economically attractive for enriching medium-quality coal mine gas to pipeline quality.

3.4.6 GAS STORAGE

Coal mines should consider gas storage an integral part of any coalbed methane use strategy. With storage facilities, gas can be used as demand dictates. For example, gas that mines produce when demand is low (such as during the summer) can be stored and used during periods of higher demand.

The primary means of coalbed methane storage in China is surface storage tanks using the Higgins floating lid design. Coalbed methane drained from underground mines is transported to the storage tanks, and then supplied to nearby households, schools, and other consumers via pressure adjustment stations and pipelines. So far, there are two sizes of storage tanks available, one with a capacity of 5,000 cubic meters and the other with a capacity of 10,000 cubic meters. At present, China's total gas storage capacity is about 680 thousand cubic meters, and the total length of the main pipelines exceeds 655.6 km. This is insufficient to meet China's storage needs. To expand coalbed methane development, gas storage must be available at or near the mines themselves, as they are a primary user. Gas storage facilities exist at several of the larger CMAs, such as Tiefa, Fushun, and Hebi; however, mines still vent much of the gas because of a lack of storage facilities. Construction of additional facilities is planned, and will play a major role in expanding methane recovery and use.

In areas where a CMA has several large coal mines within a relatively small area, construction of local pipelines and storage tanks could link the individual mines, allowing optimal gas use by local industry and residential districts. A CMA such as Songzao, which currently has several large mines with some pipeline infrastructure and gas storage facilities, would benefit from such a combined option.

In many gas producing areas of the world, underground storage is the most common means of storing gas to meet peak seasonal market demands. Although the initial cost may be prohibitive, underground storage systems can handle much larger capacities than surface storage. Preferred sites are porous subsurface reservoirs, including depleted oil and gas fields as well as aqueous reservoirs. Other sites used for storage are natural and man-made salt and rock caverns. Underground gas storage was first utilized in the United States in 1916, and currently there are over 400 storage fields with a total capacity of more than 228 billion cubic meters of gas. This is equivalent to almost half the annual U.S. gas consumption. In addition, the use of underground gas storage can allow capitalization of spot gas market purchases, and better supports management of marketing and production by producers (Thompson, 1991).

In addition to conventional storage facilities, another available option is gas storage in abandoned coal mines. Since the early 1980's, two abandoned mines in Belgium have stored imported natural gas (Moerman, 1982). In China, abandoned coal mines or inactive shafts of operating mines are potential locations for gas storage. A thorough evaluation of the geologic and hydrologic conditions at these mines is, of course, necessary to determine economic feasibility and mine safety.

3.4.7 NATURAL GAS VEHICLES

Vehicles are a major contributor of air pollution worldwide, emitting carbon monoxide, reactive hydrocarbons, and nitrogen oxides. Diesel vehicles also emit particulate matter. With an increasing number of vehicles in China, the availability of oil as the main fuel source becomes less desirable in the future. Natural gas is environmentally preferable because its use would reduce emission of all of the major vehicle pollutants. The economic and environmental benefits of using methane as a fuel source are significant, especially considering the large amount of methane vented from coal mines each year in China, and the current shortage of vehicle fuel.

Compressed natural gas (CNG) provides a low cost, efficient, clean burning and abundant fuel source that any internal combustion engine can use. Current natural gas vehicle technology possesses energy efficiency ratings that are equal to or greater than gasoline and other alternative fuels. According to the American Gas Association (1993), 2830 cubic meters (100 Mcf) of CNG is equivalent to 3785 liters (1000 gallons) of gasoline. Countries which currently use CNG vehicles include Ukraine, Canada, New Zealand, Mexico, Spain, and the United States (see Box 7 for a discussion of incentives in the US). One of the most common uses of CNG vehicles is for urban fleets such as taxis, trucks, delivery vans, and buses. CNG is a well established technology; it is proven reliable, safe, and economical, and is clean burning.

BOX 7. INCENTIVES IN THE US FOR INCREASED USE OF NATURAL GAS VEHICLES

Natural gas vehicle technology has accelerated in the US since passage of the Clean Air Act Amendments (CAAA) in 1990. The CAAA is promoting alternate fuel vehicles by requiring areas that have not adopted a Federal Ozone Program to convert a certain percentage of their fleet vehicles to clean-fuel vehicles by 1998. Also, the CAAA requires attainment of national ambient air quality standards. If metropolitan areas do not attain ozone, CO, and particulate matter standards, they face rigid non-compliance penalties. Transit authorities can convert about 55 percent of public transit buses to natural gas consumption.

Fleet vehicles are excellent targets for conversion to natural gas, because fleets consume a large portion of the motor fuel in the US, are centrally fueled, and release large quantities of pollutants. The Energy Policy Act of 1992 mandates that a percentage of fleet vehicles must be powered by clean fuels in the future. Conversion to natural gas fueled vehicles is happening nationwide, primarily in major private fleets, public utility fleets, transit bus fleets, and school buses. Total range of a natural gas vehicle depends on the amount of natural gas stored in the vehicle. Converted and bi-fuel vehicles actually have an extended range, since the driver has access to two fuels—the normal gasoline range and the added natural gas range. Dedicated vehicles have a range of about 330 km (Natural Fuels Corporation, 1994).

Because natural gas is cheaper than gasoline, fleet owners often see a payback of the initial cost in three years or less, depending upon annual mileage and vehicle type. With tax and rebate incentives, the payback period can be substantially shortened. According to the Energy Policy Act of 1992, businesses and individuals are entitled to a tax deduction of up to $2,000 for cars, and $5,000 to $50,000 for trucks and vans (depending on vehicle weight), for conversion and/or use of alternative fueled vehicles (AFVs). A deduction of up to $100,000 is also offered for the cost of establishing an AFV refueling station (Natural Fuels Corporation, 1995). In addition, several states, including California, Colorado, Oklahoma and Texas, also offer financial incentives for AFVs, such as investment tax credits or fuel tax exemptions.

In order to use CNG as vehicle fuel, its methane concentration should reach 90-100 percent, and the concentration of paraffin should not exceed ethane by more than 6.5 percent. As methane is the primary component of coal mine gas, after enrichment, the methane concentration could be increased to 95 percent, while the ratio of paraffin to ethane is minimally increased. Therefore, coalbed methane is highly suited for production of CNG for vehicle fuel.

Currently, there are over seven million vehicles in China, and the number of vehicles increases 13 percent annually. Most of these have inefficient engines and high fuel consumption, which create major problems with the domestic energy supply and local air quality. As the number of vehicles increases dramatically in the next several years, a key issue in China's energy and environmental policy is to increase efficiency and satisfy emission standards. One solution is the technological development of alternative fuel for transportation, including increased use of natural gas, methanol, and ethanol. During the 1960's, a shortage of conventional fuel in China spurred the use of natural gas vehicles, which were most successful in areas with natural gas resources and infrastructure. As discussed in Section 1.2.3, recent energy strategies emphasize increased development and use of natural gas. As the government reduces price controls and the economy becomes more market-driven, the price of oil and natural gas should rise to current market levels. The CMAs, which have their own fleets and municipal buses, could benefit greatly by using CNG vehicles.

A barrier in China, as with most countries, is that there is no high-pressure natural gas vehicle refueling infrastructure, so vehicles must be refueled directly from the pipeline. The paradox is that the lack of refueling stations limits the development of natural gas vehicles, and the small number of natural gas vehicles limits the development of a refueling infrastructure. Refueling stations have been imported from Canada, U.S. and New Zealand; however, due to equipment and vehicle problems, the stations have not been efficiently maintained (EIC, 1994).

Another use for CNG with potential applications in China has been developed in the U.S. This technology, developed by a Texas-based company, was designed specifically to recover and use gas produced from marginal wells, or wells isolated from existing pipelines. Gas is compressed at the source, a specially-designed CNG trailer is connected, and the gas is loaded into steel tubes. Gas can then be transported to an end user, where it is off-loaded. Although designed for conventional gas, this technology could be applied to coalbed methane. In China the most likely applications would be at the larger CMAs, where the methane produced from underground mines is of sufficient quantity and quality to economically collect and use locally.

Compressed natural gas may also serve to supply households with a cleaner source of fuel than coal for cooking and heating. This use could improve local air quality and create a market for coalbed methane where construction of a pipeline may not be economic. This could develop a market for coalbed methane incrementally, which means up-front capital costs would be lower and the market could develop until a pipeline project became economic.

3.5 CHINESE ACHIEVEMENTS IN COALBED METHANE RECOVERY AND USE

China's coal industry has accumulated enormous experience in recovering coalbed methane using in-mine methods. In the early 1990's, China began in-mine drainage projects to improve safety and production conditions in the mines. Use of this methane, however, is in its initial developmental stages. Recent reforms in the energy sector have promoted increased use of natural gas, and MOCI is now committed to develop coalbed methane as a key strategy for the coal industry.

Forty Chinese mines are currently set up to distribute the recovered methane. CMAs supply methane to employees for residential cooking at very low costs, as a form of social welfare. Coalbed methane is also sold as a commodity to urban residents outside the CMAs. The current principal industrial uses for coalbed methane are for small carbon black plants run by the CMAs, and a small gas turbine generator at Fushun. Industrial use and gas turbines are described in Section 3.4.1 (Box 3) and 3.4.3 (Box 6), respectively. Increased methane recovery, and a concomitant increase in use, could displace the use of coal for cooking and heating in the growing residential sector. Underground gob gas drainage systems, and surface gas storage facilities are in place and operating in many CMAs. Since many of China's mining operations are relatively close to population centers, a wide range of use options exist, including the deployment of waste heat from turbines for district heating.

In addition to methane recovery from mines, coalbed methane exploration and development in China's unmined areas is increasing as well. According to preliminary statistics, MOCI, the China National Petroleum and Gas Corp. (CNPGC), the Ministry of Geology and Mineral Resources, and local governments drilled 39 boreholes for methane resource evaluation and production tests during the period 1990-1994. These boreholes were drilled in both mined and unmined areas, and were financed using domestic as well as foreign capital.

Following is a summary of coalbed methane projects planned or recently undertaken[3] in China (China Coalbed Methane Clearinghouse, 1995; Wang and Li, 1995; Sun, 1995). Figure 32 shows the locations of these projects. Table 13 summarizes the projects, their locations, and status as of December 1995.

Anhui Province

1. Huainan CMA - Enron Exploration Co. drilled four wells in this CMA, two at the Xieli mine and two at the Panji mine. Testing indicated that permeability was low. Chapter 4 contains additional information about the Huainan CMA.

2. Huaibei CMA - The Huaibei CMA completed a 540 m surface well at the Taoyuan Mine, which is producing about 500-1000 cubic meters of methane per day from gob areas of Seams 7, 8, and 10 (Li D. et al, 1995). Two coalbed methane assessment wells are being drilled as part of a GEF National Assessment sub-project. Chapter 4 contains additional information about the Huaibei CMA.

[3] Relatively long-established coalbed methane projects, such as the recovery and use of methane at the Fushun CMA, are not included here.

Figure 32. Location of Coalbed Methane Projects in China

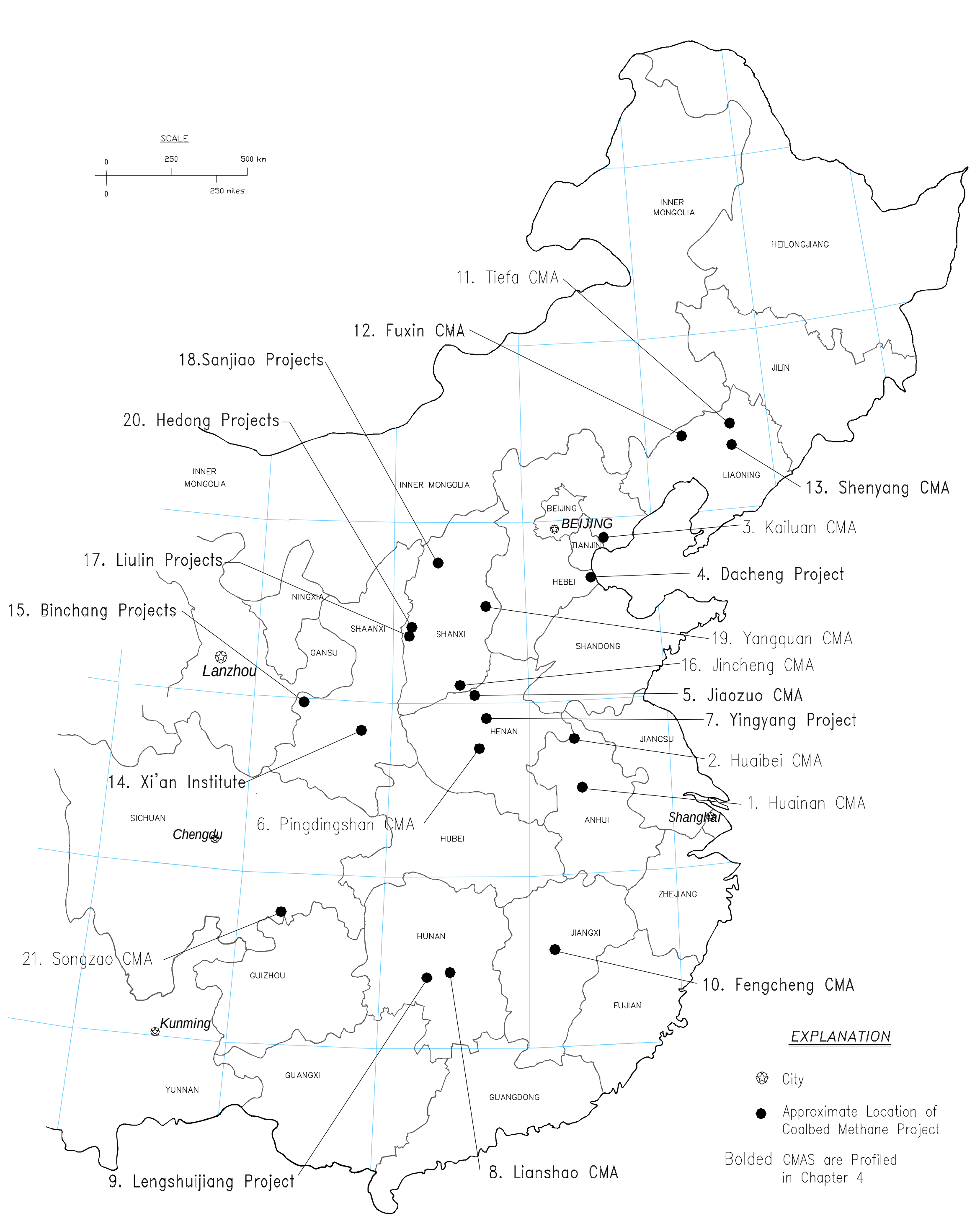


TABLE 13. STATUS OF COALBED METHANE PROJECTS IN CHINA

No.	Coal Basin	Participants	CMA / Mines Involved	STATUS (December, 1995)	Production (m^3/day)
1	Huainan	MOCI, Enron	HUAINAN / Xieli, Panji	Completed four wells	N/A
2	Xuhai	Huaibei CMA	HUAIBEI / Taoyuan	Completed a surface well	500-1,000
3	Jingtang	GEF, Kailuan CMA, GAI	KAILUAN / Tangshan	Drilling now underway	
4	Lubei	CNPGC	None	1 well completed and producing	6,000
5	Qinshui	Jiaozuo CMA, CCAO	JIAOZUO / not specified	Negotiating to drill a test well	
6	Yuxi	Pingdingshan CMA, CNAGC, Enron	PINGDINGSHAN / No. 8	Drilled 1 well	N/A
7	Yuxi	Zhengzhou City Gas Co.;Zhengzhou City Coal Dept.;Sino-American Energy	None	No. G1 well completed at 460 m	N/A
8	Lianshao	Central China Admin. Petroleum Geol.	LIANSHAO / Hongshandian	Drilled 2 wells to depth of 500 m	N/A
9	Lianshao	CNPGC, Hunan Prov. Planning Comm.	None	Drilled well to 600 m	600
10	Pingdong	Jiangxi Province, CNPGC	FENGCHENG / none	Completing Quijian No. 1 well	
11	Songliao	GEF, Tiefa CMA, REI	TIEFA / Xenon, Daxin	Drilled 3 vertical gob wells; will also drill 3 horizontal wells	21,600
12	Fuxin	Fuxin CMA, Juxin Planning Comm., Xi'an Branch CCMRI, USCBM Energy	FUXIN / Wangjiaying	Completed one test well	N/A
13	Dunhua-Fushun	Shenyang Planning Commission, Advanced Resources International	Guchengzi lignite coal field	Completed and tested 2 wells	1,800 (initially)
14	Various	GEF/UNDP, Xi'an Branch CCMRI	Various	Collected data on mining areas	
15	Ordos	MOCI, CNPGC, Amoco	None	Feasibility study in progress	
15	Ordos	MGMR, Shanxi Planning Comm., Shell Oil Co., Lowell Petroleum Pty. Ltd.	None	Lowell has drilled two wells, will drill a third well	N/A
16	Qinshui	Jingcheng CMA, Sino-American Energy	JINCHENG / Panzhuang	Completed 4 test wells; three additional wells to be drilled	tested 3,000 to 5,000
17	Hedong	NCBPG, UNDP	None	Producing/evaluating	500
17	Hedong	NCBPG, Lowell Petroleum Pty. Ltd.	None	Drilling/evaluating	
18	Hedong	Enron, Huajin Coking Coal Corp.	Sanjiao mining area	Production testing 2 wells	
18	Hedong	Shanxi Province Planning Commission, US CBM Energy Corp.	Sanjiao mining area	Ready to sign agreement	
19	Qinshui	Yangquan CMA	YANGQUAN / Hanzhuan	Negotiating proposed project	
20	Hedong	MGMR, Enron	None	Drilled two wells to date	N/A
20	Hedong	MGMR, Amoco	None	Preparing to drill first well	
21	Chuannan-Qianbei	GEF, Songzao CMA, REI	SONGZAO / Shihao, Datong No. 1	Reservoir testing completed, directional drilling to begin	N/A

Numbers in Column 1 correspond to locations in Figure 32. The acronyms list at the beginning of this report includes acronyms in this table.

Hebei Province

3. Kailuan CMA - This project, located at the Tangshan mine, includes drilling surface wells to drain methane in advance of mining; designing an optimal methane drainage system and strategy; and building compression, treatment and transportation facilities. The Kailuan CMA is cooperating with GAI Co., a U.S. contractor, on this GEF-sponsored project. They have completed the project design and drilling of five coalbed methane boreholes is now underway. Chapter 4 contains additional information about the Huaibei CMA.

4. Dacheng Project - The CNPGC is conducting this project in an unmined area. The Dacan No. 1 well is 1,100 m deep; it has been completed and fractured and produces 6,000 cubic meters per day. CNPGC is making a decision on investing in the drilling of 1 or 2 more wells.

Henan Province

5. Jiaozuo CMA - The Central China Administration of Oilfields will cooperate with the Jiaozuo CMA on this project. They plan to drill and complete a coalbed methane test well. Negotiations are underway.

6. Pingdingshan CMA - In 1993, Enron Oil and Gas International and the China National Administration of Coal Geology (CNACG) drilled a borehole at the Pingdingshan CMA specifically designed to obtain coalbed methane reservoir parameters. Testing indicated low permeability. Chapter 4 contains additional information about the Pingdingshan CMA.

7. Yingyang Project - The Zhengzhou City Gas Department, the city's Coal Department, and the Sino-American Energy Corporation have jointly invested 2 million RMB yuan in this methane recovery project. The No. G1 well was drilled to 460 m by the Central China Administration of Oilfields.

Hunan Province

8. Lianshao CMA - The Central China Administration of Petroleum Geology has drilled two wells to a depth of 500 m at the Hongshandian mine.

9. Lengshuijiang Project - The NPGC and the Planning Commission of Hunan Province are cooperating on this project. A well has been drilled to 600 m, and production testing yielded 600 cubic meters of methane per day.

10. Fengcheng CMA - In 1994, Jiangxi Province and the CNPGC cooperated in drilling a trial coalbed methane well, the Quijiang No. 1, at the Quijiang coal field. Unfortunately, the coal seam was damaged during the drilling process. Attempts to successfully complete the well are underway (Zheng, 1995).

Liaoning Province

11. Tiefa CMA - This project, funded by the GEF and administered by UNDP, has been undertaken by the Tiefa Coal Mining Administration and Resource Enterprises Incorporated (REI), a US consulting firm. The primary objectives of the project are to demonstrate the

effectiveness of surface vertical gob wells, and to remove gas from the working seam via directionally-drilled in-mine horizontal gob boreholes (Schwoebel et al, 1995).

Three vertical gob wells have been drilled, cased and completed at the Daxing Mine, and results are encouraging. The three wells are producing a total of about 15 cubic meters of methane per minute. Late in 1995, the Tiefa CMA began drilling the horizontal gob boreholes, also at the Daxing Mine. This entails directionally drilling three long (~1000 m) in-mine boreholes above the working coal seam. Chapter 4 contains additional information about the Tiefa CMA.

12. Fuxin CMA - The Fuxin CMA, the Fuxin Municipal Planning Commission, Xi'An Branch of the CCMRI, and US CBM Energy Corporation are cooperating in the development of coalbed methane in this area. The No. 9420 testing well at the Wangjiaying Mine was completed in 1994. The permeability of the upper coalbeds was measured at 3 to 4 md. The concentration of methane in the gas is 90 percent. Due to unspecified difficulties, drilling had to be suspended before reaching the lower seams.

13. Shenyang Project - The Planning Commission of Shenyang City and Advanced Resources International, a US firm, are cooperating on this project. Two wells were drilled at the Guchengzi lignite coal field in the northern part of the city. The wells produced 1800 cubic meters per day after fracturing at the initial stage.

Shaanxi Province

14. GEF/UNDP Project with the Xi'an Branch of the CCMRI (in various provinces and basins) - This project will include a detailed evaluation of China's coalbed methane resources, production potential, and use methods. The Xi'an branch will also conduct detailed analyses on coalbed methane investment and market prospects. They have collected data pertaining to the coalbed methane resources of 17 mining areas. They will drill at least ten test boreholes in eight different mining regions, including the Huainan, Huaibei, and Jiaozuo CMAs, to further evaluate their coalbed methane resources. To date, the Xi'an branch has drilled boreholes at the Huainan and Huaibei CMAs, and other test boreholes will be completed soon.

Shanxi Province

15. Bingchang Projects - MOCI, the China National Petroleum and Gas Corp. (CNPGC), and Amoco USA are cooperating on a project that will take place in the unmined Bingchang area. A feasibility study is in progress.

Elsewhere in the region, under an agreement with the Ministry of Geology and Mineral Resources (MGMR) Lowell Petroleum Pty. of Australia has drilled two wells, financed by Shell Oil. They are preparing to drill a third well.

16. Jincheng CMA - The Jincheng CMA and Sino-American Energy Co. are cooperating in this demonstration project at the Panzhuang mine. To date they have completed four of seven proposed wells. One of the completed wells, Pan No. 2, has produced 3000-5000 cubic meters per day. Production tests of the Pan No. 3 and Pan No. 4 wells yielded water and gas (Sun et al, 1996). Chapter 4 contains additional information about the Jincheng CMA.

17. Liulin Projects - Since 1991, the North China Bureau of Petroleum Geology (under the MGMR) has drilled six coalbed methane test wells, in the unmined Liulin Pilot Area of the Hedong Basin, with UNDP assistance. Well depths range from 350 to 400 m. In October, 1994 these wells began producing an average of 500 cubic meters per day. The Bureau has conducted reservoir evaluation and permeability studies (Quan et al, 1995; Chen et al, 1995). The Bureau has also conducted twelve large-scale hydraulic fracturing treatments on the six wells (Li Z. et al, 1995).

Another project is underway at the Liulin Contract Area. This area encompasses 218 km^2 and is the first joint venture coalbed methane exploration area authorized by the Chinese government (Zhao et al, 1995). The North China Bureau of Petroleum Geology and Lowell Petroleum Pty. Ltd. are participating in the venture. To date, they have drilled two of three planned exploration wells; production testing, reservoir simulation, economic analysis, and a detailed assessment will follow.

18. Sanjiao Projects - Since 1992, Enron Oil and Gas International has been cooperating with the Huajin Coking Coal Corporation by conducting in-depth exploration and evaluation for coalbed methane resources in the Sanjiao mining area of the Hedong Basin (Fisher, 1995). They are presently production testing two wells in Sanjiao, and preliminary results suggest that the potential for coalbed methane production in the area is excellent.

The Shanxi Province planning commission has organized another project in the northern Sanjiao mining area, involving six partners, including the Lulian Subprovince Planning Commission, Huaxiang Corp., the Geological Exploration Corp., Huatai Corp., and US CBM Energy Corp. The Administration of Geology and Mineral Resources has approved the license for exploration, and the partners are ready to sign an agreement on the project.

19. Yangquan CMA - The Yangquan CMA plans to develop coalbed methane at the Hanzhuang mining area of the Qinshui Basin. This exploration project would include methane drainage in advance of mining, and would be synchronized with development of the Yangquan mining area (Dong, 1995). CBM Associates has drilled two wells at Yangquan CMA. Chapter 4 contains additional information about the CMA.

20. Hedong Projects - Enron Exploration Corp. negotiated a project with the MGMR to explore for methane in unmined areas of shallow coal deposits in southern Liulin County in the Hedong Basin. They have drilled two wells to date.

Amoco has negotiated with the MGMR for development of coalbed methane in deep deposits. They are preparing to drill a well.

Sichuan Province

21. Songzao CMA - This project takes place at the Shihao and Datong No. 1 mines. The GEF is funding the project, UNDP is administering it, and REI of the US is providing technical direction. The primary objective of the project is to demonstrate the applicability of directional drilling for improved methane drainage (Jianling et al, 1995). In addition, the project includes: reservoir testing and computer simulation to optimize borehole spacing;

in-mine hydraulic fracturing; improving surface and underground gas collection systems; and, improving current ongoing drilling and gas collection techniques.

To date, all major equipment design, reservoir testing, and sorption testing have been completed. Permeability is low, and the coal seam appears to be undersaturated. Directional drilling is expected to start during the first quarter of 1996, and hydraulic fracturing will follow. Chapter 4 contains additional information on the Songzao CMA.

In summary, China has seen much progress in coalbed methane development in recent years, both in mined and unmined areas. Coal mines have been improving their underground drainage systems, and are beginning to recover methane from surface wells. Major energy companies are proposing several methane exploration and development projects in unmined areas.

Certain technical barriers to widespread coalbed methane development in China still remain. These include the lack of a widespread pipeline network, and relatively low permeability of the coal seams. With increased capital investment and ongoing research efforts, China can likely overcome these problems.

CHAPTER 4

PROFILES: SELECTED REGIONS WITH STRONG COALBED METHANE POTENTIAL

4.1 INTRODUCTION

4.1.1 SELECTION CRITERIA FOR PROFILES

As Chapter 1 discussed, there are currently 108 Coal Mining Administrations (CMAs) in China, which manage approximately 650 mines. In addition to the CMAs, there are numerous gassy local, township, and private mines that cumulatively produce over one-half of China's coal. Varying physical and geologic criteria (including type of basin, age, depth, rank, reserves, annual production, and life of mine) cause some coal mining regions to have higher coalbed methane development potential than others. Mines located near industrial and population centers, for example, are more conducive to near-term recovery and use options, as recovery is most economical for mines with ready gas markets nearby.

This chapter profiles ten CMAs and one coal basin. Each of the profiled areas meets most or all of the following criteria:

- Depth of coal seam burial between 300 to 1000 m;
- Minimum seam thickness of 2 m;
- Coal rank ranging from low to medium volatile bituminous; vitrinite reflectance 0.5 to 2.0 percent;
- Minimum gas content of 9 cubic meters/ton (based on desorption testing);
- Coal seam permeability of 1 md or greater;
- Well-developed local industrial infrastructure, nearby markets or population centers, and high demand for natural gas.

Chapter 5 uses the information provided in the CMA profiles, with the recovery and use options described in Chapter 3, to provide criteria for selecting the technologies appropriate to specific conditions. Chapter 5 also contains guidelines for the development of coalbed methane projects.

4.1.2 CMA PROFILES USER'S GUIDE

This chapter profiles the following ten CMAs with high project potential, the locations of which are shown in Figure 22 (Chapter 2).

NORTHEAST REGION

- 4.2 Fushun CMA - Liaoning Province
- 4.3 Tiefa CMA - Liaoning Province

NORTH REGION

- 4.4 Hebi CMA - Henan Province
- 4.5 Jincheng CMA - Shanxi Province
- 4.6 Kailuan CMA - Hebei Province
- 4.7 Pingdingshan CMA - Henan Province
- 4.8 Yangquan CMA - Shanxi Province

SOUTH REGION

- 4.9 Huaibei CMA - Anhui Province
- 4.10 Huainan CMA - Anhui Province
- 4.11 Songzao CMA - Sichuan Province

Section 4.12 profiles the Hedong Coal Basin, whose location is shown in Figure 14 (Chapter 2). It is in the North Region in Shanxi and Shaanxi Provinces on the eastern edge of the Ordos Basin. As noted in Section 3.5, the Hedong Basin, like most of the CMAs listed above, is an area where coalbed methane projects are planned or currently underway. The source of information for the Fushun CMA profile is Huang L. (1995) and JP International (1991); the majority of data for the remaining profiles were provided by the CII. Additional sources are cited within the individual mine profiles.

There are five appendices at the end of the report that may be useful to companies interested in pursuing methane projects in China. Appendix A lists contacts that potential foreign investors may find useful. Appendix B explains Chinese terminology regarding resources, coal rank, and other frequently used terminology pertaining to coal and coalbed methane. To avoid repetition, Appendix B contains information which is not included in the individual mine profiles. Appendix C consists of selected summary tables compiled on the individual CMAs. Appendix D consists of provisional rules and regulations for coalbed methane development in China. Appendix E contains more information about USEPA publications and programs related to coalbed methane.

Individual CMA profiles include the following types of data (to the extent these data were available):

- Coal geology, reserves and production; includes geologic setting, coal reserves and rank, coal production and quality;
- Methane liberation, ventilation, recovery, and resources;
- Present and planned use of mine methane; and,
- Mining economics.

Specific mining economics data for individual CMAs are not readily available. CII data from sixteen coal mining regions throughout China, however, indicate that coal sale prices during September, 1995 ranged from 125 to 310 yuan for bituminous coal (average 215 yuan, or approximately $US 26.18), and from 130 to 356 yuan for anthracite (average 225 yuan, or approximately $US 27.40) per ton. No coalbed methane cost recovery data are available for individual CMAs or mines. According to the CII, estimated average costs for methane drainage in China are 30 yuan ($US 3.65) per thousand cubic meter for underground drainage and 400 yuan ($US 48.70) for vertical (surface) wells, respectively.

In selecting regions for coalbed methane development, it will be necessary to further evaluate resource conditions, market demand, and local infrastructure. Based on a preliminary evaluation of methane resources (Table 14), however, it appears that the mining areas profiled in this chapter have great potential for future development.

TABLE 14. ESTIMATED COALBED METHANE RESOURCES CONTAINED IN AREAS PROFILED IN CHAPTER 4

CMA or Coal Basin	METHANE RESOURCES (Billion cubic meters)	1994 COAL PRODUCTION (Million Tons)
Huainan	500.0	11.5
Yangquan**	290.0	10.5
Hedong Coal Basin	220.0	N/A
Huaibei **	158.4	14.2
Kailuan	30.0	18.0
Tiefa	28.3	11.0
Jincheng	24.0	10.3
Songzao **	22.7	2.7
Pingdingshan**	17.2	17.1
Hebi	10.6	4.7
Fushun **	*3.1	8.6

* The Fushun estimate is for recoverable methane resources only.
** 1993 Production listed for these CMAs
Resource estimates were provided by CII (1995) and Huang L. (1995); details on resource estimation methodology were not available.

4.2 FUSHUN CMA

The Fushun CMA is located in eastern Liaoning Province (Figure 22) in the city of Fushun, an industrial center. Coal mining operations began in the area in 1907. The CMA is situated in the Dunhua-Fushun Basin and consists of three underground coal mines and one surface mine.

4.2.1 COAL GEOLOGY, RESERVES, AND PRODUCTION

Structurally, the Fushun Basin is a large, asymmetrical syncline. In addition to coal, there are significant quantities of oil-bearing shale and mudstone in the basin. Coal is mined from a group of Eocene age coal seams whose thickness totals 8 m in the western portion of the basin and 130 m in the east; average recoverable thickness is 50 m. In 1993, the mine produced 8.6 million tons of coal. The coal is high volatile bituminous in rank, and is low in sulfur, phosphorous, and ash. Large quantities of gas are associated with this coal, primarily in the Laohutai Mine, Shengli Mine, and Longfeng Mine.

4.2.2 METHANE LIBERATION, VENTILATION, RECOVERY AND RESERVES

The Fushun CMA began recovering methane in the early 1950's. Total drainage volume from 1952 to 1994 is 3.7 billion cubic meters (Xu, 1995). Since 1980, the CMA has drained more methane annually than any other CMA, recovering 113 million cubic meters in 1993. The CMA recovers methane underground, in advance of, during and after mining (gob recovery). Box 8 is an example of methane recovery from working seams at the Laohutai Mine.

Currently there are eight methane drainage systems in the Fushun CMA, 0.48 million meters of gas supply pipeline, and six gas storage tanks. There are also six ventilation systems discharging low-methane gas into the atmosphere. The CMA, in cooperation with CCMRI, has conducted several hydraulic fracturing tests using vertical (surface) wells at the Longfeng Mine (Xu, 1995).

Key methane characteristics of the three underground mines at the Fushun CMA are as follows:

BOX 8. METHANE RECOVERY FROM WORKING SEAMS AT THE LAOHUTAI MINE

The Laohutai Mine is located in the center of the Dunhua-Fushun basin, currently mining at a depth of about 600 m. Total seam thickness averages 43.0 m thick, and dip is 21° to 25°. Coal rank is high volatile bituminous B (gas coal), and volatile content is 45.8 percent. Methane content averages 13.2 cubic meters per ton, and permeability ranges from 2.9 to 3.1 md.

The natural flow of methane from boreholes is only 3.5 to 4.0 m^3/min (per 100 m of borehole). In contrast, when vacuum pumps are used to drain methane from the seam, the flow rates reach 120 cubic meters per minute. Boreholes are 75 to 127 mm in diameter and are drilled upward or downward into the seam. Recovery efficiency is as high as 54.5 percent.

The No. 502 mining district, in which they are mining from 5 active faces, is a typical example. One drilling site is set up at each face. At each drilling site, five boreholes were drilled downward at a dip of 5 to 15°.

Mine	Coal Methane Content	CH_4 Concentration in the Gas*
Laohutai	26.5 m^3/ton	58 percent
Longfeng	34.8 m^3/ton	33 percent
Shengli	34.8 m^3/ton	33 percent
* Presumably, this refers to gas recovered from the mines' drainage systems		

According to Huang L. (1995), methane reserves of the three mines are about 14.4 billion cubic meters; of this, an estimated 3.1 billion cubic meters of methane could be recovered.

4.2.3 PRESENT AND PLANNED USE OF METHANE

About 75 percent of the methane recovered at Fushun mines is used for domestic purposes; 20 percent by the chemical industry, and 5 percent is used for power generation. In 1990, there were 160,000 households in Fushun using coalbed methane as fuel, for cooking and heating; of these, 47,000, or 30 percent, were part of the mining complex. By 2000, there will be an estimated 300,000 households in the city using coalbed methane.

Methane consumption at the Fushun CMA fluctuates daily and seasonally. When meals are not being prepared, and during the summer months, there is a surplus of methane, and large quantities are vented to the atmosphere, while at mealtimes and during the winter months, there are methane shortages. Thus, it is necessary to increase gas storage capacity in the region. There are presently 188,000 cubic meters of storage capacity at the CMA, and two new surface tanks are under construction; when completed, the new facilities will provide an additional 20,000 cubic meters of storage.

The chemical industry at Fushun uses methane for making carbon black. Because of its low sulfide content, methane is the ideal feedstock for carbon black production. One cubic meter of methane can produce between 120 and 150 grams of carbon black. The Fushun Glass Factory, a local plastic factory, and a local gun powder factory also use coalbed methane.

As discussed in Box 6 of Chapter 3, the Laohutai Mine built a coalbed methane-fired turbine power plant that uses surplus methane recovered during the summer months. At a methane concentration of 40 percent, the plant uses 35 cubic meters of methane per minute.

4.3 TIEFA CMA

The Tiefa CMA is located in northern Liaoning Province, 90 km north of the city of Shenyang, in the southern Songliao coal-bearing area (Figure 22). The CMA was established in 1958, and covers an area of 613 km^2. There are currently eight active underground mines, with an additional mine to begin production in 1996. All mines in the CMA are connected with the national railroad network.

4.3.1 COAL GEOLOGY, RESERVES, AND PRODUCTION

Coal deposits of the Tiefa CMA are contained in Upper and Middle Jurassic sediments. There are a total of 20 seams contained in the coal bearing section, 10 of which are considered recoverable. Major mineable coal seams are contained in an upper and lower coal bearing section, with the lower section coals being slightly higher rank. Depth of burial of these seams range from 30 to 1000 m. The overlying strata consist primarily of sandy mudstone.

Coal rank is predominantly low, sulfur, high volatile bituminous with seam thicknesses ranging from 1 to 3 m. The CMA has 2.25 billion tons of proven coal reserves. The CMA consists of eight active mines with a producing capacity of 15.15 million tons per annum. Raw coal production in 1994 totaled 11 million tons.

4.3.2 METHANE LIBERATION, VENTILATION, RECOVERY, AND RESOURCES

Recovery of coalbed methane at the Tiefa CMA began in 1974. In 1994, ten gas drainage systems were in place with an annual recovery of 16 million cubic meters, primarily from gob areas. Coalbed methane recovery volumes for the CMA have increased from approximately 2 million cubic meters in 1985 to over 16 million cubic meters in 1993 (CII, 1995).

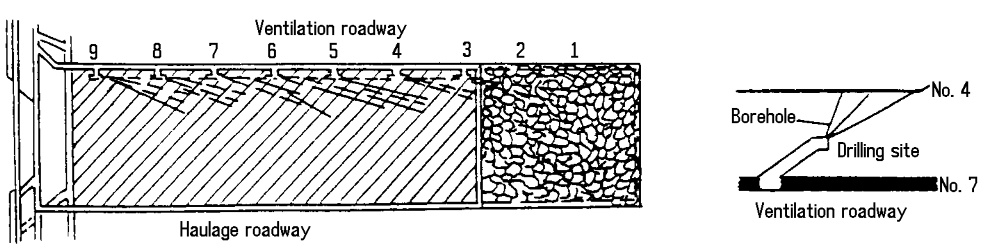
Drainage methods at the Tiefa CMA include overlying adjacent seam borehole drainage, in-seam drainage, and gob drainage. Gob gas is drained using horizontal long holes and strike-oriented roadways in the roof strata. The CMA's Xiaonan Mine drains gob gas using roof boreholes, as described in Box 9 and Figure 32. The average drainage rate at this mine is 3.37 cubic meters per minute and the recovery efficiency is 73.1 percent.

BOX 9. THE XIAONAN MINE: METHANE RECOVERY FROM GOB AREAS

The Xiaonan Mine of the Tiefa CMA produces 2.1 million tons of coal annually from Jurassic age sediments. The depth of the first mining level is 385 m. The primary seam is the No. 7, with an average thickness of 2.9 m. The methane content of this seam ranges from 7 to 8 cubic meters per ton. The No. 4 seam is partly recoverable with an averaged thickness of 1.6 m. The methane content ranges from 13 to 14 cubic meters per ton. Rank is high volatile bituminous C, with a volatile content of 36 percent.

Horizontal long boreholes are drilled in roof strata at the S1-722 face for methane recovery from gob areas. Nine drilling sites are set up at intervals of 130 to 140 m in the ventilation roadway (Figure 33). At each drilling site, 3 to 4 boreholes are drilled; they are 117 mm in diameter, and range in length from 150 to 255 m. A total of 34 boreholes are drilled.

FIGURE 33. PLAN VIEW OF BOREHOLE PLACEMENT FOR METHANE RECOVERY FROM GOB AREAS



Xiaonan Mine imported a modern drill from Acker, a US drill vendor, which uses a 95 mm and 117 mm roller bit. In order to achieve high drainage efficiencies, boreholes should be drilled into the fracture zone above the gob cavity. The mine used directional drilling technology and improved the drill steel, in order to maintain the desired drilling path.

During mining of the S1-722 coal face, methane flow from a single borehole averages 0.95 cubic meters per minute, with a maximum rate of 3.48 cubic meters per minute. During a 426-day period a total of 2.07 million cubic meters (3.37 cubic meters per minute) were recovered, with an efficiency of 73.1 percent.

The Daxin Mine is the gassiest coal mine in the Tiefa CMA. Specific emissions range from 11 to 15 cubic meters per ton for the upper seams and 16 to 22 cubic meters per ton for the lower seams. The estimated methane reserves contained in the Daxin Mine workable seams are 11.5 billion cubic meters (Schwoebel et al, 1995).

The CII estimates that the Tiefa CMA contains 28.3 billion cubic meters of coalbed methane reserves. Of these, 23.5 billion cubic meters are contained in the Tiefa coal basin, and 15.3 billion cubic meters are recoverable. The gas content of mineable coal seams is high, ranging from 11.05 to 24.23 m^3/t for current mining depths. Coal seam permeability in the region is relatively low.

As discussed in Section 3.5, there is a GEF-funded project for surface (vertical well) gob gas recovery at the Tiefa CMA. To date, three wells have been drilled with the cooperation of the Tiefa CMA and the US company REI.

4.3.3 PRESENT AND PLANNED USE OF MINE METHANE

The Tiefa CMA first used coalbed methane in 1975, initially for dining facility uses such as boiling water. Residential use of coalbed methane began in 1985. Concentration of methane in the gas mixture ranges from 30 to 90 percent. Methane use by local residents and industry is limited, averaging 25 percent, with the remaining 75 percent vented to the atmosphere (Schwoebel et al, 1995).

In 1992, the CMA built three gas storage tanks in the region. Total storage capacity is 25,000 cubic meters, supplying gas for 9,000 households. In 1992, Tiefa CMA coal sold for 78 yuan per ton, and the price of coalbed methane was 0.15 to 0.50 yuan per cubic meter. Gas consumption per household averaged 1.36 cubic meters per day in 1992.

4.4 HEBI CMA

Hebi CMA is located in northern Henan Province (Figure 22). It covers an area of 15.5 km^2, and was founded in 1957. It mines coal from the Hebi Coal Basin.

4.4.1 COAL GEOLOGY, RESERVES, AND PRODUCTION

The Hebi CMA mines Permo-Carboniferous age coals. Burial depth is less than 1,000 m. There are up to 17 coal seams; 4 to 6 of these seams are mineable, with a cumulative thickness of 10 m. Coal rank in Hebi CMA is primarily low volatile bituminous and anthracite.

Coal reserves within the Hebi CMA total 1.77 billion tons. The designed annual production capacity is 4.20 million tons, and 1994 raw coal production was 4.67 million tons.

Since 1970, the Hebi CMA has had five mines with gas drainage systems. As of 1992, a total of 132 million cubic meters of methane have been recovered. Drainage borehole lengths totaled 9.9 km, and the drainage rate was 15.26 cubic meters per minute. Recovery efficiency was 14.2 percent. In 1993, the Hebi CMA recovered 6.5 million cubic meters of methane. Box 10 discusses successful efforts to increase recovery at the CMA's No. 2 mine.

BOX 10: ENHANCING PERMEABILITY AT THE HEBI CMA NO. 2 MINE

The No. 2 mine at the Hebi CMA has tested the use of high-pressure water jets to cut slots in their coal seams. Slots with a depth of 0.4 to 0.8 m and a width of 0.2 m were cut at both sides of the borehole using a jet with a pressure of 8 to 18 MPa. This resulted in a release of pressure from the coal seams, as well as fracturing. After cutting the slots, methane flow from boreholes increased dramatically.

4.4.2 METHANE LIBERATION, VENTILATION, RECOVERY, AND RESOURCES

Methane content in the Hebi CMA averages 13.76 cubic meters. Coalbed methane reserves in 1992 were about 10.6 billion cubic meters and recoverable reserves were 2.2 billion cubic meters.

4.4.3 PRESENT AND PLANNED USE OF MINE METHANE

Coalbed methane concentrations range from 30 to 40 percent, with a heating value of 11 to 18 MJ per cubic meter. Gas of this quality is used as residential fuel without being processed. Currently the region has five gas storage tanks with a total capacity of 40 thousand cubic meters, and 48 km of gas pipeline. About 60 thousand cubic meters of gas are consumed each day; of this, residential consumers use 87 percent, and mine facilities use 13 percent. The use ratio of coalbed methane in the region is 90.6 percent.

Residential areas with an existing transportation infrastructure are nearby, making the Hebi CMA an attractive area for coalbed methane development. Advanced surface recovery technology could recover significant quantities of coalbed methane, providing a long-term, stable gas supply for residential users, as well as developing additional industrial use options.

4.5 JINCHENG CMA

Jincheng CMA is located in southeastern Shanxi Province (Figure 22), covering an area of 3,680 km^2. Currently Jincheng CMA has three active mines; all three mine coal from within the Qinshui Basin. The Tai-Jiao Railway crosses the eastern part of the region.

4.5.1 COAL GEOLOGY, RESERVES, AND PRODUCTION

Coal-bearing formations in the Jincheng CMA are of Permo-Carboniferous age, within the Taiyuan and Shanxi Formations. They contain up to 15 coal seams, three of which are mineable seams (Seams No. 3, 9, and 15). Individual seam thicknesses range from 1.7 to 6.0 m; cumulative coal thickness averages 13.8 m. Coal rank is predominately anthracite, with ash content ranging from 14 to 19 percent, and volatile matter from 6 to 9 percent.

The Panzhuang Mine has three mineable anthracite seams with an average thickness of 10 m and gentle dip. Overburden thickness ranges from 300 to 600 m, and seam thickness exceeds 1.5 m.

Coal reserves in the region are 11.6 billion tons. Associated methane reserves to a depth of 1,000 meters are estimated at 6.3 billion cubic meters. In 1994, raw coal production was 10.32 million tons.

4.5.2 METHANE LIBERATION, VENTILATION, RECOVERY, AND RESOURCES

Currently, there is no underground methane recovery at the Jincheng CMA (and therefore, it is not listed in Table 10). However, since 1991 the Jincheng CMA has been cooperating with Sino-American Energy Corp. at the Panzhuang Mine to develop coalbed methane resources via surface wells. As discussed in Section 3.5, four of seven proposed wells have been completed and production tests at one well yielded 3000 - 5000 cubic meters of methane per day.

Total methane reserves for the three mineable seams in the region are 24 billion cubic meters. The majority of these resources occur at the Panzhuang Mine. Average gas content is 19 cubic meters per ton, with a maximum gas content of 40 cubic meters per ton (Wang Y. et al, 1995). The methane concentration of this gas exceeds 85 percent.

4.5.3 PRESENT AND PLANNED USE OF MINE METHANE

There is a small residential area of 6,000 households and some public facilities five km from the mine. Use of coalbed methane as a fuel source would eliminate the need for construction of a coal gas plant, estimated to cost of 40 million yuan. Other potential uses for coalbed methane at the Jincheng CMA are supplying methane to a thermal power station, as a source of vehicle fuel, methanol factories, and as a chemical feedstock.

4.6 KAILUAN CMA

The Kailuan CMA is located in the city of Tangshan in eastern Hebei Province (Figure 22). The CMA was built in 1978, and currently consists of ten mines. The CMA covers an area of 890 km^2. The Jingshan and Daqing railways cross the region.

4.6.1 COAL GEOLOGY, RESERVES, AND PRODUCTION

Kailuan CMA lies with the Kailuan Syncline, Jinggezhuang Basin, Chezhoushan Basin, and the Jiyu Basin. The Kaiping Syncline, which covers an area of 670 km^2, is the main structural feature in the Kailuan Basin. Coal reserves to a depth of 2000 m are 13.2 billion tons.

Kailuan Coal Basin contains Permo-Carboniferous coals. There are 30 coal seams, nine of which are mineable; seam thickness ranges from 1 to 4 m. Ash content is 12 to 20 percent, and volatile matter ranges from 34 to 40 percent. Coal rank is primarily high volatile bituminous.

The designed production capacity of the region is 19 million tons annually. For the past several years, raw coal production has averaged 18 million tons per annum. Kailuan is the largest coking coal producing region in China.

4.6.2 METHANE LIBERATION, VENTILATION, RECOVERY, AND RESOURCES

The axis of the Kaiping Syncline divides the area into two sub-basins with two distinct reservoir characteristics. Gas contents south of the axis are low (less than 9 cubic meters per ton), and gas contents north of the axis are high (9 to 15 cubic meters per ton with a maximum of 20 cubic meters per ton). Based on research by the Xi'an Branch of the Central Coal Mining Research Institute, coalbed methane reserves to a depth of 2,000 m are 30 billion cubic meters in the Kaiping Coal Basin. Cumulative thickness of the No. 8 and No. 9 seams in the Kailuan CMA is 9.50 m. Injection permeability and drop permeability are 18.0 md and 0.8 md, respectively. The No. 8 and No. 9 seams are the primary targets for coalbed methane development.

Gas drainage at the Kailuan CMA began in 1973. The primary methods used are surface borehole pre-mine and gob drainage. For several years, gas drainage has averaged 8 to 9 million cubic meters per annum. Box 11 and Figure 33 describe methane recovery from the CMA's Zhaogezhuang mine. Currently, under a UNDP-funded project, the Tangshan Mine of the Kailuan CMA has completed initial stages of construction for two vertical production wells. This is described in more detail in Section 3.5.

4.6.3 PRESENT AND PLANNED USE OF MINE METHANE

The Kailuan CMA is located within the city of Tangshan, providing an on-site gas market. Coalbed methane recovered from Kailuan CMA is used for residential and mine facilities. In 1992, the coalbed methane supply was 66 thousand cubic meters per day, meeting the demand of 20 thousand households. The CMA's Tangshan Mine injects coalbed methane directly into the city gas system. Currently, the Kailuan CMA has six gas storage tanks with a total capacity of 40 thousand cubic meters. The region uses 90 percent of the methane recovered from the mines.

BOX 11. ZHAOGEZHUANG MINE: RECOVERY FROM ADJACENT SEAMS

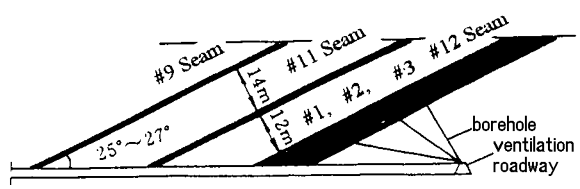
The Zhaogezhuang Mine of the Kailuan Coal Mining Administration is located 30 km to the northeast of the city of Tangshan. The mine has been producing coal for approximately 100 years, and currently produces 1.8 million tons annually. Present mining depth is 1002 m.

The Zhaogezhuang Mine has been recovering methane from coal seams since the 1970's. The No. 9 and 12 seams, with a total thickness of 13 m, are the primary targets for methane recovery. The No. 9 seam has a methane content of 7.5 cubic meters per ton, and a permeability of 0.001 md. Gas and coal outbursts have occurred during mining of this seam. Methane content of the No. 12 seam is 7.3 cubic meters per ton, and the permeability is 0.0013 md. Three additional seams, Nos. 5, 7, and 11, also have potential for methane production.

Since 1987, the peak flow of methane reached 1.5 cubic meters per minute. At several locations along the No. 11 seam cross-cut, methane concentration is 30-40 percent. The average amount of methane recovered from adjacent seams totals about 450 thousand cubic meters, accounting for 37 percent of the total methane recovered from the mine.

In recent years, the Zhaogezhuang Mine has experimented with pre-drainage of methane from adjacent seams. Figure 34 shows the placement of boreholes for methane recovery from adjacent seams. Drilling sites are located in ventilation roadways at 30 m intervals, from which boreholes are drilled upward into seams that underlie the target No. 11 seam. The seam is mined first to allow underlying strata to relax.

FIGURE 34. BOREHOLE PLACEMENT FOR RECOVERY FROM ADJACENT SEAMS AT ZHAOGEZHUANG MINE



Methane flow from the No. 12 seam, or other seams underlying the No. 11 seam, increased rapidly as the working face of the No. 11 seam passes by the borehole. A maximum flow rate from a single borehole reached 0.365 cubic meters per minute as the face passed 30 m past the borehole. The flow stabilized at 0.113 cubic meters per minute after completion of mining operations. Recovery efficiency was estimated at 36 percent.

The experience with methane recovery at the Zhaogezhuang Mine indicates that pressure from adjacent seams was released and permeability increased as a seam of multi-seams was mined out first. This adjacent-seam drainage technique is considered the best option for methane recovery at the Zhaogezhuang Mine.

4.7 PINGDINGSHAN CMA

The Pingdingshan CMA is located in the North Region of central Henan Province (Figure 22), an important bituminous coal region. The CMA contains 14 mines which mine coal from the Pingdingshan and Hanliang Coal Basins, covering areas of 650 km^2 and 61 km^2, respectively. The Pingdingshan CMA is an important coal center in China, with a long history of coal production.

4.7.1 COAL GEOLOGY, RESERVES, AND PRODUCTION

The coals are found within seven Permo-Carboniferous coal groups. The Shanxi Formation is the major economic coal-bearing section. One seam within the Shanxi Formation is the primary target for coal mining, accounting for over 60 percent of the total coal resources in the CMA. Total thickness of the coal-bearing package is 800 m. There are 10 mineable seams, whose thickness totals 13 to 30 m. In 1994, coal reserves of Pingdingshan Coal Basin were estimated at 7.41 billion tons. In 1994, fourteen coal mines produced 18.5 million tons of coal (Wang H. et al, 1995).

The Pingdingshan Coal Basin contains numerous coal seams, which are mainly high volatile bituminous, with some medium and low volatile bituminous in rank. Volatile matter ranges from 20 to 23.4 percent. Most seams have well-developed cleating, and permeability averages 1 md.

The thickness of the mineable seams generally exceeds 2 m, and they are laterally continuous throughout the basin. Dip of the coal-bearing sediments ranges from 5° to 15°. Strata overlying the coal seams in the Pingdingshan Coal Basin are primarily mudstones and sandy mudstones.

4.7.2 METHANE LIBERATION, VENTILATION, RECOVERY, AND RESOURCES

Methane drainage increased from 0.13 million cubic meters in 1992 to 0.65 million cubic meters in 1993. Coalbed methane resources of the Pingdingshan CMA, to a depth of 1000 m, are estimated at 17.2 billion cubic meters. Gas contents tend to be fairly high. Average methane content in coal seams of the Permian Shanxi Formation exceeds 8 cubic meters per ton, with a maximum of 16 cubic meters per ton (Wang H. et al, 1995).

Data from gas contained in coals at depths less than 600 m indicate that methane concentrations exceed 80 percent and carbon dioxide content is less than 10 percent. Coalbed methane content increases with increased depth of burial. Desorption studies show that coals from this region tend to desorb rapidly and completely, with little residual gas remaining in the coal.

As described in Section 3.5, Enron Oil and Gas drilled a coalbed methane test well at the Pingdingshan CMA. The coalbeds penetrated by this well had low permeability.

4.7.3 PRESENT AND PLANNED USE OF MINE METHANE

The Pingdingshan CMA currently has 11 mines, including two mines classified as gassy mines and four outburst mines. If newer surface recovery technology is used to increase the drainage efficiency to 50 percent, coalbed methane could become an important energy source in the region.

Within 200 km, there are five large to medium sized cities, and transportation is convenient, providing a significant market for coalbed methane. There are over 80,000 households in the city of Pingdingshan. Based on currently available demand, and a methane drainage efficiency of 25 percent, the Pingdingshan CMA could extract its coalbed methane resources to a depth of 1,000 m for 100 years.

4.8 YANGQUAN CMA

The Yangquan CMA is located in central Shanxi Province in the Qinshui Coal Basin. It is near the cities of Yangquan and Taiyuan (Figure 22) and is connected to markets via several railways. It is an important production base for anthracite coal in China, and covers an area of 3,300 km^2. Currently, the Yangquan CMA has 8 active coal mines that are connected to markets via several railways.

4.8.1 COAL GEOLOGY, RESERVES, AND PRODUCTION

Geologic structure in the Yangquan region is relatively simple, with coalbeds dipping up to 10°. Depth of cover to the primary coal seams ranges from 300 to 1200 m. The Permo-Carboniferous Taiyuan and Shanxi formations have an average cumulative thickness of 180 m. Within the Shanxi Formation, the No. 8 and No. 9 Seams are the primary mineable seams. The entire region has up to 7 mineable seams. Total coal seam thickness ranges from 2.3 to 37 m; individual seam thickness ranges from 0.6 to 6.5 m.

Coal reserves are mainly anthracite, with some low volatile bituminous. Available coal reserves of the Yangquan CMA are 19.3 billion tons. In 1994, raw coal production totaled 13.5 million tons. Design capacity for the CMA is 15.85 million tons per annum (Qie and Lu, 1995).

4.8.2 METHANE LIBERATION, VENTILATION, RECOVERY, AND RESOURCES

Coalbed methane resources of the Yangquan CMA are estimated at 290 million cubic meters to a depth of 800 m. Coal gas content is relatively high, ranging from 17.1 to 45.7 cubic meters per ton. Many of the mines are considered to be high gas, and several are outburst mines. However, coalbed permeability is relatively low, generally less and 1 Md.

Since 1954, the CMA has drained gas from adjacent seams to increase mine safety. Methods include cross-measure boreholes, drainage of roof strata via development roadways, and vertical boreholes. The Yangquan CMA also drills boreholes within the mined seam to drain coalbed methane contained in adjacent limestone. In 1994, total emissions from the Yangquan CMA were 398 million cubic meters. Estimated cumulative methane emissions total 2 billion cubic meters since 1954 (Qie and Lu, 1995). As discussed in Section 3.5, the Yangquan CMA plans further coalbed methane development at the Hanzhuang mining area of the Qinshui basin. CBM Associates has drilled two coalbed methane wells at the CMA.

4.8.3 PRESENT AND PLANNED USE OF MINE METHANE

Significant volumes of coalbed methane are drained from the Yangquan CMA annually. In 1993, annual drainage was 90.53 million cubic meters. The drained methane supplies gas to about 60,000 households in the city of Yangquan (Qie and Lu, 1995).

4.9 HUAIBEI CMA

The Huaibei CMA is located in northern Anhui Province in central-eastern China (Figure 22), covering an area of 9,600 km^2, with the coal-bearing region covering an area of 6,912 km^2. It is a major coal and industrial center for China, with well developed transportation and infrastructure, but very high demand for energy relative to supply.

4.9.1 COAL GEOLOGY, RESERVES, AND PRODUCTION

The topography of the region is relatively flat, but the structure is complex, and the coal-bearing section is contained in several synclinal basins. The Huaibei Basin is one of several synclinal basins that contains Permo-Carboniferous coal-bearing intervals. The 1200 m thick coal-bearing interval occurring in this basin comprises the Shanxi and Shihezi Formations. The total thickness of the coal-bearing strata is about 1,200 m. Within these strata are up to 25 seams, with thicknesses ranging from 7.1 to 22.0 m. Of these, 2 to 12 seams are mineable, their total thickness ranging from 3.0 to 20.9 m.

The basin is divided into four mining regions: Suixiao, Suxian, Linhuan and Woyang. The basin contains 35.46 billion tons of coal reserves, to a depth of 2,000 m. There are currently 21 active mines and three additional mines under construction. In 1993, these mines produced 14.2 million tons of coal.

Coals in the region are relatively thick and the rank is predominately low volatile bituminous, semi-anthracite, and anthracite. Coals in the northern part of the region underwent a high degree of metamorphism and are thus of higher rank, while the southern region is dominated by high volatile bituminous coal. The overburden thickness is about 100 m in the north and 200 to 300 m in the south.

4.9.2 METHANE LIBERATION, VENTILATION, RECOVERY, AND RESOURCES

In general, the coal gas content exceeds 8 cubic meters per ton throughout Huaibei CMA. The CII considers 13 of the 21 active mines to be high gas. Coalbed methane reserves of the Huaibei Coal Basin are distributed over the Suxian and Linhuan mining regions. Gas content of the coals in the Suxian mining region ranges from 6.9 to 25.5 cubic meters per ton; the concentration of methane contained in this gas is 79 to 98.5 percent. Gas content of the coals in the Linhuan mining region ranges from 6.1 to 14.6 cubic meters per ton; the methane concentration in the gas is 75 to 91 percent.

Currently there are two underground gas drainage systems; the first was established at the Luling Mine in 1973. In-seam, roof, and floor boreholes are used for gas drainage. Drainage efficiency is about 15 percent, yet in 1993, the mine drained 4.7 million cubic meters (Li et al, 1995). Box 12 discusses a recently-initiated surface well methane recovery project at the CMA's Taoyuan mine. As noted in Section 3.5, two coalbed methane wells are being drilled at the Huaibei CMA as part of a GEF National Assessment sub-project.

An estimated 158.4 billion cubic meters of methane are contained in the CMA, with a gas distribution of 95 million cubic meters per km^2 (Li et al, 1995). Of this total, 36.77 billion cubic meters are in the Suxian mining region and 86.33 billion cubic meters are in the Linhuan mining region.

BOX 12. SURFACE RECOVERY OF METHANE AT THE HUAIBEI CMA'S TAOYUAN MINE

The Taoyuan Mine is located 13 km south of Suzhou City, northwest of the Sunan Syncline. The syncline covers an area of 32 km^2, with a strike length of 15 km, and a width ranging from 1.5 to 3.5 km. Seams are divided into three different groups: the upper, middle, and lower groups. The main workable seam, No. 3, is in the upper group; Seam Nos. 7, 8 and 9 are in the middle group; and the No. 10 Seam falls into the lower group. Cumulative coal seam thickness is 12.9 m. All seams are high volatile bituminous A and B. Ash content is average, sulfur content is low, and gas content is high. Vitrinite reflectance is 0.74% to 0.88%.

There are eight coal seams in the area of panel 1018 in which the surface well was drilled. The distance between the No. 10 seam and the overlying No. 9 seam is more than 80 meters, as shown in the table below. In the middle group, the gas pressure is 5 to 10 MPa, while the gas content ranges from 4 to 7 cubic meters per ton; the methane concentration in this gas is 95 percent. The depth of the gas depletion zone (weathering zone of gas) ranges from 300 to 340 m. Within the zone where it is necessary to relieve pressure (pressure relief zone), the economic coal reserves of Seam Nos. 7, 8, and 9 reach 293 thousand tons, and methane reserves total 1.7 million cubic meters.

CHARACTERISTICS OF TAOYUAN MINE COAL SEAMS

COAL SEAM	LEVEL (m)	AVERAGE THICKNESS (m)	DISTANCE FROM OVERLYING SEAM (m)	GAS PRES-SURE (kPa)	COAL RESERVES (10^3 TON)	GAS RESERVES (10^3 m^3)
7_1	-346	3.11		71.8	121	674
7_2	-352	0.48	18	77.9	42	249
7_3	-355	0.25	9	79.7	63	59
8	-368	0.55	20	87.9	49	301
9	-390	0.47	33	2.7	17	118
10		1.01	80			
TOTAL					**292**	**1,701**

Methane Drainage Activities

A surface well, located in the middle and lower sections of panel 1018, was drilled to the No. 10 Seam, at a depth of 506 m**.** Coal Seam Nos. 5_2 and 6_2 are found within the weathering zone, and have been sealed. Therefore, only Nos. 7_1 7_3, and 9 are considered suitable for methane drainage within the pressure relief zone. Total thickness of the three coal seams is 1.66 m. The well was completed in November, 1994. Methane began to blow out from the well with 12 m still to drill before reaching the targeted depth. Gas flowed from the well at 0.2 to 0.3 cubic meters/minute, with methane concentrations of 95.2 percent, and a wellhead pressure of 830 kPa.

A two-month recovery test, completed at the end of February, 1995, yielded 55,000 cubic meters of methane. As of July, 1995, the well continues to produce over 1,000 m^3 per day of gas, with a methane concentration of 94.5 percent. Preliminary calculations indicate the methane reserves in coal Seam Nos.

7, and 9, within the pressure relief zone at panel 1018, to be 1.7 million cubic meters. Assuming a 50 percent recovery factor, 850,000 cubic meters could be recovered.

4.9.3 PRESENT AND PLANNED USE OF MINE METHANE

Gas recovered from the Luling Mine is supplied to about 4,000 households; there are, however, many other opportunities for methane use at the Huaibei CMA. The CMA is situated near dense population centers and associated gas markets. The nearby city of Huaibei has a population of approximately 500,000, and the region is located only 70 km from the city of Xuzhou and 80 km from the city of Bengbu. The local economy is well-developed and demand for energy exceeds supply. Therefore, there is strong market potential for this resource.

4.10 HUAINAN CMA

The Huainan CMA is located in the South Region of central Anhui Province (Figure 22). The region covers 2,365 km^2. It is an important energy base for eastern China and has over 80 years of mining history. It has a well developed railway, highway, and waterway network.

4.10.1 COAL GEOLOGY, RESERVES, AND PRODUCTION

The Huainan Coal Basin contains Permo-Carboniferous coals covered by Cenozoic sediments. The maximum burial depth of the coal seams is 2,000 m. Geologic structure in the basin is relatively complex, and continuity of coals is controlled by numerous folds and faults.

Thickness of the portion of the coal-bearing section which contains mineable seams is about 350 m. This section consists of 9 to 18 mineable coal seams, with a cumulative thickness of 22 to 34 m. Coal rank is bituminous, with volatile matter ranging from 33 to 42 percent. Vitrinite reflectance ranges from 0.8 to 1.1 percent (Yang et al, 1995).

The coal bearing area of the basin area covers 3000 km^2, and estimated coal reserves are about 80 billion tons. In 1994, Huainan CMA produced 11.50 million tons of raw coal; annual coal production by the year 2000 is projected to be 40 million tons.

4.10.2 METHANE LIBERATION, VENTILATION, RECOVERY, AND RESOURCES

Typical gas content of the coal seams ranges from 4 to 12 cubic meters per ton, reaching a maximum of 20 cubic meters per ton (Yang et al, 1995). Gas contents of the coals increase with increasing burial depth; for each 100 meters of depth, gas content increases by 1.4 to 2.8 cubic meters per ton. Based on this gradient, coalbed methane reserves exceed 900 billion cubic meters, of which an estimated 500 to 600 billion cubic meters are recoverable.

There are currently 20 coalbed methane wells in the Huainan CMA, which recovered approximately 4.2 million cubic meters in 1994. Since 1985, the Huainan CMA has consistently recovered over 4 million cubic meters of methane annually (Table 9). As noted in Section 3.5, Enron Exploration Co. has drilled four coalbed methane test wells at this CMA.

4.10.3 PRESENT AND PLANNED USE OF MINE METHANE

Currently, coalbed methane recovered from Huainan CMA is used primarily as residential fuel. The region uses 20,000 cubic meters of coalbed methane daily, meeting the demand of 7,235 households. Seven gas storage tanks have a total capacity of 150,000 cubic meters.

Electricity generation is a large potential gas market for the CMA; available electricity supply does not currently meet the demands of economic development. By the end of this century, Huainan CMA will require over 4,000 MW of installed capacity. Meeting these power generation needs will require 10 billion cubic meters of coalbed methane annually; based on a market price of 0.8 yuan per cubic meter, the potential economic value of coalbed methane resources in the Huainan CMA may exceed 500 billion yuan.

4.11 SONGZAO COAL MINING ADMINISTRATION

The Songzao CMA is located in Sichuan Province, approximately 175 km south of Chongqing and 300 km from Guizhou Province (Figure 22). All of its six large underground mines produce coal from the Songzao Basin. Coal mining in the basin began in 1958, although large-scale production did not begin until the 1960's.

4.11.1 COAL GEOLOGY, RESERVES, AND PRODUCTION

Geologic Setting

The Songzao Basin is a northeast-southwest trending anticlinorium approximately 140 km^2 in size. Within this broad feature lie several smaller-scale anticlines and synclines resulting in local steeply dipping coal measures. The overall structure is relatively simple, with localized faulting and folding. More than 300 faults, both normal and reverse, have been identified within the basin (JP International, 1991b), and they form the boundaries of many of the mines. Faults are generally less than 3000 m in length, and displacement ranges from 10 to 55 m. These faults are well documented within the mine boundaries.

Anthracite coal occurs in the Permian Longtan Series, where the coal-bearing interval ranges from 50 to 100 m thick. Within this interval, 14 seams are present, of which 5 are of mineable thickness (0.7 to 3.0 m thick). The main mineable seam is the No. 8, with an average thickness of 2-4 m. The No. 8 seam represents 60 percent of the basin's coal reserves, and is 300 to 400 m deep at most of the basin's major mines. Although dips of beds vary locally from 3° to 13°, the average regional dip is 12°. Present mining depth is 250 - 450 m.

Coal Reserves

Total coal resources are estimated at 900 million tons; reserves in the balance category total 688 million tons (Appendix B contains an explanation of Chinese resource classification terminology used in this report). Within the balance reserves are 592 million tons classified as industrial reserves. These are defined as that portion of the Class A, B, and C reserves which are slated for extraction. The remaining resources are Class D (predicted, or possible resources) which total 97 million tons.

Coal Production and Quality

Currently, there are six mines operating within the CMA: Songzao 1 and 2; Datong 1 and 2; Shihao; and Fengchun. All of these active underground mines use the longwall method; three of the mines have varying degrees of mechanization, ranging from 50 percent (Datong 2 and Shihao) to 100 percent (Datong 1). Annual production capacity for the six mines totals 3.2

million tons. For the past several years, production has averaged 3 million tons per annum; raw coal production in 1994 was 2.70 million tons. By the year 2000, the CMA estimates that seven mines will be operating with an annual production of 5.4 million tons.

In 1991, there were 23 operating longwalls with a total development length of 57.5 km. By the year 2000, four additional longwall systems will be in operation for a total of 27, and the length of development headings will increase to 100 km, nearly double the present length.

In the mineable No. 8 seam, volatile matter ranges from 8 to 9 percent, ash averages 19 percent, and sulfur content is high, generally over 4 percent. Heating values range from 17,600 to 26,400 kJ/kg. Overall, ash and sulfur content increase from north to south, with a corresponding decrease in volatile content.

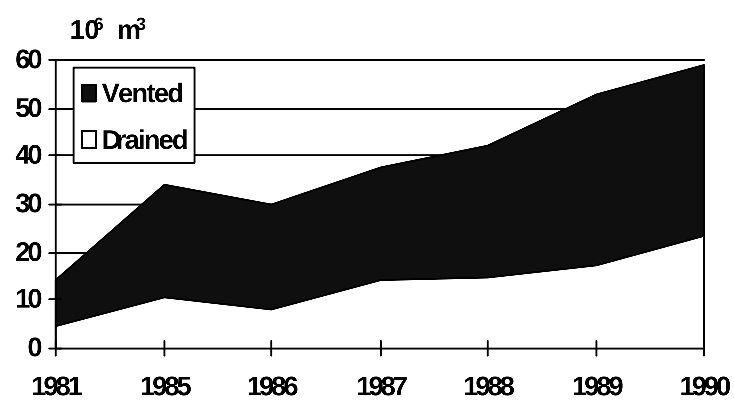
Most of the coal is shipped by rail and sold for power generation in coal-fired power plants in Chongqing. The Chongqing Power Company operates two power generating stations, which were designed specifically to use coal that has the same characteristics as Songzao Basin coal.

4.11.2 METHANE LIBERATION, VENTILATION, RECOVERY, AND RESOURCES

Methane Liberation

Figure 35 shows trends in methane ventilation, drainage, and total liberation from 1981 through 1990. In the Songzao CMA, the current methane recovery efficiency is only 30 to 40 percent of the total gas released to the underground workings. While this rate remains relatively constant, both the volumes of methane drained and vented have increased over the past 10 years. Mine management plans to increase methane recovery. The CMA forecasts that their methane production will increase to over 100 million cubic meters per annum by year 2000.

FIGURE 35. METHANE DRAINED AND VENTED 1981 - 1990



Gas content of the mined coal averages 17.3 cubic meters per ton, but locally varies from 17 to 29 cubic meters per ton. Specific emissions range from 56.7 to 88.4 cubic meters per ton, and absolute emission rates range from 15 to 45 cubic meters per minute. Permeability of the seams ranges from 1.36 to 7.59 X 10^{-4} darcies, which can be increased to 0.1 md by mining the methane-liberating seam to release pressure for adjacent seams.

Methane Ventilation

Eleven large air shafts and 15 electrically driven fans provide ventilation for the mine complex. Collectively, these fans can consume 5.3 MW of electrical power, although current consumption is only 2.2 MW. The mines experience relatively frequent occurrences of elevated methane concentrations, resulting from insufficient ventilation air movement underground. This problem is exacerbated by an occasional power outage, due to the fact that the mine lies at the end of the power transmission facility.

Methane Recovery

The Songzao CMA installed the first recovery system in 1967, and now all six mines have systems in place. Drainage personnel remove methane in advance of or during mining operations, via tunnels in the underlying rock. They drill boreholes in a fan-shaped array upward into the roof to drain the working and overlying seams. Drilling stations are located in the rock tunnels at intervals of 15 to 150 m. Currently, there are eight recovery stations operating in the six mines, with a total of 27 vacuum pumps. The quality of the recovered methane ranges from 40 to 70 percent, and averages 50 percent.

In 1990, the Songzao CMA drained a total of 59.2 million cubic meters of methane via its degasification systems. By 1994, drainage had increased to more than 90 million cubic meters. While historical data on the amount of methane used and vented from the Songzao CMA are unavailable, recovery efficiency averages 36 percent. Table 15 shows past and projected methane recovery at each of the Songzao CMA mines.

TABLE 15. METHANE DRAINAGE AT THE SONGZAO CMA

MINE	1991	1992	1993	1994	1995*	2000*
Songzao No. 1	8.32	9.33	10.46	11.87	13.17	13.17
Songzao No. 2	2.66	3.09	3.92	4.61	5.61	5.61
Datong No. 1	16.20	18.82	20.96	24.02	27.77	37.87
Datong No. 2	13.71	15.01	17.26	18.17	20.69	28.65
Shihao No. 1	17.35	21.41	22.61	24.61	25.87	30.18
Fengchun	3.90	4.05	5.60	7.25	9.0	9.00
TOTAL	**62.14**	**71.71**	**80.81**	**90.53**	**102.11**	**124.48**
* Projected						
1993 total differs from data in Table 10; reason for discrepancy unknown						

In 1992, Songzao's coalbed methane development project was included in the GEF's "Development of Coalbed Methane Resources in China", in which directional long borehole drilling and fracturing technology are to be introduced from the US. Section 3.5 discusses the status of this project at the Songzao CMA.

Methane Resources

Based on a report prepared by the Central Coal Mining Research Institute, the Songzao CMA contains an estimated 22.7 billion cubic meters of methane, of which 11.4 billion cubic meters are recoverable. No further details concerning the methodology used in these estimates are available.

4.11.3 PRESENT AND PLANNED USE OF MINE METHANE

Of the 59. 2 million cubic meters of methane recovered in 1990, only 23.5 million cubic meters (40 percent) were used, mainly by households for cooking and heating, and by the nearby carbon black plant. Songzao mines vented the remaining 35.7 million cubic meters (60 percent) to the atmosphere. By 1992, methane use had increased; more than 30 million cubic meters (about 49 percent) of the methane recovered from the Songzao mine were used that year, mostly by mine facilities, residences, businesses, and farms, as shown in Table 17. This methane was used for cooking, heating, and industrial steam generation. A 600 ton-capacity carbon black production plant, located at the CMA, is one of the primary industrial users. Coalbed methane supplies about 75 percent of the plant's fuel needs.

TABLE 16. COALBED METHANE USE AT THE SONGZAO CMA

1992 Consumption	Mine Facilities*	Residences	Other Industry	Other	Total
Million cubic meters	14.3	10.5	4.1	1.5	30.3
Percent	47	35	13	5	100
* Includes such facilities as cafeterias, bath houses, and worker housing.					
Methane concentration = 100 percent.					

In the future, a new on-site machinery factory and additional residential customers will increase demand for mine methane in the area, and the CII projects that by 2000, annual coalbed methane recovery from the Songzao CMA will be 100 million cubic meters. Future use options include power generation, transportation (vehicle fuel) and production of chemical products.

The largest growth market for this gas appears to be for power generation. The mines need increased power generation capacity; currently, there are electricity shortages that often lead to power outages and resulting losses in coal production. This mine area is located on the outskirts of the transmission grid and experiences frequent low voltage conditions, straining the ventilation fans. According to a report detailing results of a GEF/UNDP mission to Songzao (Lunarzewski et al, 1992), by year 2000 the amount of methane required by the domestic and commercial sectors of the CMA will be about 30 percent of the total amount recovered, leaving an adequate and dedicated supply of methane to fuel a 25.2 MW power plant.

As of 1993, four of the six mining districts had gas storage tanks, with a total capacity of 30,000 cubic meters. The CMA is building additional gas storage facilities and expects to double this capacity. The addition of these facilities will create an integrated network between the mines, and allow the six-mine complex to coordinate their methane supplies.

Another potential future use for the recovered methane is chemical feedstock production. Currently, there is not a feedstock plant in the area.

4.12 HEDONG COAL BASIN

The Hedong Coal Basin is located at the eastern edge of the Ordos Basin (Figures 14 and 23) covering an area of 12,000 km^2. It is contained in portions of Shaanxi and Shanxi Provinces, and the Inner Mongolian Autonomous Region. Coalbed methane activity in this basin occurs outside the boundaries of coal mining administrations or other mining areas.

4.12.1 COAL GEOLOGY, RESERVES, AND PRODUCTION

Coal-bearing strata in the Hedong Basin belong to the Permo-Carboniferous Shanxi Formation. The basin contains 17 coal seams with a total thickness of 19 m. Of these, nine seams are mineable and four seams are primary targets for mining. Seam thickness ranges from 0.1 to 9.3 m, but mined seams are generally 1.6 to 3.9 m thick. Coal rank is primarily medium volatile bituminous, with a small percentage of low volatile bituminous and semi-anthracite coal.

4.12.2 METHANE LIBERATION, VENTILATION, RECOVERY, AND RESOURCES

Based on desorption tests, gas contents in the Hedong Basin range from 3 to 20 cubic meters per ton. Coalbed methane resources within a depth of 1,000 meters are estimated at 220 billion cubic meters.

In 1991, the Huaibei Petroleum Geology Bureau of the Ministry of Geology and Mineral Resources drilled six test wells in the Liulin area. Gas production for the wells ranged from 500 to 3,000 cubic meters. Currently, the Chinese company Huajin Coking Coal Corp. and the US company Enron Corp. are cooperating to conduct a preliminary evaluation of coalbed methane in Sanjiao mining region. Data obtained from these boreholes indicate that the permeability is high. Section 3.5 briefly discusses the status of this project.

4.12.3 PRESENT AND PLANNED USE OF METHANE

The geology of the Hedong Basin is comparable to that of the Black Warrior Basin of the US. MOCI considers it an optimal region for surface recovery of coalbed methane. However, in terms of economic factors, the region has less industrial development, infrastructure, and demand for coalbed methane, so near-term use options may be somewhat limited.

CHAPTER 5

SUGGESTED APPLICATIONS OF TECHNOLOGY AND ISSUES RELATED TO PROJECT DEVELOPMENT

5.1 CRITERIA FOR SELECTION OF APPROPRIATE TECHNOLOGY

5.1.1 APPLICATIONS OF TECHNOLOGY SUITABLE FOR GEOLOGIC AND MINING CONDITIONS IN CHINA

Mines seeking appropriate technology for methane recovery should consider the following:

- geologic conditions;
- mining conditions; and,
- source and quantity of methane emissions.

The various recovery methods that may be employed in China, and the circumstances under which they are used, are as follows:

- If methane is emitted primarily from the working seam, then drainage efforts should be directed toward the working seam; similarly, if it is emitted primarily from adjacent seams, then recovery efforts should focus on the adjacent seams.
- If significant quantities of methane accumulates in gob areas, then it should be drained and recovered from gob areas via surface gob wells or in-mine horizontal longholes.
- If methane is difficult to drain because of low coal seam permeability, then measures to relieve seam pressure should be taken; most commonly this is done by mining an overlying seam, causing relaxation of the seam in need of drainage.
- Recovery of methane via surface wells is feasible when topography will allow access for drilling and gathering, and coal seams have a high methane content, sufficient permeability, and are between 300 and 1000 m deep.

5.1.2 SUGGESTED APPLICATIONS OF NEW TECHNOLOGY FOR IN-MINE RECOVERY

China has been using in-mine recovery systems for several decades. In-mine recovery will maintain an important place in the ongoing development of coalbed methane recovery in China. Chapter 3 lists the CMAs that currently recover large amounts of methane; these CMAs, with their large methane reserves and well-established recovery systems, will remain important contributors to China's coal mine methane industry.

Of the total methane that Chinese mines drain, more than 42 percent is from working seams. In most cases, the recovery efficiency is low. Under optimal conditions, such as thick coal seams with good permeability (as is the case at the Fushun CMA) mines achieve higher recovery efficiencies.

Multi-seam recovery technology is used in many CMAs in China, such as Songzao, Tiefa and Yangquan. Therefore, many mines currently use in-mine degasification from adjacent seams, accounting for nearly 53 percent of the methane drained in China. Mining relieves the pressure of adjacent seams, resulting in improved permeability. Mines can also use the adjacent seam degasification boreholes for in-mine pre-drainage and gob drainage, creating an integrated drainage approach that can recover up to 80 percent of the gas in place.

Gob drainage significantly adds to the recovered quantities of methane, and is gaining more attention in China. In some areas it may be feasible to use horizontal longhole drilling technology to combine in-mine degasification from adjacent seams with pre-drainage and gob drainage efforts.

The US and Germany have developed horizontal and directional drilling technology, and the Tiefa and Songzao CMAs have imported horizontal and directional drills from the US. Unfortunately, these types of technology remain unaffordable for many Chinese mines. However, changing market conditions for methane may improve the economic conditions and provide incentives for investment in such capital-intensive technology.

5.1.3 SUGGESTED APPLICATIONS OF NEW TECHNOLOGY FOR RECOVERY USING SURFACE WELLS

The Ministry of Coal Industry considers the development of coalbed methane to be an important strategy for the coal industry. It recognizes that the progress of China's coalbed methane industry will depend largely on recovering methane from surface wells. In recent years, China has initiated more than 20 coalbed methane projects (discussed in Chapter 3); some of these have begun to produce methane, but their output is low at present.

Many of the geological characteristics of China's gassy mines differ from those of other countries. The most obvious of these are the complex tectonic setting of China's gassy mines, the occurrence of methane under high pressure with little or no water, and low permeability.

Enhancing the permeability of coal seams at Chinese mines is of utmost importance. China has already begun to experiment, on a limited basis, with various methods of increasing access to in-situ permeability. Generally, good results have been achieved through the use of hydraulic fracturing. At least one CMA has attempted an open-hole cavity well completion, however the soft, non-cohesive nature of the mudstone comprising the roof and floor strata caused problems.

Of the existing coalbed methane projects in China, about one-half are operated in cooperation with foreign companies. At this preliminary stage of coalbed methane development, China needs advanced technology and training, as discussed in Section 5.2.3 below.

5.1.4 MARKETS FOR METHANE

Near-Mine Residential or Industrial Users

Medium quality gas can be used in the vicinity of CMAs, eliminating the need for costly gas treatment or compression, and providing an affordable fuel source for residential users and small industry. Near-mine uses of recovered medium quality gas include: residential or commercial space heating; use in boilers for central heating, steam production or power generation; cooking; and industrial uses that do not require high heating value gases.

Methane for Power Generation

The sale of electricity generated from coal mine methane offers opportunities at various scales determined by the quantity and quality of methane produced. Smaller (1.5 up to 15 MW) turbine electric power generation sets can be used as a supplementary power supply to the mine or nearby industrial consumers, and as peak load supply in areas where seasonal brownouts are prevalent. These turbines offer the advantage of single units with the option of additional units that can be added as development proceeds.

Mines may install larger units (25 MW and greater) in remote regions to augment or replace the electricity supplied by the regional power grid. In Australia, a mine and power company are presently installing methane-fueled turbine generation sets with even greater generation capacity. Revenues captured from the sale of the generated electricity will make a welcome contribution to the mine’s cash flow stream. Installation of larger power generation facilities is more likely to be economic where gas supply is assured and production rates can exceed 100 cubic meters of methane per minute.

Injection of High Quality Methane Into Local or Regional Transmission Pipelines

Development of coalbed methane resources from unmined coal seams, and recovery of gas from sealed gob areas, can offer the opportunity to exploit those markets open to high heating value natural gas. Because the heating value of the gas developed from these sources is relatively high, mines can offer it as a substitute for conventional natural gas. Potential consumers are local industries and commercial enterprises, as well as more distant consumers that can receive natural gas delivery via regional transmission pipelines.

5.2 ISSUES RELATED TO PROJECT DEVELOPMENT

5.2.1 PROJECT IDENTIFICATION AND DEVELOPMENT THROUGH STRATEGIC TEAMING

Consumers are segregated by location into two groups: those consumers near the gas-producing mines, and those consumers located in more distant cities or industrial centers. Each market group possesses unique characteristics and challenges for the methane producer, requiring an appropriate match of technical expertise, technology, and economic goals.

The ability to match expertise to the technical challenges of a coal mine methane recovery project is generally dictated by the technology that is to be employed by the project. Simply increasing methane recovery using existing technology and techniques requires little or no additional expertise; whereas a major utilization project, such as generating electricity with a gas turbine, will require specialized knowledge of the equipment to be employed. If specialized expertise is not available to the mining partner, it may require outside help to identify the most appropriate experts. The mining partner must assess its long term needs for knowledge and advice, and have assurance that the expertise will be available to meet those needs.

The structure of the joint venture will affect the mix of money, technology, and manpower each of the participants must bring to the venture so that they may enjoy equitable benefits and return on their investment. As an example, treatment of personnel costs can differ depending on the structure of a joint venture. In China, if the partnership is a Contractual Joint Venture, the cost will be expensed and shared according to the distribution of profits; but if the partnership is an Equity Joint Venture the cost of supplying the experts and training Chinese counterparts can be considered as part of the capitalization of the new entity. Joint venture formation is encouraged in China, and laws regarding the formation of these entities are written so that these joint ventures are treated as equally and fairly as wholly-owned Chinese entities. The best joint venture option for a given development project depends on the details of the project; partners should design and plan in a way that best emphasizes each of their strengths.

Developing a team that will be able to meet the needs of the market and effectively compete in the marketplace is the greatest challenge facing the joint venture. Project developers must consider the following economic parameters when preparing for discussions regarding the market and the best way to compete:

- the size of the project, in terms of the amount of gas that will be produced and the amount of capital needed for its development;
- the length of time over which the project is likely to produce revenues;
- the desired monetary return on the investment, and the time required for that return.

5.2.2 DISCUSSION OF KEY INVESTMENT, PERMITTING AND TAX ISSUES

<u>Forms of Business Enterprises</u>
The principal forms of foreign investment enterprises in China are as follows (Price Waterhouse, 1995):

- *Equity joint ventures*. An equity joint venture is a separate legal entity and takes the form of a limited liability company registered in China. The partners have joint management of the company, and they distribute profits and losses according to the ratio of each partner's capital contribution.

  The Ministry of Foreign Trade and Economic Cooperation has overall responsibility for approving equity joint ventures and for issuing the approval certificates. The equity joint venture law requires that the foreign partner to the venture contribute at least 25 percent of the registered capital. In general, the Chinese partner will contribute cash, land development or clearance fees and land use rights, while the foreign partner will contribute cash, construction materials, equipment, and machinery. The profits and losses of an equity joint venture are distributed according to the ratio of each partner's investment. During the life of an equity joint venture, the foreign partner's equity contribution cannot be repaid.

- *Cooperative/contractual joint ventures*. A cooperative venture may operate under a structure similar to that of a Western-style partnership with unlimited liability, or the parties to the venture may apply for approval to have the company structured as a separate legal entity with limited liability. The profit and loss distribution ratio is defined in the contract and can vary over the contract term.

  To establish a cooperative joint venture, the Chinese and foreign partners must submit such documents as the signed agreement, contract, and articles of association to the department in charge of foreign economic relations and trade or the relevant local government authority for examination and approval. If it is agreed in the cooperative joint venture contract that all of the venture's fixed assets will belong to the Chinese party after the venture's operating period has expired, then the parties to the venture may also state in the contract that the foreign party can recover its investment during the contract period.

- *Unincorporated joint ventures*. Joint ventures that are established by two or more parties for a particular project and dissolved upon the completion of the project are generally structured as unincorporated joint ventures. Many of these projects are engaged in coproduction of offshore oil and other minerals. The foreign venturer in the coproduction project is taxed in its own name on the basis of its own operating profit, computed by deducting its share of the exploration, production and development expenses from its hare of the oil or mineral production from the coproduction.

- *Wholly foreign-owned enterprises.* Wholly foreign-owned enterprises are established exclusively with the foreign investor's capital. They are limited liability companies, the profits and losses of which are borne solely by the foreign investor. The law specifies that wholly foreign-owned enterprises are to be "conducive to the development of China's national economy."

  There are more restrictions on approval of wholly foreign-owned enterprises than on joint ventures. Another disadvantage is the absence of a local partner to assist in such areas as labor recruitment and obtaining access to marketing and distribution channels.

Regulatory and Permitting Issues

Prior approval is required for the establishment of all foreign business ventures, and registration with the appropriate government authorities is mandatory. The Ministry of Foreign Trade and Economic Cooperation is responsible for the approval of foreign investment projects. Many of the key aspects of permitting, however, take place on the local level. Those seeking to develop coalbed methane projects must therefore become familiar with local and regional, as well as national, government requirements. Potential investors should make contact with local and regional authorities in the early stages of project conception.

Tax Issues

On the national level, the principal taxes applicable to foreigners, foreign investment enterprises, and foreign corporations doing business in China are:

- income taxes;
- taxes on transactions;
- property taxes; and,
- other taxes, including customs duties, stamp taxes, vehicle taxes, and resources taxes.

In addition to these national taxes, businesses may be subject to various local taxes. These taxes are set by local authorities and are often negotiable. The CMA or other Chinese partner can be of assistance in such negotiations.

Special tax incentives are offered to enterprises operating in Special Economic Zones, Economic and Technological Development Zones, and Old Urban Districts of the 14 coastal cities, as well as other special open zones. Subject to certain conditions, enterprises with foreign investment established in the Special Economic Zones and engaged in the service industries may be eligible for tax exemption from the first profit-making year, followed by a two-year 50 percent reduction period.

Additional information on China's tax system is available from Price-Waterhouse (1995); and in the publication "Investment in China", compiled jointly by the China Foreign Investment Administration, the China Economic and Trade Consultants Corporation, and the Ministry of Foreign Trade and Economic Cooperation.

5.2.3 GUIDELINES FOR POTENTIAL JOINT VENTURE PARTNERS

This section provides information that should be useful to potential joint venture partners interested in developing coalbed methane projects in China. The purpose of this section is to help foreign partner understand the Chinese business environment and the need for expertise, technology, and investment; and to aid the Chinese partner in understanding the potential needs and expectations of the foreign investor with regard to regulations, policies, incentives, and return on investment.

Needs of the Chinese Partner

The exploration, development, and production technologies and methodologies associated with coalbed methane and conventional energy fuels are constantly advancing. In order to effectively execute coalbed methane projects, Chinese partners need state-of-the-science expertise and training in the following areas:

- *Exploration Technology*. Several developments in geophysical technology in the past decade have boosted the ability to evaluate coalbed methane potential. Three-dimensional seismic surveying has evolved rapidly in recent years and is an important tool for defining subsurface structural and stratigraphic trends. In addition, modern borehole logging and imaging techniques provide data that were previously unavailable to geologists and engineers attempting to evaluate methane resources. Much of this technology has not been available to Chinese partners, who could benefit from expertise gained elsewhere.

- *Development Technology*. Advanced drilling techniques, including horizontal, directional and longhole drilling, can be important to the success of coal mine methane projects. In many cases, hydraulic fracturing, cavity completions and other stimulation techniques will be required to overcome problems with low permeability in Chinese coals. It will be necessary to train Chinese engineers in the use of these techniques, and methodology for selecting technology appropriate to specific project conditions.

- *Production Technology*. There are currently some innovative trends in the US and Australia in solid-state monitoring and control of methane drainage. These methods are used to reduce air entrainment in the gas stream during the production process, thereby improving the quality of the gas.

Chinese partners may need assistance in developing expertise in project development and management. In particular, foreign experts can assist with feasibility and market studies, implementation of accounting and reporting systems and procedures that are required by most lending institutions or foreign partners, and new and efficient strategies for managing personnel and equipment needs.

<u>Needs of the Foreign Partner</u>

Before entering into a joint venture, foreign partners must feel confident that they are investing under reliable and clearly defined circumstances. In particular, foreign investors will require:

- *Clearly Documented Regulations*. Foreign partners want clear documentation and understanding of all rules and regulations related to business formation and resource licensing. They need to thoroughly understand all national and local government policies that may affect their investment, including those related to business structure, taxes, and repatriation of profits.

- *Equal Access to Markets*. Foreign investors need assurance that they will be at no competitive disadvantage in selling their product, and that pricing will be fair and unregulated. It may be necessary to establish a mutually agreed-upon market price.

- *Incentives for Coalbed Methane Development*. Foreign investment in coalbed methane projects could be substantially increased if China creates incentives for coalbed methane development and use. Such incentives could, for example, take the form of tax credits for companies that use coalbed methane (or electricity generated by coalbed methane). These incentives could be temporary, in place just long enough to give this emerging industry a boost, and stimulate the use of methane.

- *A Firm Basis for Economic Projections*. Investors need a sound basis for estimating revenues, taxes, production costs, and the rate of return that can be expected. They also need reliable data that will help them determine the size of the project, the size of the investment, the life of the investment, and the time required for return on the investment.

5.2.4 A HYPOTHETICAL COALBED METHANE PROJECT

This section describes and discusses a hypothetical power generation project, with a Chinese coal mining administration and American power generation firm as partners. The American firm is experienced in methane resource development, and includes a team of power generation installation experts. The intent of this hypothetical project is to use coalbed methane from the CMA to produce electrical power via the use of a combined cycle gas turbine generation facility. The joint venture would thus earn revenues from the sale of this electricity.

In addition to contributing money to the project, the CMA and the American firm would each contribute other essential, yet unique, resources. The CMA would, obviously, provide the methane resource itself; in addition, it would contribute an understanding of the laws and regulations related to the project. These regulations would encompass a wide range of matters, from taxation issues to environmental concerns. The CMA would also provide skilled manpower for the project. The CMA would be responsible for monitoring and maintaining the methane concentration in the gas to be used, and for managing gas storage facilities so that a reliable quantity of gas is available at all times.

The American firm, on the other hand, would provide the resource development expertise and some of the capital, as well as technology and technical know-how related to gas turbine electricity generation. The firm would use its experience in assessing the quantity and quality of the methane resource, and estimating the potential life of the project based on resource availability. It would also play a key role in evaluating the economics of the project. In addition, the American firm would be responsible for securing the turbines, compressors, water treatment equipment and other necessary components of the generation system. It would provide experts who have had first-hand experience in installing gas turbine systems that can use low or medium quality mine gas fuel to generate electricity. It would also contribute understanding and experience in the areas of business development and management, as well as electricity markets and marketing.

There are four primary steps involved in executing a project of this type: 1) a preliminary evaluation; 2) a detailed evaluation; 3) project design; and 4) project implementation.

1. *Preliminary evaluation.* The partners should first work together to determine basic information, including the scope of the project, the market for the electricity, and the role each partner will play. The Chinese partner should investigate permitting and licensing requirements.

2. *Detailed evaluation*. If the project appears prospective based on the preliminary evaluation, further evaluation is in order. This would typically include:

    - a review of existing data and information related to the methane resource, including geologic maps and mine plans, and data related to coal production and methane liberation;

    - a review of data related to the market potential for the electricity, including current and forecast energy supply and demand, and current electricity contracts in place;

    - an analysis of engineering factors, including the efficiency of the current methane drainage system, projected methane production decline rates, estimated recovery factor, and optimum power plant capacity; and,

    - an economic analysis, including gas transmission and power plant capital and operating costs over the life of the project at various discount rates, cost savings attributed to the project, and overall cash flow analysis.

3. *Project Design*. If the detailed evaluation indicates project feasibility, the design phase can begin. In this example, the American firm would design the gas drainage and power generation systems based on the layout of the existing drainage system (including borehole layout), amount of gas available, and demand for the electricity. All engineering details of the project would be included. Project design should be sufficiently flexible to allow for changes in electricity demand or gas availability; e.g., there should be avenues for future expansion of the facility if desired.

4. *Project Implementation*. After all parties have agreed on the project design, implementation can begin. Progress should be monitored closely and re-evaluated on a regular basis. The American partner would provide Western-style project management know-how that includes tracking progress, results, costs, savings, and project benefits. This would allow the project design to be optimized based on project results.

The above outlined project is but one example of many possible types of joint coalbed methane ventures between Chinese and foreign partners. Each partner would make an important contribution to the venture, with the benefits from the sales of the gas and increased efficiency enjoyed by each. In addition, they would have the satisfaction of knowing that their project is increasing mine safety, and helping reduce methane emissions to the atmosphere.

CHAPTER 6
POLICIES TO ENCOURAGE COALBED METHANE DEVELOPMENT IN CHINA

Numerous barriers currently prevent China from achieving economic methane recovery from coal mining to its full potential. Critical barriers include the lack of an appropriate policy framework, limited capital for project investments and equipment, and the need for additional information and experience with technologies. Artificially low gas prices, and difficulty with repatriation of profits, create barriers to the development of foreign investment in joint ventures for production of domestic energy resources (USEPA, 1993).

Coalbed methane policies in the US have focused on incentives for recovery of coalbed methane from vertical wells in unmined areas. As discussed in previous chapters, China has tremendous opportunities for increased recovery and use in its large, gassy underground mines. If China is to take full advantage of these opportunities, however, government-provided incentives for coal mine methane use will likely be necessary. Incentives that focus on use of methane will inherently encourage its recovery. These incentives could be eliminated once coal mine methane becomes competitive with conventional natural gas and coal.

Section 6.1 below discusses policies that have been proposed or adopted internationally to promote coalbed methane recovery. Sections 6.2 and 6.3 discuss existing foreign support and investments in Chinese coalbed methane projects and policy options for China, respectively.

6.1 DISCUSSION OF INTERNATIONAL POLICIES

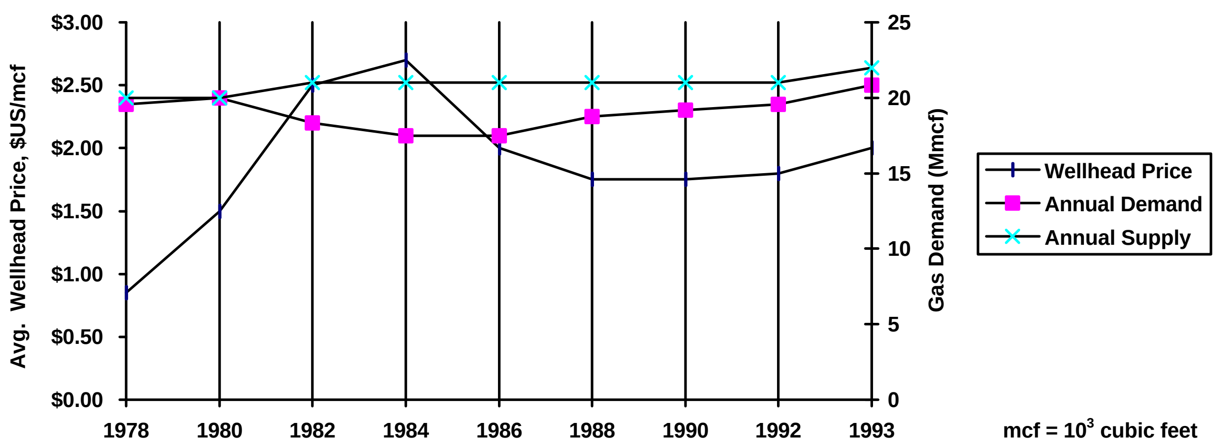
6.1.1 INCENTIVES

US Gas Industry: Market Forces and Policy Change

The US is the world's second largest gas producer, accounting for 24 percent of the total gas produced worldwide. US policies and regulations influence coalbed methane development, as the coalbed methane produced is distributed into the natural gas pipeline system. An overview of gas policy and regulations practiced in the US may be relevant to China's developing coalbed methane industry.

Since the late 1970's, major policy changes within the US gas industry have stimulated increased competition and had a significant effect on wellhead prices. Figure 36 illustrates annual natural gas wellhead prices, supply and demand for 1978 through 1993. Prior to 1978, gas prices were very low, due to a single ceiling rate (regulated prices) for all US production resulting in lower rates of investment in gas exploration and production. This resulted in increased demand for gas and widespread gas shortages. From 1978 to 1984 deregulated wellhead prices and gas exploration and production dramatically increased; as the market was saturated, demand fell. Since then, wellhead prices have stabilized, achieving a dynamic balance between gas supply and demand.

FIGURE 36. EFFECT OF INCREASING COMPETITION ON NATURAL GAS PRICES



mcf = 10^3 cubic feet
Mmcf = 10^6 cubic feet

Tax Credits: US Section 29 Tax Credit

The Crude Oil Windfall Profits Act of 1980 provided an incentive for production of unconventional fuels. The intent was to create a production tax credit for those times when low oil prices restrict the competitiveness of unconventional gas, including coalbed methane. The original tax credit has been revised several times and extended twice (1989 and 1990). Even though the Energy Policy Act of 1992 extended credits for other types of unconventional gas production, it expired for coalbed methane at the end of 1992. However, qualified companies whose gas production facilities qualified before 1992 will receive the credit until the year 2002. To be eligible for the credit, wells must have been drilled between 1980 and 1992 (Lemons and Nemirow, 1989).

The tax credit is calculated as follows (Soot, 1991):

TC = (US $3/BOE) x IAF x PH

Where:
TC = Tax credit in US $/MMBTU;
BOE = Barrel of oil equivalent, 5.88 MMBTU;
IAF = Inflation adjustment factor (Based on GNP implicit price deflator);
PH = Phase out factor (Ph<1); PH = 1-(Domestic oil price - US $23.50/bbl x IAF)/ (US$6/bbl x IAF).

Table 17 shows historical and projected increases in the coalbed methane production tax credit, based on a 4 percent inflation rate.

TABLE 17. SECTION 29 COALBED METHANE PRODUCTION TAX CREDIT

YEAR	INFLATION ADJUSTMENT FACTOR (IAF)	PRODUCTION TAX CREDIT $US/Million ($10^6$) BTU
1992	1.8095	0.936
1993	1.8819	0.973
1994	1.9572	1.012
1995	2.0355	1.053
1996	2.1169	1.095
1997	2.2016	1.139
1998	2.2896	1.184
1999	2.3812	1.232
2000	2.4764	1.281
2001	2.5755	1.332
2002	2.6785	1.385
(Data for years 1995-2002 are projected)		

The tax credit stimulated tremendous growth of the coalbed methane industry in the United States throughout the 1980's. Producers applied it primarily to vertical wells in unmined areas. Annual coalbed methane production increased from 708 million cubic meters in 1983 to 20.7 trillion cubic meters in 1993. However, a study by ICF Resources Inc. (Oil and Gas Journal, 1992) concluded that, as of 1992, most gas production claiming Section 29 credits had been developed using conventional technology in the most geologically favorable eligible areas, and that the credit contributed to low wellhead prices during a period of surplus supply. Unlike the US in 1992, however, China faces gas shortages, rather than a surplus.

As discussed in Section 6.3 below, China should develop tax credit policies that will help stimulate its coalbed methane industry. The Section 29 tax credit could serve as one model for these policies, although some variations on this approach may be more appropriate to China's taxation system.

Incentives to sell coalbed methane to nearby power plants or utilities

Use of coal mine methane to generate electricity has benefits beyond immediate market incentives. The Chinese government may want to consider an approach similar to that described below, as a means of favoring power projects that using methane that otherwise would have been wasted.

The US Public Utility Regulatory Policies Act of 1978 (PURPA) was designed to promote conservation of energy and energy security by removing barriers to the development of cogeneration facilities and facilities that employ waste or renewable fuels. Such facilities are called qualifying facilities, or QFs. Under PURPA, utilities are required to purchase electricity from QFs at each utility's avoided cost of generating power. An electricity generation facility at a coal mine methane project may be granted QF status if the coal mine methane meets the definition of “waste” fuel.

In the past, at least one US coal mine methane facility applied for and obtained QF status (USEPA, 1995d). This project involved generation of 19.8 MW of electricity. The coal company was able to justify that the gob gas had no other commercial uses. In particular, long pipeline distances, low natural gas prices, and high upgrading costs rendered a pipeline project uneconomic. The gas would have been vented and, therefore, wasted, unless it was used to generate electricity on-site. The mine owners were able to support this argument and the facility thus obtained QF certification.

Expanding Pipeline and Gas Gathering and Storage Infrastructure

Countries with a fully integrated natural gas pipeline system have an advantage in recovering and using pipeline-quality coalbed methane. These are countries with a well-developed natural gas industry, and extensive oil field services, materials, and infrastructure. This natural gas infrastructure lowers the initial capital costs required for distribution and marketing of natural gas.

In many countries, the remote location of coal basins with tremendous coalbed methane potential results in extremely high costs for building pipelines and gathering systems. On-site use (such as power generation) and local use (co-firing or co-generation) of these energy resources may be more cost-effective. In a complementary action, government policy could help expand local and regional gathering systems; for example, in China additional gathering systems for key state-run CMAs could provide the incentive necessary for increased coalbed methane use.

6.1.2 LEGAL NEEDS

Coalbed Methane Leasing and Ownership

Unresolved legal issues concerning coalbed methane ownership represent a major barrier to recovery and use of this resource (USEPA, 1994b). Coalbed methane ownership is a complex issue because of the nature of the resource itself. The strata containing conventional oil and gas resources are usually deeper than the strata containing the coal resources. Thus, rights to mineral reserves located on the same tract of land may be easily segregated, according to strata, between the owner of the coal rights and the owner of the oil and gas rights. However, a discrete geologic separation does not exist for coalbed methane. Coalbed methane is a gas resource located in the same strata as coal reserves, making separation of ownership problematic.

Until recently, miners considered coalbed methane a hazard to coal mining, not a potential economic resource. Therefore, leases have not historically included coalbed methane, and the owners of the coal rights, oil and gas rights, and surface rights may all claim ownership of the coalbed methane. The situation is particularly complicated in the Appalachian region of the eastern United States, where there are often multiple mineral resource owners. In the United States, ownership of coalbed methane is not standardized, and only those states that are actively exploiting the resource have established clear ownership provisions. In many states, unclear ownership provisions have constrained coalbed methane development. The US

Congress passed coalbed methane ownership legislation as part of the Energy Policy Act of 1992. Under this act, states which lack regulatory procedures to address ownership issues had until October 1995 to enact ownership legislation, or the federal government would impose legislation administered by the US Bureau of Land Management (EPA, 1994b).

In the United Kingdom, a bill is currently before parliament that would establish a legal framework for long-term coalbed methane production. There are numerous coalbed methane exploration licenses in England, Scotland, and Wales, and several US companies have begun exploration projects. During the recent three rounds of Tenders inviting the licensing of coalbed methane exploration, 15 British and US companies won the licenses with a total exploitation area of 9 million acres.

Countries with established oil and gas production have instituted policies for the acquisition of hydrocarbon leases or concessions. Countries with significant coalbed methane resources, but no previous oil and gas development, lack this legal framework. In several countries whose economies are in transition, laws that govern ownership and leasing of mineral resources are currently unresolved. In Eastern Europe, for example, many US and foreign-based companies are pursuing exploration and development concessions on vast coalbed methane resources; but the absence of laws which define the ownership of these lands makes leases difficult to acquire.

In Poland, the government is establishing policies for the exploration and development of coalbed methane, based in part on the new Geological and Mining Act guidelines (February 1994). Poland is addressing issues related to exploration concession licenses, and laws which govern foreign investment, to create opportunities for joint ventures with foreign companies to develop coalbed methane resources.

6.2 FOREIGN SUPPORT AND INVESTMENT IN CHINA'S COALBED METHANE

Since the 1980's, the global environment has been the focus of international attention. A key issue concerns greenhouse gases, such as carbon dioxide and methane, their effect on the atmosphere, and potential long-term impacts on global climate. In June 1992 the United Nations Environment and Development Conference in Rio de Janeiro passed the Framework Convention on Climate Change. Over 150 heads of government jointly signed the Convention, and committed to reducing greenhouse gas emissions in their respective countries.

Methane liberated during coal mining is a greenhouse gas, approximately 24.5 times more potent than CO_2 in terms of the impact on global warming over a 100 year time-frame. Methane is also a clean and efficient energy source, equivalent in quality to conventional natural gas. Various international government agencies and non-governmental organizations encourage coalbed methane recovery and use, as it not only creates a new energy source, but also protects the environment.

6.2.1 UNITED NATIONS GLOBAL ENVIRONMENT FACILITY (GEF)

Based on USEPA investigations, methane liberated during coal mining from Chinese mines accounts for one-third of the world's total. The UNDP later built on the findings of these USEPA studies, and through a definitional mission developed a project to provide incentives for China to recover and use the coalbed methane liberated during coal mining, improve regional and global atmosphere quality, and create an additional energy source. The UNDP signed a project agreement for development of coalbed methane resources in China with the former Ministry of Energy in June, 1992. The project is supported by the Global Environment Fund Facility (GEF) with US $10 million, and includes three coalbed methane development projects and one coalbed methane resource evaluation project. The goals of these projects include:

- to define the necessary technologies and organizations for the Chinese government to establish coalbed methane development strategies;
- to introduce and demonstrate coalbed methane development technologies; and
- to advise Chinese central and local government policy-makers of the potential economic significance of coalbed methane development.

6.2.2 US ENVIRONMENTAL PROTECTION AGENCY (USEPA)

According to studies undertaken by the USEPA, China has a great opportunity to profitably recover coalbed methane liberated during coal mining. Coalbed methane could reduce China's need for coal burning power plants by approximately 25 percent by 2020. One barrier to project development is the lack of capital and technical expertise that foreign companies may bring to a project. The development of a coalbed methane industry in China also creates potential business opportunities for US and international businesses. The USEPA will assist Chinese and US companies to create partnerships for methane recovery, and to support the transfer of information and technology necessary to evaluate, develop and manage coalbed methane projects. As part of the cooperative activities between the United States and China, the USEPA, the Chinese Ministry of Coal Industry (MOCI), and the China Coal Information Institute have created the China Coalbed Methane Clearinghouse. Its role is to disseminate information to Chinese and international experts on coalbed methane technology, markets, and policies. In addition, the Clearinghouse is involved in activities which promote cooperation in coalbed methane development between China and international companies.

6.2.3 US DEPARTMENT OF ENERGY (USDOE)

The Deputy Energy Secretary of the USDOE reported to a US Senate Hearing that foreign investment in all energy sectors, including the coalbed methane industry, is needed for China and other Asian countries. Development of coalbed methane projects in China would be a long-term cooperative opportunity for US businesses. On March 5, 1995 in Beijing, the Chinese Coal Minister and US Energy Secretary signed the Protocol for Cooperation for Fossil Energy Research and Development between MOCI, China, and USDOE for coalbed methane recovery and use. The planned cooperative project will include an evaluation of China's coalbed methane resources and demonstration projects to apply new technologies for coalbed methane recovery and use.

6.2.4 US INITIATIVE ON JOINT IMPLEMENTATION (USIJI)

At the 1992 Earth Summit in Rio, the United States joined more than 150 countries in signing the Framework Convention on Climate Change, which explicitly provides for signatories to meet their obligation to reduce greenhouse gas emissions “jointly with other parties”. Thus, Joint Implementation refers to arrangements between entities in two or more countries, leading to the implementation of projects that reduce, avoid, or sequester greenhouse gas emissions.

In October, 1993 the United States established the US Initiative on Joint Implementation (USIJI). An interagency Secretariat, chaired by the USEPA and the USDOE, administers the organization, which promotes the development of overseas projects to reduce greenhouse gas emissions. USIJI's funds come from companies, governments, private banks, trust funds, and regional development banks.

According to a brochure prepared by the USIJI secretariat, the panel evaluating projects submitted for inclusion in the USIJI program will consider several issues, including:

- Specific measures to reduce greenhouse gas emissions;
- Appropriateness of methodologies for calculating emissions reductions;
- Non-greenhouse gas environmental impacts of the project;
- Development impacts of the project; and,
- Acceptance by the national or federal government of the host country.

The USIJI's Evaluation Panel will examine project proposals within 90 days of their submission. So far, the USIJI has not received any project proposals from the Chinese government agencies. The USIJI encourages MOCI to submit project proposals for projects that reduce greenhouse gas emissions (including coalbed methane projects).

6.3 POLICY OPTIONS FOR CHINA

6.3.1 REVIEW OF CHINA’S POLICIES ON RECOVERY AND USE OF COALBED METHANE

China is encouraging coal mines to expand recovery and use of coalbed methane through the following policies.

<u>State Investment Plan for Capital Construction</u>

In 1982, the State Planning Commission began incorporating coalbed methane use into its plan for capital construction of energy conservation projects. In 1989, the State Council drafted the “Decision on Current Industry Policies”, in which coalbed methane development was designated one of the key industries to be financed in the Catalogue of Industry Development Priorities. The State Planning Commission, together with the Ministry of Finance and the Development Bank, has set aside a certain percentage of low-interest investment loans for coalbed methane development projects.

<u>Coal Industry Development Program</u>

In 1994, MOCI included coalbed methane development as one of its three strategies for development of China’s coal industry. The “1994-2000 Coal Industry Programme for Developing Utilization, Economic Diversification and Service Industries”, indicated that coalbed methane development should be given priority. The Programme proposes developing seven coalbed methane use projects during the next seven years, increasing utilization capacity by 280 million cubic meters, and investment by 1.1 billion yuan. At present, the special low-interest loans given to MOCI by the State amount to 3 billion yuan, a portion of which can be used for comprehensive coalbed methane use projects.

Coal Mine Safety Technology Fund

The Coal Mine Safety Technology Fund was founded in the early 1970's. Its goal is to improve safety conditions at coal mining areas. Initially, the source of the fund was a portion of MOCI's Technical Renovation Fund granted by the State Economic Commission. The funding amounted to approximately 70 to 100 million yuan per year, of which one third was used for gas drainage projects. In 1988, the then-existing MOCI was dissolved and the National Coal Corporation, Northeast and Inner Mongolian Corporation, and China Local Mine Corporation were established. The State no longer provides technical renovation funds to coal mines and each corporation has to raise its own safety technology funds.

MOCI was later re-established and currently retains a portion of the relief fund of 1 yuan per ton of coal, which is remitted every year by various coal mines. MOCI uses this fund as a technology-based safety measure fund. Many coal mines have financial problems and the budget for coal mine safety is insufficient. Some of the more economic mines fund technology-based safety measures on their own. For instance, in 1994, the State-owned key coal mines in Shanxi Province invested 43 million yuan in gas control, an average of 0.7 yuan per ton. They plan to increase this to 1 yuan per ton in 1995.

Tax-Preferential Policies

In September 1985, the State Council approved the National Economic Commission's "Catalogue of Comprehensive Utilization of Resources". In this Catalogue, coalbed methane is classified as a "waste resource"; the recovery of waste resources is eligible for tax reduction policies. The products of comprehensive use projects created with *self-raised* funds and included in the Catalogue of Comprehensive Utilization of Resources will pay no income and adjustment taxes for the first five years. However, for the products of comprehensive use projects constructed with *government* funds, product, income, and adjustment taxes must be paid in accordance with the National Tax Law.

The document "Provisional Regulations on Comprehensive Utilization of Resources" issued by the State Economic Commission and the Ministry of Finance in 1986 discusses financing for utilization projects. Loans for projects at State-run enterprises can be repaid after the project begins. For those projects financed both internally and by loans, profits should be used first to pay loans; if the payment period of a project exceeds five years, after paying all loans with the profits, the tax interest should be paid according to the regulations; those who have paid all loans within five years will continue enjoying the reduction of income and adjustment tax until the end of five years, according to the proportion of self raised funds in the total investment.
The periodic reduction and exemption of production taxes shall be examined and approved by the appropriate tax authorities. The Ministry of Finance is in charge of examination and approval for the State-run enterprises, whereas the relevant province- or municipality-level departments or bureaus are in charge of examination and approval for local enterprises. The reduction and exemption of taxes for introduced technologies and imported equipment for utilization projects are implemented according to administrative methods applied for renovation projects using introduced technologies.

According to the State Council's Stipulations on Environment Protection (issued May, 1984), the profits from pollution control projects will not be paid as government revenue for the first five years, even once the new tax law is implemented. Products produced by collectively-owned enterprises within the coal industry (mainly waste stock, waste gas and waste water) will not be subject to income tax.

Incentive Policies for Methane-Fired Power Stations

The "Notice on Additional Provisions Concerning Perfection of Existing Comprehensive Utilization Policies" issued by the State Economic Commission and the Ministry of Finance in 1986 stipulates that the procurement price of electricity produced by power plants connected to the supply network is determined, in principle, according to the power generation cost plus the average power generation profits of local large power supply networks. In addition to power supply costs, line losses, and power supply taxes, only 5 percent commission may be added to the price of electricity sold via the supply network.

The development of methane-fired power plants and co-generation pants is encouraged. In 1989, the State Planning Commission issued "Provisions on Encouraging the Development of Small-Scale Cogeneration Plants", which requests local governments to allocate a certain proportion of collected energy and communication construction funds to be used as the cogeneration fund. The State would allocate a portion of special loans for energy conservation and technical renovation, and the loan for capital construction of energy conservation, to arrange special projects. For small cogeneration plants connected to the supply network, the electric power authorities will purchase and sell electricity at market prices and charge the electricity plants only small fees for using the network.

Price Policies

In 1986, the wellhead gas price in most oil fields in China was 0.08 yuan per cubic meter. In 1987, the State Council decided to implement a contract system for constant gas output. There was no change in the price of contracted gas, while the surplus gas was sold at 0.26 yuan per cubic meter. The differential income from the market prices and regulated prices could be used as a special fund for gas exploration and development.

The central government's 1994 wellhead price regulations for different areas are shown below:

REGULATED WELLHEAD GAS PRICES IN 1994 (RMB Yuan per 1000 cubic meters)

Area	Fertilizer Manufacture	Residential	Industry	Commercial
Sichuan Province	470	530	490	670
Others	440	460	520	520

The CNPGC is currently responsible for their contracted amount of 8.8 billion cubic meters per year, which must be sold at the regulated price. The surplus gas production is permitted to be sold at market price, but no higher than 900 yuan/1000 cubic meters. Due to artificially low gas prices, most gas enterprises are uneconomic.

Much of the gas drained from coal mines is used by mining area residents for cooking. As a social benefit, this gas is free or very inexpensive. This low price makes gas drainage and use projects uneconomic, seriously hindering coalbed methane development. Some would-be foreign investors have already encountered this problem.

Industrial Management

The State Planning Commission clearly stipulated in its “Reply on Management of Exploration and Development of Coalbed Methane Resources” in February 1994 that the exploration and development of coalbed methane in mining areas should be approved in advance by legal representatives of coal mining enterprises and coal authorities; and that the exploration and development of coalbed methane in mining areas under national planning should obtain MOCI’s advance approval. Accordingly, in April MOCI formulated the “Provisional Regulations and Rules for the Management of Coalbed Methane Exploration and Development” which appear in Appendix D of this report.

6.3.2 THE COAL INFORMATION INSTITUTE’S POLICY SUGGESTIONS FOR PROMOTING DEVELOPMENT OF COALBED METHANE IN CHINA

The CII recommends the following policies to the authorities for use in decision-making, based on its analysis of the above relevant policies and considering the development and use potential of coalbed methane in China. The opinions expressed in this section are those of the CII.

1. **Adopt coalbed methane development as one of the national energy strategy objectives.** If the government adopts policies favoring coalbed methane development, its progress will accelerate markedly and coalbed methane will play a significant role in China’s energy mix. Considering that coalbed methane development has been listed as a priority for national industry development, this report suggests that the State Planning Commission incorporate coalbed methane development in its Ninth Five-Year Plan for energy development, and consider giving it major support while formulating industrial policies and arranging national energy investment so as to promote its development.

2. **Determine a coalbed methane development strategy.** The coalbed methane development strategy should adopt the principle of giving priority to surface recovery, and secondarily to in-mine drainage. Plans for near-term, medium-term, and long-term goals should be made. In the near term, emphasis should be placed on successful completion of existing projects and demonstration projects. In the medium term, several key objectives should be met, and technical projects should be undertaken. For the long term, compulsory coalbed methane development in large mining areas, and infrastructure projects, should be planned. Currently, MOCI is undertaking an assessment of national coalbed methane resources. Based on this assessment, it plans to select mining areas with favorable conditions on which to focus coalbed methane development and build two or three coalbed methane production bases by the end of this century. In the future, coalbed methane will be considered an important aspect of mine area development.

3. **Develop coalbed methane projects by using multiple investment sources. Coalbed methane development shall be considered as the key State-supported industry for capital construction.** The State Planning Commission and Ministry of Finance and Banks should arrange for access to a certain proportion of coalbed methane investment loans with low interest. Since coalbed methane development in China is still in its early stages, loans and central government-supplied capital input may each contribute to funding for investment in key coalbed methane projects. Key aspects related to investment are:

- A portion of capital construction loans for energy conservation can be allocated to coalbed methane projects.

- Coalbed methane drainage and utilization belong to the category of comprehensive resource use. When arranging for State financing, the loan for coalbed methane projects should be factored into the overall arrangement. In addition, a portion of a low-interest State loan can be used.

- Since coalbed methane recovery can significantly improve mine safety, the CII suggests using a certain proportion of the safety fund for coalbed methane projects.

- Since recovery of coalbed methane is beneficial to the protection of the atmosphere, the State should consider coalbed methane projects to be environmental protection projects.

- As the development and use of coalbed methane can provide gas and electricity to local areas and create job opportunities, local governments should actively support coalbed methane projects and take part in investments.

- When possible, enterprises should raise funds themselves for coalbed methane projects.

- The State should develop policies to encourage foreign investment. Incentive policies could make foreign investment one of the most important sources of funds for coalbed methane development.

4. **Preferential tax policies.** In previous documents issued by the State Planning Commission and the Ministry of Finance, coalbed methane drainage and use were classified as waste resource and environmental protection comprehensive use projects.

   It is recommended that the government give the following preferential tax policies to coalbed methane projects:

   - place coalbed methane projects in the revised Catalogue of Comprehensive Resource Use;

   - waive income taxes and investment orientation adjustment taxes for five years, or formulate a tax credit policy similar to that adopted in the US;

   - the State has reduced the value added tax (VAT) tax of coal enterprises to about 3.5 percent. Coalbed methane enterprises should enjoy the same preferential VAT policy, i.e. a 3.5% VAT; and,

   - remit the resource compensation cost.

5. **Price policy.** At present, many urban residents still enjoy financial subsidies for gas use, particularly in mining areas where recovered methane is considered a social benefit for miners. As stated in Section 6.3.1, this artificially low price can render coalbed methane projects uneconomic and cause hesitation among foreign investors. With ongoing

economic reform and price liberalization in China, the market environment is improving, but further reform of gas prices is necessary. Local governments in coal mining areas should try to change the practice of artificially lowering coalbed methane prices and create favorable market conditions for foreign investors.

6. **Improve the coalbed methane infrastructure.** Due to the lack of pipelines, surplus gas must be directly emitted to the atmosphere when there is no demand by local residents. In order to achieve large-scale production of coalbed methane, marketing problems must first be solved. To sell coalbed methane to a regional market, a gas pipeline system must be built. CII recommends that that the government integrate plans for developing and transporting coalbed methane with plans for the national natural gas pipeline. Before a national gas pipeline system is constructed, the central government should consider building gas pipelines from coalbed methane producing areas to nearby large cities. Gas pipeline construction belongs to national infrastructure construction projects and should be funded and constructed by the government.

   For those mining areas that are far from population centers and lack pipeline systems, the development of coalbed methane-fired power plants would be ideal. The CII recommends that the State encourage the development of coalbed methane-fired power plants, treat them as comprehensive resource use projects and give them preferential policies. For example, after a coalbed methane power plant is connected to the electricity network and is supplying electricity, it should be allowed to negotiate directly with the electricity consumer, and the electricity department should charge the power plant only the grid transmission cost.

7. **Strengthen scientific research on coalbed methane.** Coalbed methane development in China is still in its preliminary stages, and certain key technical problems must be solved. This CII suggests that the State Science and Technology Commission and the State Planning Commission incorporate coalbed methane research and development projects in the national key scientific research plan and increase financial support of research projects.

8. **Encourage use of foreign capital and introduction of advanced technology.** Since coalbed methane development falls in the category of environmental protection and clean energy projects, The United Nations, World Bank, Global Environmental Facility, Asian Development Bank, and US Initiative on Joint Implementation are all potential funding sources. It is recommended that the government should give the necessary preferential policies to joint venture and other cooperative coalbed methane projects, and reduce or eliminate tariffs on technologies and equipment imported for coalbed methane projects. This could be undertaken in light of the policy for preferential methods of management and tariffs used in renovation projects at existing enterprises with new technologies.

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER ACTION

7.1 OVERVIEW

As outlined in this report, China has tremendous coalbed methane resources, as well as increasing demand for energy, including natural gas. China's coal industry, as the largest coal producer in the world, has acquired substantial experience in recovering coalbed methane using in-mine methods. Use of this methane, however, is in its initial developmental stages. Recent reforms in the energy sector have promoted increased use of natural gas, and MOCI is committed to develop coalbed methane as a key strategy for the coal industry.

Based on this report, as well as the current trends in China's energy demand, coalbed methane development should be a priority with the Chinese government. Mechanisms for coalbed methane development should be evaluated to develop appropriate policies, incentives and a regulatory framework. This is an opportune time to evaluate coalbed methane and its potential role in China's energy mix, as the energy sector is currently undergoing a major restructuring program. Many barriers to coalbed methane development, including government subsidies, have already been eliminated. China's move towards a more market-based economy creates an environment conducive to developing additional energy sources such as coalbed methane.

This chapter summarizes the policies, incentives, technical activities, feasibility assessments, outreach, and investment considerations that promote coalbed methane recovery and use in China. This includes current activities that need to be expanded, as well as recommendations for additional actions. Section 7.6 summarizes conclusions and recommendations made by the China Coalbed Methane Clearinghouse.

7.2 FOLLOW UP TECHNICAL ACTIVITIES

7.2.1 FEASIBILITY ASSESSMENTS

Cooperation with international agencies and foreign governments is important for obtaining technical and financial assistance for specific coalbed methane projects. Section 6.2 outlines existing foreign support and agencies playing an active role in expanding China's coalbed methane industry.

Establishment of policies by the Chinese government to encourage foreign companies to invest in such projects could also create long-term benefits. Follow-up strategies include:

- training Chinese technical experts and government personnel on mine safety and productivity, as well as energy and the environmental benefits of increased coalbed methane development; and,
- studies to evaluate the feasibility of project development at specific sites, leading to the implementation of demonstration projects.

Technological and economic feasibility determine the potential for commercial development of coalbed methane. Relevant feasibility assessments for China include:

- production enhancement;
- the impact of coalbed methane projects on the environment;
- reservoir modeling;
- determination of optimal well placement;
- supply and demand analysis; and,
- investment risk analysis.

Feasibility studies should assess the necessity of the development of a given project. Among the key considerations are technical viability of the project, and the technical risks associated with the project, relative to methane recovery and use options. Project economics and financial viability should also be addressed. Important related issues, including regulatory, legal, and environmental issues, should also be examined.

In preparing feasibility studies, consultants or corporate experts should work closely with in-country personnel from the mining community, relevant local government agencies, and industries, and national government agencies. Widespread participation during the project design and assessment stages may help expedite project approval and development states for those projects considered worthwhile.

7.2.2 TRAINING

Personnel training and information services play a key role in promoting coalbed methane development. Some training related to developing China's coalbed methane has already occurred; several technical personnel have been to the US to receive training. Also, activities of the recently established China Coalbed Methane Clearinghouse involve various aspects of training and technology transfer (see Section 7.3).

Training programs can be designed for mining industry technical personnel and government representatives. Technical personnel training emphasizes methane recovery, including pre-mine drainage from the surface, methane use, and resource assessment. Programs for government representatives include development of specific environmental and regulatory guidelines to ensure safe and efficient implementation of methane recovery projects, legal and economic training, and training in project feasibility assessment. Mining economics and business management courses would also provide beneficial information for coalbed methane project participants.

These training programs should be coordinated with the Clearinghouse and with other follow-up studies. Agencies interested in providing training should work closely with Chinese representatives to identify specific needs and design relevant programs.

7.3 OUTREACH: THE COALBED METHANE CLEARINGHOUSE

In August 1994, the Ministry of Coal Industry (MOCI) established the China Coalbed Methane Clearinghouse in Beijing. The Clearinghouse is part of MOCI's China Coal Information Institute (CII). The CII supplies information on coal-related topics to top-level decision makers at MOCI, as well as to subordinate branches and enterprises. The Clearinghouse is one of 21 divisions of the CII, which has approximately 700 employees.

The Clearinghouse has made significant contributions to the development of coalbed methane in China. In addition to co-authoring this report, the following activities have taken place or are currently ongoing by the Clearinghouse:

- Providing consulting services and hosting technical seminars (see Box 13);
- Publication of the journal *China Coalbed Methane* in both English and Chinese. The first English-language issue of this journal was published in May 1995, and contains numerous articles, most of them written by Chinese experts, on a variety of topics directly related to coalbed methane in China;
- Completion of a bibliographic database, and a database containing coalbed methane recovery and use data;
- Completion of a report on coalbed methane development in selected coal producing countries, for use by MOCI in formulating coalbed methane policy;
- Appointment of Mr. Sun Maoyuan, Clearinghouse Director, to membership on the Coalbed Methane Steering Committee of MOCI;
- Participated in the Intergas '94, symposium in Alabama, US; and
- Provided extensive information on coalbed methane development to Southwest Petroleum University of China. With assistance from the Clearinghouse, the university's Well Completion Technology Center was awarded a contract for coalbed methane research projects from the Pingdingshan CMA.
- Organized the October, 1995 UNDP International Conference on Coalbed Methane Development and Utilization;
- Integration into the new China United Coalbed Methane Co. Ltd. (China CBM), with Mr. Sun Maoyuan as a member of its Board of Directors.

BOX 13. PROVIDING ASSISTANCE TO FOREIGN COMPANIES: A CLEARINGHOUSE ACTIVITY

In December, 1994 the China Coalbed Methane Clearinghouse hosted a technical exchange between Conoco and China's Ministry of Coal Industry (MOCI). Conoco representatives presented their experience in coalbed methane recovery for more than 15 senior MOCI officials and mining experts. The Clearinghouse provided Conoco with the assistance and information needed to assess methane development opportunities in some key coal mining areas. It also explained the procedures for management of coalbed methane projects in China, and proposed some target areas for coalbed methane development. As a result, Conoco is now pursuing projects in China (Sun, 1995).

The Clearinghouse will continue to play a key role in China's coalbed methane development, and plans to undertake the following activities:

- Organizing experts to write a handbook of coalbed methane;
- Dissemination of information on coalbed methane throughout China;
- Organization of technical seminars and workshops;
- Organization of technical training programs;
- Presentation of policy recommendations for promoting coalbed development;
- Setting up branches of the Clearinghouse in key coal basins;
- Development and use of an economic analysis model for coal mine methane projects; and,
- Development of materials for marketing Clearinghouse services.

7.4 DEMONSTRATION PROJECTS

Demonstration projects for specific methane recovery and use options can expedite development of coalbed methane resources, and effectively transfer necessary technologies. There are various options for conducting demonstration projects, depending on the objectives of the international funding agencies and national and local officials. The demonstration projects should involve carefully selected project sites in coal basins with optimal coalbed methane conditions, as defined in this report, and focus on technologies most pertinent to China. Projects that address technical issues, such as well completion and stimulation techniques, or those that investigate on-site use options, such as cofiring methane with coal or using it in gas turbines, would have direct applications for China.

Currently, a GEF project (“China Coalbed Methane Resources Development”) is underway in China. It includes three demonstration projects for coalbed methane recovery administered by the Songzao, Kailuan, and Tiefa CMAs. The projects are GEF-sponsored; UNDP is the executing agency, and US contractors were selected as cooperative partners with the individual CMAs. Section 3.5 includes a summary of each of these demonstration projects. In addition, MOCI, MGMR, and CNPGC are involved in coalbed methane development in several mining areas; over 39 wells were drilled by the end of 1994.

Ideally, successful demonstration projects will be widely replicated by the mining industry. Demonstration projects should expedite development of those projects considered too risky or uncertain for the private sector to undertake without some assistance. Demonstration projects may serve to convince Chinese experts that certain technical options with which they may be unfamiliar can work in site-specific conditions. Since demonstration project results will be made public, they serve as an example within China and in other countries that various methane recovery and use options are feasible, thereby stimulating a wider basis for interest.

7.5 INVESTMENT CONSIDERATIONS

In many regards, China has a relatively favorable climate for foreign investment in coalbed methane projects. Because the nation has recently suffered from energy shortages, the government is keen on energy-related projects, particularly those related to increasing China’s power-generating capacity.

China has recently taken steps aimed at increasing foreign investment in energy-related projects. For example, they are designating several key infrastructure projects to experiment with the “build, operate and transfer” (BOT) method of attracting foreign investment (China Energy Report, 1995). China is considering more widespread adoption of the BOT policy because it has been difficult to attract foreign investors to some of the major infrastructure development projects due to a perceived poor rate of return. China is thus shifting its method of attracting foreign investment, from simply giving favorable conditions to providing for mutual economic benefit and long-term cooperative agreements.

In order to increase foreign participation in coalbed methane development, however, several issues that will affect the desirability of investments by foreign companies must be resolved. Some of these issues, such as taxation policies and legal frameworks for project development, are relevant to a wide range of business opportunities in China, and the government will likely address them through general initiatives to encourage foreign investment. There are other issues specifically related to coalbed methane development, however, which must be considered in developing policies to promote coalbed methane development in China. Among the issues (both positive and negative) specifically related to coalbed methane development are:

- Ownership of natural resources in China is clearly defined. The State owns all mineral resources, and development of these resources by foreign entities must be approved by the State.

- Chinese law provides for the formation of joint venture entities for the development of mineral resources. Joint ventures are encouraged as a means of developing resources and transferring technology.

- Taxation in China can be complex and development of a successful enterprise is dependent on thorough understanding of the tax liabilities associated with any business undertaken in China. Local tax relief is available, and numerous areas such as economic and technological development zones are present, within which enterprises enjoy special tax holidays.

- Commercial incentives for the development and use of coalbed methane will be necessary for large-scale development of coalbed methane resources. Realistic pricing of the gas and the energy into which it is converted must be implemented. China is rapidly moving in this direction by freeing energy prices in a stepwise fashion, and removing subsidies.

China will thus need to focus on incentives for methane development and use, as well as realistic energy pricing, as part of its ongoing formulation of coalbed methane policies. A high-level group within the Ministry of Coal Industry is currently drafting recommendations for policy and development guidelines.

7.6 CONCLUSIONS AND RECOMMENDATIONS BY THE CHINA COALBED METHANE CLEARINGHOUSE

Following are conclusions and recommendations made by the China Coalbed Methane Clearinghouse:

1. Increased production of natural gas: Currently, China has one of the fastest growing economies in the world, with steady annual growth in energy production and consumption. Unlike several developed countries, which rely on oil and gas for over half of their primary energy demand, coal comprises approximately three-fourths of China’s energy mix.

According to MOCI, coal production will increase from 1.29 billion tons in 1994 to 1.4 billion tons in 2000. China's current strategies for energy development focus on conserving and optimizing energy resources, and expanding natural gas production.

2. Increased coalbed methane development: Although a newly exploited source of energy, coalbed methane is now recognized worldwide as a significant energy source. In the US, the coalbed methane industry has experienced tremendous growth over the past decade. In 1983, annual coalbed methane production was 708 million cubic meters. In 1994, production increased to 21.5 billion cubic meters, exceeding China's conventional natural gas production of 17 billion cubic meters. The Clearinghouse recommends that China include coalbed methane in its strategic energy development.

3. Selection of target areas and coal basins for coalbed methane development: Since the geology of many of China's coal basins is complex, geologic conditions should be considered in the selection of areas targeted for coalbed methane development. In addition to geologic conditions, other key selection criteria include infrastructure, available technology, and market conditions. China's major coal basins with high potential for methane development are described in this report. Among the areas that have recently attracted attention from investors is the Hedong Basin of Shanxi Province.

   In the US, most coalbed methane projects are in coal basins whose ranks range from low to medium volatile bituminous. Yet China has many coal basins whose mines produce anthracite, which is typically highly fractured and gassy. Examples include the major coal-producing regions of Yangquan, Jiaozuo, and Jincheng. These anthracite regions should be considered as potential target areas for coalbed methane development.

4. Environmental impacts: Coalbed methane is a greenhouse gas. Based on a UN study on methane emissions, Chinese coal mines liberate 19.4 billion cubic meters of methane per annum, accounting for one-third of the world's total from this source. The UN and USEPA are encouraging Chinese coal mines to expand their methane recovery and use, as it benefits the regional and global environment. It is therefore recommended that the Chinese authorities include methane recovery in their environmental protection programs.

5. Increase coalbed methane recovery: Chinese coal mines have a long history of coalbed methane recovery. In 1993, over 100 mines produced 543 million cubic meters of methane, led by Fushun and Yangquan CMAs. Although numerous mines have increased their methane recovery over the past several years, the recovery rate for Chinese coal mines averages less than 20 percent. It is recommended that the efficiencies of existing recovery methods be improved. For in-mine drainage, recovery from adjacent seams and gob areas using long holes should be used. A comprehensive drainage program before, during, and after mining can increase recovery efficiencies up to 50 percent. Horizontal directional drilling, as used at the Tiefa and Songzao CMAs, is an efficient method when reliable, high power drills are used.

6. Hydraulic fracturing in mined areas: In the US, methane is recovered in both mined and unmined areas. In unmined areas, coalbed methane well drilling and completion methods are modified from conventional oil and gas technologies. In mined areas, companies recover methane using horizontal boreholes and gob wells, as well as vertical wells in advance of mining. Hydraulic fracturing to increase permeability, and therefore gas production has been applied successfully in vertical wells in advance of coal mining.

Currently, there are vertical well degasification tests at the Tiefa, Huaibei, and Jincheng CMAs. It is recommended that additional hydraulic fracture tests be conducted at selected Chinese coal mines.

7. Development is beginning: Coalbed methane development in China is now beginning. Since the onset of the GEF-funded project "China Coalbed Methane Resources Development" in 1990, methane recovery has come into focus, attracting the attention of MOCI, the CNPGC, and the MGMR. Through 1994, 39 vertical wells have been drilled in at least ten coal basins.

8. Well drilling and completion: In China, problems have occurred due to inappropriate use of technologies, including formation damage, roof strata collapse, and inefficient fracturing methods. Advanced technologies used in the US, including rotary percussion drilling and open hole completion, may be applied to China in appropriate geologic conditions. Fracturing parameters and drilling fluids should also be selected to maximize production.

9. Disposal of produced water: Water produced from coalbed methane wells often needs to be treated prior to discharge. The US has developed regulations for disposal of produced water. The methods used are site-specific, depending on water quality, quantity and regional conditions. It is recommended that China evaluate water treatment and disposal methods, and select those that are site-appropriate. In addition, environmental regulations need to be established for the disposal of produced water.

10. On-site coalbed methane use: Unlike the US, China lacks a full integrated natural gas pipeline system between mines, cities and provinces. This restricts large-scale use of pipeline-quality coalbed methane. Some of the larger CMAs, including Kailuan, have integrated pipeline systems that connect the mines to the cities. However, integrated pipelines are non-existent in most mining regions, so that gas produced is supplied primarily for miners' families in the immediate area. It is recommended that additional pipeline infrastructure be built in key locations to allow the distribution and marketing of gas, including coalbed methane.

    Use of coalbed methane should be a priority in China. The remoteness of many coal basins with high coalbed methane potential results in extremely high costs for pipeline construction. On-site use, including power generation with gas turbines, is the most cost effective use of coalbed methane in these areas. Several countries have installed gas turbines using methane as fuel, and China built a gas turbine demonstration project in 1990. There is international interest in methane-powered power generation projects in China; however, the costs for using China's electric grid are prohibitive. Coalbed methane as an energy source has numerous, cost-effective industrial uses, including feedstocks for producing ammonia, carbon black, formaldehyde, and other chemical products. Jincheng CMA in Shanxi Province serves as a model for on-site coalbed methane use.

11. Gas prices and tax policy for surface wells: China's central government should develop preferential policies to promote methane use. Prior to 1993, the US implemented state-regulated wellhead prices, which lowered prices and resulted in decreased gas production. Now, US gas prices are based on a free-market system, creating a balance between production and consumption. China's wellhead and sales prices for conventional natural gas are regulated; gas enterprises are commonly unprofitable due to low gas prices.

Coalbed methane produced from coal mines is sold at an even lower price. Freeing gas prices would provide a financial incentive to increase gas production and sales.

Projects which involve gas recovery and use from active mines are now included in the Catalogue of Utilization of Comprehensive Resources, and are eligible for relevant preferential policies. However, it is currently uncertain whether coalbed methane produced from surface wells qualifies for these same preferential policies. It is suggested that the State Planning Commission include vertical coalbed methane wells in the Catalogue of Comprehensive Utilization of Resources, qualifying for preferential policies on taxation and investment.

12. State loans and funding for coalbed methane projects: The state should allocate additional funds and loans for coalbed methane projects, as coalbed methane is now included in the Catalogue of Priorities of Current Industrial Development.

13. MOCI loans for coalbed methane use: Coalbed methane development is an important part of comprehensive use at high gas coal mines, as well as being cost-effective. MOCI arranges state loans with low interest rates for the coal industry. Since coalbed methane recovery and use are a tertiary industry of the coal sector, MOCI should allocate a percentage of loans specifically for coalbed methane projects.

14. Market conditions and foreign investments: Current market conditions and policies in China may deter investment in coalbed methane projects. Foreign investors are currently interested in coalbed methane projects in China. Changes in market conditions and policy could attract foreign investment. Examples include freeing natural gas prices, construction of pipelines in key areas, and preferential policies for power generation.

15. Demonstration projects and training: Coalbed methane projects often require sophisticated technologies, and technological barriers for site-specific projects in China need to be addressed. It is recommended that funding for R&D coalbed methane projects is available for the key State R&D programs. In addition, a training program should be available to educate both technical personnel of the mining industry, and government officials to aid in their decisions on energy policy.

16. Clearinghouse activities: Established in 1994, the China Coalbed Methane Clearinghouse provides an important information service and promotes the development of coalbed methane in China. The Clearinghouse currently plans to expand its activities to include a variety of information services for organizations and companies, both in China and abroad.

REFERENCES CITED

American Gas Association, 1993, Status of the natural gas vehicle conversion and refueling infrastructure: Energy Analysis (AGA Policy & Analysis Group), August 13,1993, 10 p.

Baker, R.W., Pinnau, I., and Wijmans, J.G., 1993, Nitrogen separation from natural gas using membranes: AICHE National Meeting, Houston, TX, March 28 - April 1, 1993.

Bend Research, 1995, oral communication.

Bai Qingzhao, 1995, Evaluation of target regions of coalbed methane development in China: p. 10 - 13, *in* China Coalbed Methane No. 1, May 1995, China Coalbed Methane Clearinghouse, 54 p.

Biggs, Rod, 1995, CMG Development, Bridgeport, WV, oral communication.

Byrer, Charles, 1995, USDOE/METC, Morgantown, WV, oral communication.

Chen Weilong, Ma Qiang, Qin Yuying, and Lu Jing Chang, 1995, Application of injection/falloff test at Liulin pilot area of coalbed methane exploration and development *in* International conference on Coalbed Methane Development and Utilization, Beijing, 1995, Proceedings, Vol. A: Beijing, United Nations, p. 301-305.

China Coal Industry Yearbook 1993: China Coal Industry Publishing House, 132 p.

China Coal Industry Yearbook 1994: China Coal Industry Publishing House, [In Chinese] 349 p.

China Coalbed Methane Clearinghouse, 1995: China Coalbed Methane Number 1, May 1995, 54 p.

China Energy Report, 1994, Dispute over oil and gas reserves continues: China Energy Report, v. 1, no. 7, p. 2.

China Energy Report, 1995, China examining BOT financing: China Energy Report, v. 2, no. 7, p. 2-3.

China Energy Report, 1996, State Council launches methane company: China Energy Report, v. 3, no. 5, p. 7.

Coal & Synfuels Technology, 1995, v. 16, no. 19, May 15, 1995.

Consolidated Natural Gas Company (CNG), 1987, Cofiring - A new combustion technique: Consolidated Natural Gas Company, 4 p.

Dadi, Z. 1992, Energy management system pricing and market mechanisms: US-China Conference.

Dai Chong-xiao, 1993, History and overview of coalbed methane extraction in China: p. 429-433 *in* Proceedings of the 1993 International Coalbed Methane Symposium, v. II, Tuscaloosa, AL, May 17-21, 1993, 375 p.

D'Amico, Joseph and Reinhold, Herbert, 1993, A PSA Process for nitrogen rejection from natural gas: AICHE National Meeting, Houston, TX, March 28-April 1, 1993.

Department of Resources, Conservation and Comprehensive Utilization (DRCCU), 1994, China Energy Annual Review: Wang Quingyi, ed., [In Chinese and English], 150 p.

Diamond, W. P., 1993, Methane control for underground coal mines: *in* Law, B.E., and Rice, D.D., eds., Hydrocarbons From Coal Tulsa, Oklahoma, American Association of Petroleum Geologists, Studies in Geology #38: p. 237-267.

Diamond, W.P., Bodden, W.R., Zuber, M.D., and Schraufnagel, R.A., 1989, Measuring the extent of coalbed gas drainage after ten years of production at the Oak Grove Pattern, in Proceedings of the 1989 Coalbed Methane Symposium: Tuscaloosa, AL, 1989, p. 185-193.

Dong Qiantai, 1995, The researches of the relationship between the geological features and coalbed methane occurrence law of Sanjiao mining area in Hedong Coalfield, Shanxi Province, *in* International Conference on Coalbed Methane Development and Utilization, Beijing, 1995, Proceedings, Vol. A: Beijing, United Nations, p. 90-99.

Dorian, J. P., 1995, Energy in China: Financial Times Energy Publishing, 149 p.

Eastern Region Natural Gas Center (ERNGC), 1995, Warrior basin coalbed methane production data for 1994: University of Alabama, Tuscaloosa, oral communication.

East-West Center/Argonne National Laboratory, 1993, National response strategy for Global Climate Change: PRC Office of Environment-Asian Development Bank.

Economic and Social Commission for Asia and the Pacific, 1985, Stratigraphic correlation between sedimentary basins of the ESCAP region: *in* ESCAP Atlas of Stratigraphy IV - PRC, v. X: United Nations, 81 p.

EIU (Economist Intelligence Unit) 1993, China and Mongolia country profile: London, The Economist Intelligence Unit, 80 p.

Energy Analysis Program/LBL, 1992, China's energy system - historical evolution, current issues, and prospects: Levine, Liu, and Sinton, eds., Annual Review of Energy and the Environment, 17: p. 405-435.

Energy Information Center (EIC), 1994, China - An untapped market for natural gas vehicles: Fuel For Thought; Newsletter of the Clean Coal Technology Information Center, MSU - Billings, MT, 7/94, 4 p.

Fay, J.A., Golomb, D.S., and Zachariades, S.C. 1986, Feasibility and cost of converting oil- and coal-fired utility boilers to intermittent use of natural gas: Massachusetts Institute of Technology Energy Laboratory, 32 p.

Fenggi, Z., 1992, To develop the coal market enthusiastically and open the price of coal progressively: US-China Conference.

Fisher, Roger, 1995, Technical evaluation and development potential of coalbed methane resources in the San Jiao mine area, Shanxi Province, People's Republic of China, *in* International Conference on Coalbed Methane Development and Utilization, Beijing, 1995, Proceedings, Vol. B: Beijing, United Nations.

Fushun CCMRI, 1995, Data presented to Raven Ridge Resources while in China, August 1995.

Gas Research Institute (GRI), 1993, GRI Quarterly review of methane from coal seams technology: v. 11, no. 1, August 1993, 60 p.

Gas Research Institute (GRI), 1995, Gas cofiring - a viable dual fuel option: Chicago, Gas Research Institute, 7 p.

Gas Separation Technology (GST), 1995, GST company brochure.

Guanghua Liu, 1990, Permo-Carboniferous paleogeography and coal accumulation and their tectonic control in the north and south China continental plates: International Journal of Coal Geology, v. 16, p. 73-117.

Hendrix, M.S., Brassell, S.C., Carroll, A.R., and Graham, S.A., 1995, Sedimentology, organic geochemistry, and petroleum potential of Jurassic coal measures - Tarim, Junggar, and Turpan Basins, northwest China: American Association of Petroleum Geologists, v. 79, no. 7, July 1995, p. 929 - 958.

Huang Lianchen, 1995, Coalbed methane utilization of Fushun Coal Mining Administration: p. 42 - 44, *in* China Coalbed Methane No. 1, May 1995, China Coalbed Methane Clearinghouse, 54 p.

Huang Shengchu, 1995, unpublished data provided to Raven Ridge Resources via fax, August, 1995.

Hsu, Kenneth, 1989, Origin of sedimentary basins of China: p 207 - 227 *in* Chinese Sedimentary Basins, X. Zhu, ed, Elsevier Publishing.

ICF Resources, Inc., 1990, Economic analysis of China's coal and natural gas industries - Implications for coalbed methane development: Report to the USEPA, 97 p.

IEA Coal Research, 1983, Concise guide to world coalfields: Paris, International Energy Agency, 17 p.

IEA, 1994, World Energy Outlook: Paris, OECD/IEA, 305 p.

IEA, 1996, Practical utilisation of methane: Greenhouse Issues (Publication of the IEA Greenhouse Gas Programme), no. 23, March 1996.

Jianliang Li, Schwoebel, J.J., and Brunner, D.J., 1995, Horizontal in-seam longhole methane drainage strategies for low permeability coal seams at Songzao, China, *in* International Conference on Coalbed Methane Development and Utilization, Beijing, 1995, Proceedings, Vol. B: Beijing, United Nations.

JP International, 1990, Opportunities for coalbed methane recovery and utilization in China; The potential for US-China cooperation: Report to the USEPA.

JP International, 1991a, Review and use of coalbed methane in China: Data Review.

JP International, 1991b, Geologic data, Songzao Mining Administration, 14 p.

JP International, 1991c, Investigation into methane recovery and utilization in China's coal mines: Data bank Analysis, June 30, 1991.

JP International, 1991d, Figures in China's coalbed methane resources - A national study.

Kruger, Dina, 1993, International opportunities to reduce coal mine methane: p. 599 - 608, *in* Proceedings of the 1993 International Coalbed Methane Symposium, v. II, Birmingham, AL, May 17-21, 1993, 375 p.

Lee, K.Y., 1989, Geology of petroleum and coal deposits in the North China basin, Eastern China: U.S. Geological Survey Bulletin 1871, 36 p.

Lemons, B.N. and Nemirow, Larry, 1989, Maximizing the Section 29 credit in coal seam methane transactions: p. 238 - 245, The Journal of Taxation, April 1989.

Lewis, Mike, 1995, Virginia Division of Oil & Gas; oral communication.

Li Dawei, Liu Huamin, Ma Jiarong, Zhang Shuqi, Zhang Suian, Li Jianwu, Yuan Ping, Zhang Qun, 1995, Developing and investing conditions for coalbed methane resources in Huaibei Coalfield, China, *in* International Conference on Coalbed Methane Development and Utilization, Beijing, 1995, Proceedings, Vol. A: Beijing, United Nations, p. 398-400.

Li Zhigang, Xia Hehai, Zhang Biao, Liu Maoshen, and Gong Caixi, 1995, The practices of hydraulic fracturing technology in coalbed methane wells at the Liulin Pilot Area, P.R. China, *in* International Conference on Coalbed Methane Development and Utilization, Beijing, 1995, Proceedings, Vol. A: Beijing, United Nations, p. 306-314.

Liu Guanghua, 1990, Permo-Carboniferous paleogeography and coal accumulation and their tectonic control in the North and South China Plates: International Journal of Coal Geology, v. 16, p. 73-117.

Liu Hefu, 1986, Geodynamic scenario and structural styles of Mesozoic and Cenozoic basins in China: American Association of Petroleum Geologists Bulletin, v. 70, no. 4, p. 377-395.

Lunarzewski, L.W., 1994, Prediction of gas capture from active gas resources for coalbed methane utilization, *in* The Silesian International Conference on Coalbed Methane Utilization Proceedings: Katowice, Poland, Coalbed Methane Clearinghouse.

Lunarzewski, L.W., Lunarzewski, A.L., and Pilcher R.C., 1995, A new approach to predict underground gassiness for design of gas capture and ventilation systems, in Proceedings of the 7th US Mine Ventilation Symposium: Lexington, Kentucky, Society for Mining, Metallurgy and Exploration, Inc., p. 61-66.

Lunarzewski, L.W., Pilcher, R.C., Raizen, A., and Sturgill, C., 1992, Pre-feasibility study for the use of coalbed methane as fuel for power generation in the Songzao Coal Mining Association: Unpublished report submitted to the United Nations DESD, 10 November, 1992, 41 p.

Mayer, Brown, and Platt, 1993, China's power generation opportunities: Project Finance Newsletter no. 3/93.

Mehra, Yuv and Wood, Glen, 1993, Noncryogenic N_2-rejection process gets Hugoton field test: Oil & Gas Journal, May 24, 1993.

Meyer, H.S., Leppin, D., and Savidge, J.L., 1990, Gas Research Institute's gas processing research and development program: Unpublished document submitted to the Gas Research Institute, Chicago.

Miao Fen, 1993, Developing prospects of coalbed methane in major coal basins of eastern China: p. 57-60 *in* Proceedings of the 1993 International Coalbed Methane Symposium, v. I, Birmingham, AL, May 17-21, 1993, 382 p.

Moerman, A., 1982, Internal report on gas storage in Peronnes-Lez-Binche: S.A. Distrigaz, 19 p.

MOE, 1991, Coalbed methane recovery in China: An information report for consultants of UNDP.

Natural Fuels Corporation, 1994, Questions and answers - natural dollars and sense: Natural Fuels Corporation brochure.

Natural Fuels Corporation, 1995, Natural incentives - information from Natural Fuels Corporation: fact sheet.

Oil & Gas Journal, 1992, ICF - Change section 29 tax credits: August 19, 1992, p. 22-24.

Oil & Gas Journal, 1994, China's new oil import status underpins world's most dynamic petroleum scene: May 9, 1994, p. 33.

Petroleum Information, 1994, Coalbed methane production report: Rocky Mountain Coalbed Methane Report, April 1994.

Petroleum Information, 1995, Coalbed methane production report: Rocky Mountain Coalbed Methane Report, April 1995 and May 1995.

Polish Coalbed Methane Clearinghouse, 1994, unpublished data provided to Raven Ridge Resources.

Price-Waterhouse, 1995, Doing business in the People's Republic of China: Price-Waterhouse World Firm Services BV, 193 p.

Qie Bingyin and Lu Shaolin, 1995, Inherent patter and development of coalbed methane in Yangquan mining area *in* International Conference on Coalbed Methane Development and Utilization, Beijing, 1995, Proceedings, Vol. A: Beijing, United Nations, p. 298-305.

Quan Yuke, Wang Li, Hou Hongbin, Su Fuyi, and Cai Yunfei, 1995, Using simulation techniques to evaluate coalbed methane reservoirs of the Yangjiaping Pilot, Liulin area, *in* International Conference on Coalbed Methane Development and Utilization, Beijing, 1995, Proceedings, Vol. A: Beijing, United Nations, p. 106-112.

Rice, D.D., Law, B.E., and Clayton, J. L., 1993, Coalbed gas - an undeveloped resource: p. 389 - 404 *in* The Future of Energy Gases, U.S. Geological Survey Professional Paper 1570, D.D. Howell, ed., 890 p.

Ryan, Megan and Flavin, Christopher, 1995, Facing China's limits: p. 113 - 131 *in* General State of the World, Worldwide Institute Report on Progress Towards a Sustainable Society, W.W. Norton, publisher.

Schraufnagel, Richard A., 1993, Coalbed methane production: p. 341 - 359 *in* Hydrocarbons From Coal, American Association of Petroleum Geologists, Studies in Geology # 38, Law, B.E., and Rice, D.D., eds, 400 p.

Schwoebel, J., Jianliang L., Xingguo Y., Shian Y., and Yongyan W., 1995, Application of innovative gob gas recovery techniques at Tiefa, China, *in* International Conference on Coalbed Methane Development and Utilization, Beijing, 1995, Proceedings, Vol. B: Beijing, United Nations.

Shen and Zhen, 1992, The overview of economy development, present situation and prospects for environmental protection and energy conservation in China: US-China Conference.

Shoemaker, Harold, 1994, Low quality natural gas upgrading: North American Coalbed Methane Forum, Morgantown, WV, October 11, 1994.

Sinor, J.E., 1992, Economic and market potential of the clinoptilolite process for methane purification: Unpublished document prepared for Gas Separation Technology, Lakewood, Colorado.

Sinton, J., ed., 1992, China Energy Databook 1992: Energy Analysis Program/Lawrence Berkeley Labs, LBL-32822.

Sinton, J., ed., 1996, China Energy Databook: Energy Analysis Program/Lawrence Berkeley Labs, LBL-32822 Rev. 3.

Soot, Pete, 1991, Tax incentives spur development of coalbed methane: p. 40 - 42, Oil & Gas Journal, June 10, 1991.

Stevens, S.H., Kuuskraa, J.A., and Schraufnagel, R.A., Technology spurs growth of US coalbed methane: Oil and Gas Journal, v. 94, no. 1, p. 56-62.

Sturgill, C.L., 1991, Power generation - on-site use and sale to utilities: Report prepared for USEPA product, Washington, DC, 26 p.

Sun Maoyuan, 1995, Unpublished data provided to Raven Ridge Resources via fax, July, 1995.

Sun Maoyuan and Huang Shengchu, 1995, Important aspects of coalbed methane development in China: p. 6 - 9 *in* China Coalbed Methane No. 1, May 1995, China Coalbed Methane Clearinghouse, 54 p.

Sun Maoyuan, Huang Shengchu, and Zhu Chao, 1996, Investment opportunities for coalbed methane in China: Report prepared for the North American Coalbed Methane Forum, April 18-19, 1996, 8 p.

Thompson, H.A., 1991, It's 10° outside - do you know where your gas is?, *in* GRID, Gas Research Institute Digest, Fall/Winter 1991-1992: Chicago, The Gas Research Institute, p. 12-23.

USDOE/EIA, 1993, International Energy Outlook, 1993: DOE/EIA 0484, Washington, DC.

USDOE/EIA, 1994, International Energy Annual, 1992: DOE/EIA 0219 (92), Washington, DC., 196 p.

USDOE/EIA, 1995, International Energy Annual, 1993: DOE/EIA 0219(93), Washington, DC, 158 p.

USEPA, 1993, Options for reducing methane emissions internationally, Volume II - International opportunities for reducing methane emissions: EPA 430-R-93-006 B.

USEPA, 1994a, Reducing methane emissions from coal mines in Russia and Ukraine - The potential for coalbed methane development: EPA 430-K-94-003, 68 p.

USEPA, 1994b, Identifying opportunities for methane recovery at US coal mines - Draft profiles of selected gassy underground coal mines: EPA/430/R-94/012.

USEPA, 1995a, Coal mine profits and environmental protection: Coalbed Methane Outreach Program, EPA 430-F-95-029, 12 p.

USEPA, 1995b, Economic assessment of the potential for profitable use of coal mine methane - case studies of three hypothetical U.S. mines: EPA/430-R-95/006, 27 p.

USEPA, 1995c, Reducing methane emissions from coal mines in Poland - A handbook for expanding coalbed methane recovery and utilization in the Upper Silesian coal basin: EPA/430-R-95-003, 122 p.

USEPA, 1995d, Finance opportunities for coal mine methane projects - a guide to Federal Assistance: EPA Expert Review Draft Copy.

Vejtasa, S.A., F.E. Biasca, D.V. Giovanni, and R.C. Carr, 1991, Gas cofiring for coal-fired utility boilers: Draft report prepared for the Electric Power Research Institute, Palo Alto, California and the Gas Research Institute, Chicago.

Wang Hongling, Xu Jiamo, Ye Jianping, and Zhang Wenxian, 1995, Reservoir characteristics of Seam II-1 and its CBM potential in Pingdingshan mining area, *in* International Conference on Coalbed Methane Development and Utilization, Beijing, 1995, Proceedings, Vol. A: Beijing, United Nations, p. 131-138.

Wang Naixen and Li Jianren, 1995, Origin and progress of UNDP project - China coalbed methane resources development: China Coalbed Methane, No. 1, p. 3-5.

Wang Yinwei, Ye Xialing, Ji AnXin, Zhang Zhihui, and Li Fuguo, 1995, The progress and situations of prospective predictions of the demonstration project for developing and utilizing the coalbed gas in Panzhuang Coal Mine, *in* International Conference on Coalbed Methane Development and Utilization, Beijing, 1995, Proceedings, Vol. A: Beijing, United Nations, p. 321-325.

West, Jim, ed., 1994, International Petroleum Encyclopedia: Tulsa, Oklahoma, Pennwell Publishing, 368 p.

Xu Fangde, 1995, Drainage methods of coalbed methane from surface or underground in Fushun Mining Area *in* International Conference on Coalbed Methane Development and Utilization, Beijing, 1995, Proceedings, Vol. A: Beijing, United Nations, p. 326-334.

Yang Zhongzhen, Zhang Bingguan, and Sun Maoyei, 1995, The evaluation of the geological characters and the resources of the coalbed methane in the Huainan coal field, *in* International Conference on Coalbed Methane Development and Utilization, Beijing, 1995, Proceedings, Vol. A: Beijing, United Nations, p. 139-147.

Yunzhan Jia, 1990, A review of methane release related with coal mining in China: *in* IPCC International Workshop on methane emissions, USEPA.

Yunzhan Jia, 1991, Reform has pushed China's coal industry forward, *in* UNDTCD Symposium on Management of Economic and Environmental Aspects in the Coal Mining Industry, Prague, 1991, Proceedings, Vol. 1: Prague, United Nations, p. 63-78.

Zhao Shu, Zuo Wenqi., Zhang Wenhui, and Wang Xingjin, 1995, Sino-Australia coalbed methane exploration project in Huawell's Liulin Contract Area, *in* International Conference on Coalbed Methane Development and Utilization, Beijing, 1995, Proceedings, Vol. A: Beijing, United Nations, p. 170-176.

Zheng Xuetao, 1995, Development prospects of coalbed methane in Pingle coal bearing area, Fengcheng coal mining area, and Qushi No. 1 well test situation, *in* International Conference on Coalbed Methane Development and Utilization, Beijing, 1995, Proceedings, Vol. A: Beijing, United Nations, p. 338-352.

APPENDIX A

LIST OF CONTACTS

APPENDIX A - LIST OF CONTACTS

Sun Maoyuan, Director
China Coalbed Methane Clearinghouse
21 Hepingli Beijie
P.O. Box 1419
Beijing 100713
tel: (86) (10) 420-1328 fax: 421-5187
Internet address: abd310@istic.sti.ac.cn

Wang Zhenyu
Director, Senior Engineer
Fushun Branch of the Central Coal Mining Research Institute
Fushun, Liaoning 113001
tel: (86) (413) 668-8521

Pan Zhenwu
Director General
Xi'an Branch of the Central Coal Mining Research Institute
44 Yanta Road (N) 710054
Xi'an, Shaanxi
tel: (86) (29) 723-4674

Meng Xiande
Project Coordinator
Office of International Cooperation
Central Coal Mining Research Institute
Qingniangoulu, Hepingli
Beijing 100013
tel: (86) (10) 421-2752
fax: 421-9234

Karl Schultz, Coalbed Methane Program Manager
USEPA Atmospheric Pollution Prevention Division
401 M Street, SW
Washington, DC 20460
tel: (202) 233-9468 fax: 233-9569
Internet address: schultz.karl@epamail.epa.gov

Voluntary Reporting of Greenhouse Gases
U.S. Department of Energy
Energy Information Administration, EI-81
1000 Independence Avenue, SW
Washington, DC 20585

Ministry of Foreign Trade and Economic Cooperation
2 Dongchangan Street
Beijing 100731
tel: (86) (10) 519-8114
telecopier: (86) (10) 512-9568
telex: 22478 MFERT CN

Carol Bibler
Manager of International Projects
Raven Ridge Resources, Incorporated
584 25 Road
Grand Junction, Colorado, USA
tel: (970) 245-4088 fax: (970) 245-2514
Internet address: tbc@ravenridge.com

APPENDIX B

EXPLANATION OF CHINESE RESOURCE AND COAL RANK CLASSIFICATION SYSTEMS

Appendix B Includes the Following Figure and Tables:

APPENDIX B

EXPLANATION OF CHINESE COAL RANK, COAL RESOURCE, AND COALBED METHANE RESOURCE CLASSIFICATION SYSTEMS

Coal Rank Classification System

China's coal rank classification system divides coal types into eleven categories, ranging from anthracite to peat. Figure B-1 shows these categories, along with their approximate equivalents in the German and US classification systems.

Coal Reserve Classification System

Based on the energy resource classification method recommended by the World Energy Conference, the Chinese energy resources classification system consists of: solid fuels; liquid fuels; gaseous fuels; hydropower; nuclear energy; electrical energy; solar energy; biomass energy; wind energy; ocean energy; geothermal; and nuclear fusion. In addition, energy resources can be divided into several categories: primary vs. secondary energy; renewable vs. non-renewable energy; conventional vs. alternative energy; and commercial vs. non-commercial energy

The Chinese coal reserves classification system is based on three exploratory stages: coal prospecting; preliminary exploration; and detailed exploration. Reserves are divided into Grades A, B, C and D. Of these, Grades A and B are the best defined and highest-confidence level of reserves. The following table is an approximate correlation between the Chinese and US coal reserve classification systems.

China	United States
Grade A Reserves	Measured Reserves
Grade B Reserves	Indicated Reserves
Grade C Reserves	Inferred Reserves
Grade D Reserves	Hypothetical Resources

The terms commonly used to describe China's coal reserves are as follows:

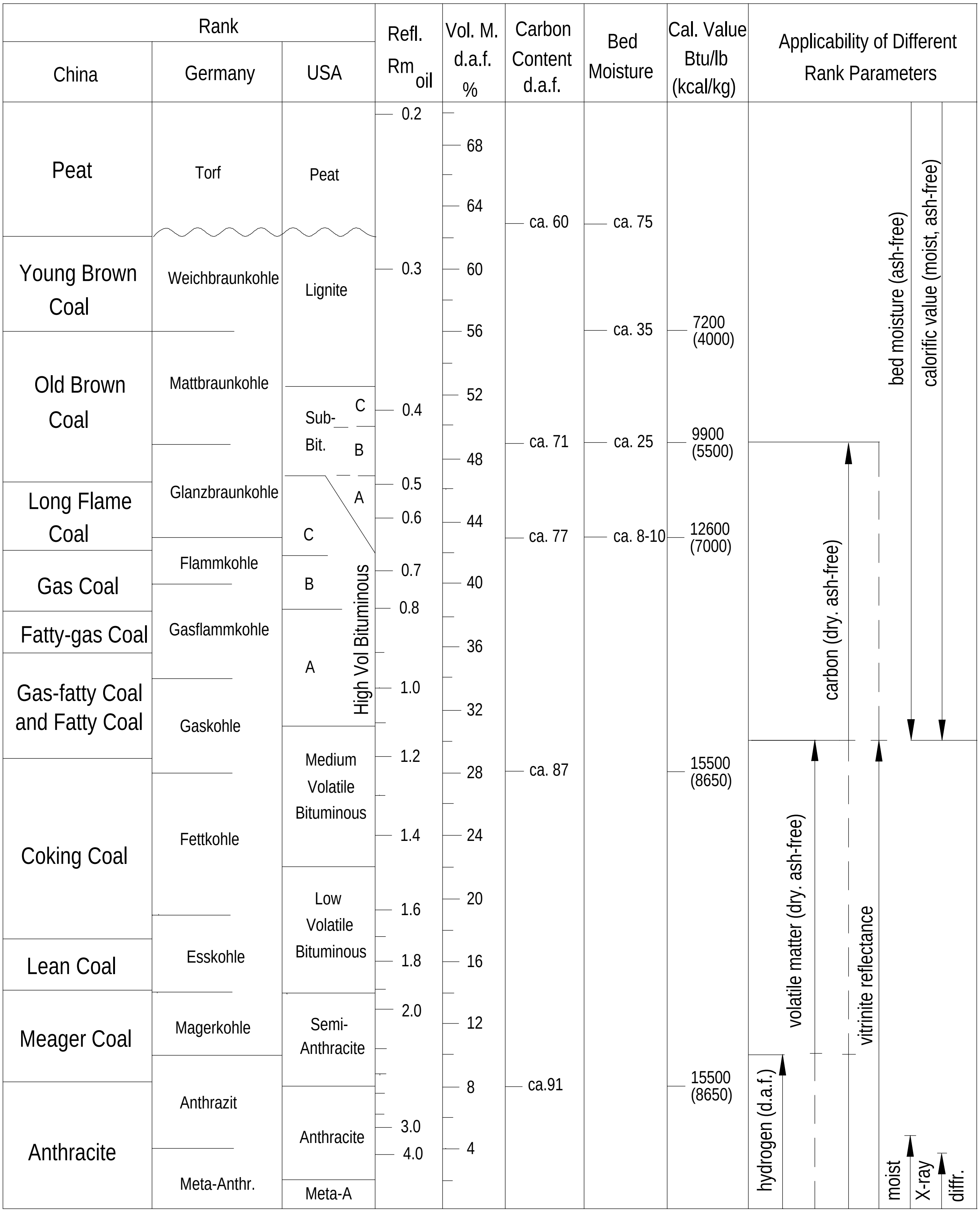
Industrial reserves: The sum of Grade A, B, and C reserves; used as a reference for mine design.

Proven reserves: Total of Grade A and B reserves.

Available reserves: Equal to demonstrated reserves, minus mined reserves.

Future reserves: Grade D reserves; obtained from coal exploration and used as reference to future planning of coal industry.

Figure B-1 Correlation of Chinese, German, and US Coal Classification Systems



05139003

Coalbed Methane Resource Classification System

Total coalbed methane resources include the recoverable volume of methane from coal seams and adjacent rocks. Currently, coalbed methane resource estimates for China refer only to mineable coal seams, excluding adjacent strata and unmined seams. Key factors that affect these resources are:

- Coal occurrence, geometry, and thickness;
- Geologic conditions, including depth of burial, tectonic history, coal rank, and permeability;
- Gas content and in-mine degasification; and
- Economic and geographic factors.

Specific exploration and development programs for coalbed methane are relatively new in China. Currently, the classification of these resources is related directly to the existing coal reserve classification system, as coal seams are both the source rocks and the reservoirs for coalbed methane. Thus coalbed methane resources are currently divided into three categories, shown in Table B-1 with their equivalent coal reserve classification system:

TABLE B-1. RELATION BETWEEN COALBED METHANE AND COAL RESOURCE CLASSIFICATION SYSTEMS IN CHINA

CATEGORY	I	II	III
COALBED METHANE	Proven	Indicated	Prospective
COAL	Industrial (A+B+C)	Demonstrated (A+B+C+D)	Future/Hypothetical (D Reserves)

In general, the absolute maximum depth of burial used to calculate prospective coalbed methane resources in China is 2,000 m. However, resource estimates may sometimes assume a maximum burial depth of 1,000 or 1,500 m, depending on the location, age, and geologic setting of the specific coal-bearing region. Generally, a depth of 2,000 m is used for north China, and 1,500 m is used for south China. An exception is Liapanshui Basin in south China, where 2,000 m is used as the maximum depth. The current reserve calculation method defines reserve blocks based on the reserve category (I, II, or III), depth of burial, age of the coal deposit, and the specific coal-bearing region. The coalbed methane reserves for a given block are calculated using the Monte Carlo method[1] for sample selection, then calculated volumetrically as follows:

Coal reserves (tons) x Methane content of coal (m^3/ton)

Total coalbed methane reserves are the sum of the reserves in each block. For a given block, coal reserves are a constant, whereas gas content is a random variable. To determine the gas content of coal seams in reserve blocks at depths above 1,000 m, data are measured using the direct method, primarily from core sample desorption. Where measured gas content data are lacking, gas contents are extrapolated using adjacent blocks or coal-bearing regions, as is done for coal reserves.

---

[1] The Monte Carlo method is a random sampling process for generating uniformly distributed pseudorandom numbers and using these to "draw" random samples from known frequency distributions.

For estimating the gas content of seams in reserve blocks below 1,000 m, predicted values based on coal rank are used, as shown in Table B-2. Both measured and predicted gas contents are calculated on an ash and moisture free basis.

TABLE B-2. PREDICTED GAS CONTENTS FOR COAL SEAMS AT DEPTHS >1,000 M:

COAL RANK (Chinese)	COAL RANK (US Equivalent)	R^o max (Percent)	GAS CONTENT (m^3/ton)	REMARKS
Long Flame	High Volatile Bituminous C	0.50 - 0.65	5 - 6	Inferred by analogy with Huainan CMA
Gas Coal	High Volatile Bituminous B	0.65 - 0.90	7 - 8	Inferred by analogy with Jixi CMA
Fatty Coal	High Volatile Bituminous A	0.90 - 1.20	14.2	Calculated
Coking Coal	Medium Volatile Bituminous	1.20 - 1.70	14.89	Calculated
Lean Coal	Low Volatile Bituminous	1.70 - 1.90	17.35	Calculated
Meager Coal	Semi-Anthracite	1.90 - 2.50	19.82	Calculated
Anthracite 3	Anthracite	2.50 - 4.00	26.19	Calculated
Anthracite 2	Anthracite	4.00 - 6.00	25 - 30	Calculated
Anthracite 1	Meta-anthracite	>6.00	2 - 3	Inferred by analogy with coals in Fujian & Jiangxi Provinces

APPENDIX C

METHANE EMISSIONS DATA

Appendix C Includes the Following Tables:

TABLE C-1. 1992 METHANE EMISSIONS FROM CHINA'S KEY STATE-RUN COAL MINES, BY PROVINCE

	Number of Mines		Methane	Methane	Methane	Drained &	Drained &	Total	Coal	Absolute	Relative
	Total	With	Vented	Drained	Total	Utilized	Vented	Emitted	Output	Emission	Emission
		Drainage	m^3	m^3	m^3	m^3	m^3	m^3	t	m^3/min	m^3/t
Xijiang Uygur Autonomous Region											
Low Methane Mines	10		12,636,000		12,636,000			12,636,000	2,914,200	24.04	4.34
High Methane and Outburst Mines											
Open-Pits	1		4,293,360		4,293,360			4,293,360	1,206,000	8.17	3.56
Totals	11		16,929,360		16,929,360			16,929,360	4,120,200	32.21	4.11
Ningxia Hui Autonomous Region											
Low Methane Mines	5		9,236,000		9,236,000			9,236,000	2,896,800	17.57	3.19
High Methane and Outburst Mines	6	3	65,663,700	8,020,000	73,683,700	3,400,000	4,620,000	70,283,700	6,331,700	140.19	11.64
Open-Pits	1		1,854,760		1,854,760			1,854,760	521,000	3.53	3.56
Totals	12	3	76,754,460	8,020,000	84,774,460	3,400,000	4,620,000	81,374,460	9,749,500	161.29	8.70
Gansu Province											
Low Methane Mines	18		17,142,200		17,142,200			17,142,200	5,584,900	32.61	3.07
High Methane and Outburst Mines	5		23,537,000		23,537,000			23,537,000	627,000	44.78	37.54
Open-Pits											
Totals	23		40,679,200		40,679,200			40,679,200	6,211,900	77.39	6.55
Shaanxi Province											
Low Methane Mines	19		28,163,900		28,163,900			28,163,900	7,507,800	53.58	3.75
High Methane and Outburst Mines	9	1	118,516,500	3,500,000	122,016,500		3,500,000	122,016,500	6,548,300	232.15	18.63
Open-Pits	1		1,152,730		1,152,730			1,152,730	323,800	2.19	3.56
Totals	29	1	147,833,130	3,500,000	151,333,130		3,500,000	151,333,130	14,379,900	287.92	10.52
Yunan Province											
Low Methane Mines	5		3,264,200		3,264,200			3,264,200	783,000	6.21	4.17
High Methane and Outburst Mines	5		20,189,600		20,189,600			20,189,600	1,823,500	38.41	11.07
Open-Pits											
Totals	10		23,453,800		23,453,800			23,453,800	2,606,500	44.62	9.00
Guizhou Province											
Low Methane Mines	4		9,402,100		9,402,100			9,402,100	1,224,500	17.89	7.68
High Methane and Outburst Mines	20	15	348,522,000	40,620,000	389,142,000	8,080,000	32,540,000	381,062,000	10,437,700	740.38	37.28
Open-Pits											
Totals	24	15	357,924,100	40,620,000	398,544,100	8,080,000	32,540,000	390,464,100	11,662,200	758.27	34.17
Sichuan Province											
Low Methane Mines	10		19,202,400		19,202,400			19,202,400	5,087,300	36.53	3.77
High Methane and Outburst Mines	44	26	490,301,900	154,140,000	644,441,900	90,940,000	63,200,000	553,501,900	13,102,000	1,226.11	49.19
Open-Pits											
Totals	54	26	509,504,300	154,140,000	663,644,300	90,940,000	63,200,000	572,704,300	18,189,300	1,262.64	36.49

TABLE C-1. 1992 METHANE EMISSIONS FROM CHINA'S KEY STATE-RUN COAL MINES, BY PROVINCE

Hunan Province											
Low Methane Mines	18		14,346,000		14,346,000			14,346,000	3,099,400	27.29	4.63
High Methane and Outburst Mines	34	3	103,030,400	1,830,000	104,860,400	1,050,000	780,000	103,810,400	3,864,300	199.51	27.14
Open-Pits											
Totals	52	3	117,376,400	1,830,000	119,206,400	1,050,000	780,000	118,156,400	6,963,700	226.80	17.12
Henan Province											
Low Methane Mines	16		68,050,300		68,050,300			68,050,300	19,415,900	129.47	3.50
High Methane and Outburst Mines	28	14	282,607,400	19,510,000	302,117,400	10,610,000	8,900,000	291,507,400	19,701,400	574.80	15.33
Open-Pits	1		3,327,890		3,327,890			33,278,900	934,800	6.33	3.56
	45	14	353,985,590	19,510,000	373,495,590	10,610,000	8,900,000	392,836,600	40,052,100	710.60	9.33
Totals											
Shandong Province											
Low Methane Mines	49		74,563,400		74,563,400			74,563,400	31,927,700	141.86	2.34
High Methane and Outburst Mines	3		28,104,500		28,104,500			28,104,500	1,869,100	53.47	15.04
Open-Pits											
Totals	52		102,667,900		102,667,900			102,667,900	33,796,800	195.33	3.04
Jiangxi Province											
Low Methane Mines	8		11,423,800		11,423,800			11,423,800	3,174,900	21.73	3.60
High Methane and Outburst Mines	15	6	114,215,700	9,260,000	123,475,700	5,060,000	4,200,000	118,415,700	4,190,500	234.92	29.47
Open-Pits											
Totals	23	6	125,639,500	9,260,000	134,899,500	5,060,000	4,200,000	129,839,500	7,365,400	256.65	18.32
Anhui Province											
Low Methane Mines	7		43,059,100		43,059,100			43,059,100	6,684,400	81.92	6.44
High Methane and Outburst Mines	17	5	239,164,300	9,510,000	248,674,300	6,100,000	3,410,000	242,574,300	18,241,300	473.12	13.63
Open-Pits											
Totals	24	5	282,223,400	9,510,000	291,733,400	6,100,000	3,410,000	285,633,400	24,925,700	555.04	11.70
Zhejiang Province											
Low Methane Mines											
High Methane and Outburst Mines	11		31,125,100		31,125,100			31,125,100	1,032,800	59.22	30.14
Open-Pits											
Totals	11		31,125,100		31,125,100			31,125,100	1,032,800	59.22	30.14
Jiangsu Province											
Low Methane Mines	20		58,361,500		58,361,500			58,361,500	15,182,700	111.04	3.84
High Methane and Outburst Mines	2		13,765,100		13,765,100			13,765,100	1,200,100	26.19	11.47
Open-Pits											
Totals	22		72,126,600		72,126,600			72,126,600	16,382,800	137.23	4.40

TABLE C-1. 1992 METHANE EMISSIONS FROM CHINA'S KEY STATE-RUN COAL MINES, BY PROVINCE

Heilongjiang Province											
Low Methane Mines	28		107,696,000		107,696,000			107,696,000	26,951,900	204.90	4.00
High Methane and Outburst Mines	32	4	373,780,800	16,340,000	390,120,800	0	16,340,000	390,120,800	21,893,400	742.24	17.82
Open-Pits	1		3,821,300		3,821,300			3,821,300	1,073,400	7.27	3.56
Totals	61	4	485,298,100	16,340,000	501,638,100	0	16,340,000	501,638,100	49,918,700	954.41	10.05
Jilin Province											
Low Methane Mines	27		20,704,100		20,704,100			20,704,100	5,672,800	39.39	3.65
High Methane and Outburst Mines	18	1	100,819,400	330,000	101,149,400	0	330,000	101,149,400	6,529,300	192.45	15.49
Open-Pits											
Totals	45	1	121,523,500	330,000	121,853,500	0	330,000	121,853,500	12,202,100	231.84	9.99
Liaoning Province											
Low Methane Mines	11		13,855,200		13,855,200			13,855,200	2,460,200	26.36	5.63
High Methane and Outburst Mines	35	12	416,812,900	132,850,000	549,662,900	114,880,000	17,970,000	434,782,900	27,404,800	1,045.78	20.06
Open-Pits	3		34,354,710		34,354,710			34,354,710	9,650,200	65.36	3.56
Totals	49	12	465,022,810	132,850,000	597,872,810	114,880,000	17,970,000	482,992,810	39,515,200	1,137.50	15.13
Nei Mongol Autonomous Region											
Low Methane Mines	29		68,150,100		68,150,100			68,150,100	18,239,500	129.66	3.74
High Methane and Outburst Mines	3	2	21,068,200	1,400,000	26,439,000	0	1,400,000	26,439,000	917,100	50.30	28.83
Open-Pits	5		26,168,490		26,168,490			26,168,490	7,350,700	49.79	3.56
Totals	37	2	115,386,790	1,400,000	120,757,590	0	1,400,000	120,757,590	26,507,300	229.75	4.56
Shanxi Province											
Low Methane Mines	44		245,560,900		245,560,900			245,560,900	66,693,600	467.20	3.68
High Methane and Outburst Mines	28	13	692,284,200	114,530,000	806,814,200	95,620,000	18,910,000	711,194,200	36,230,100	1,535.03	22.27
Open-Pits	1		37,455,470		37,455,470			37,455,470	10,521,200	71.26	3.56
Totals	73	13	975,300,570	114,530,000	1,089,830,570	95,620,000	18,910,000	994,210,570	113,444,900	2,073.49	9.61
Hebei Province											
Low Methane Mines	39		87,432,800		87,432,800			87,432,800	30,728,700	166.35	2.85
High Methane and Outburst Mines	19	7	210,480,500	20,660,000	231,140,500	10,390,000	10,270,000	220,750,500	12,781,200	439.77	18.08
Open-Pits											
Totals	58	7	297,913,300	20,660,000	318,573,300	10,390,000	10,270,000	308,183,300	43,509,900	606.12	7.32

TABLE C-2. 1994 METHANE EMISSIONS FROM CHINA'S KEY STATE-RUN COAL MINES, BY PROVINCE

	Number of Mines		Methane	Methane	Methane	Drained &	Drained &	Total	Coal	Absolute	Relative
	Total	With	Vented	Drained	Total	Utilized	Vented	Emitted	Output	Emission	Emission
		Drainage	m^3	m^3	m^3	m^3	m^3	m^3	t	m^3/min	m^3/t
Xijiang Uygur Autonomous Region											
Low Methane Mines	10		4,994,400		4,994,400			4,994,400	2,369,100	9.50	2.11
High Methane and Outburst Mines											
Open-Pits	1		2,671,890		2,671,890			2,671,890	1,266,300	5.08	2.11
Totals	11		7,666,290		7,666,290			7,666,290	3,635,400	14.59	2.11
Ningxia Hui Autonomous Region											
Low Methane Mines	3		16,240,900		16,240,900			16,240,900	2,836,500	30.90	5.73
High Methane and Outburst Mines	6	4	79,468,100	13,083,000	92,551,100	5,629,000	7,454,000	86,922,100	6,301,300	176.09	14.69
Open-Pits	1		1,893,770		1,893,770			1,893,770	330,500	3.60	5.73
Totals	10	4	97,602,770	13,083,000	110,685,770	5,629,000	7,454,000	105,056,770	9,468,300	210.59	11.69
Gansu Province											
Low Methane Mines	15		16,618,500		16,618,500			16,618,500	5,342,600	31.62	3.11
High Methane and Outburst Mines	4	2	30,131,200	3,048,600	33,179,800		3,048,600	33,179,800	892,600	63.13	37.17
Open-Pits											
Totals	19	2	46,749,700	3,048,600	49,798,300		3,048,600	49,798,300	6,235,200	94.75	7.99
Shaanxi Province											
Low Methane Mines	19		19,173,500		19,173,500			19,173,500	6,252,300	36.48	3.07
High Methane and Outburst Mines	10	2	156,557,700	4,722,000	161,279,700		4,722,000	161,279,700	6,243,600	306.85	25.83
Open-Pits	1		967,050		967,050			967,050	315,000	1.84	3.07
Totals	30	2	176,698,250	4,722,000	181,420,250		4,722,000	181,420,250	12,810,900	345.17	14.16
Yunan Province											
Low Methane Mines	5		4,075,710		4,075,710			4,075,710	785,300	7.75	5.19
High Methane and Outburst Mines	5		35,282,330		35,282,330			35,282,330	1,795,700	67.13	19.65
Open-Pits											
Totals	10		39,358,040		39,358,040			39,358,040	2,581,000	74.88	15.25
Guizhou Province											
Low Methane Mines	4		5,242,000		5,242,000			5,242,000	689,600	9.97	7.60
High Methane and Outburst Mines	19	15	368,068,300	48,496,100	416,564,400	13,907,600	34,588,500	402,656,800	11,223,400	792.55	37.12
Open-Pits											
Totals	23	15	373,310,300	48,496,100	421,806,400	13,907,600	34,588,500	407,898,800	11,913,000	802.52	35.41
Sichuan Province											
Low Methane Mines	11		15,034,200		15,034,200			15,034,200	3,983,700	28.60	3.77
High Methane and Outburst Mines	43	25	465,686,600	152,959,600	618,646,200	101,774,300	51,185,300	516,871,900	12,808,300	1,177.03	48.30
Open-Pits											
Totals	54	25	480,720,800	152,959,600	633,680,400	101,774,300	51,185,300	531,906,100	16,792,000	1,205.63	37.74

TABLE C-2. 1994 METHANE EMISSIONS FROM CHINA'S KEY STATE-RUN COAL MINES, BY PROVINCE

Hunan Province											
Low Methane Mines	19		9,763,100		9,763,100			9,763,100	2,969,400	18.58	3.29
High Methane and Outburst Mines	31	3	100,771,600	2,425,200	103,196,800	1,938,200	487,000	101,258,600	3,338,100	196.34	30.91
Open-Pits											
Totals	50	3	110,534,700	2,425,200	112,959,900	1,938,200	487,000	111,021,700	6,307,500	214.92	17.91
Henan Province											
Low Methane Mines	17		95,671,700		95,671,700			95,671,700	19,550,500	182.02	4.89
High Methane and Outburst Mines	29	18	291,101,800	23,532,500	314,634,300	13,786,600	9,745,900	300,847,700	19,405,400	598.62	16.21
Open-Pits	1		4,159,430		4,159,430			4,159,430	850,600	7.91	4.89
Totals	47	18	390,932,930	23,532,500	414,465,430	13,786,600	9,745,900	400,678,830	39,806,500	788.55	10.41
Shandong Province											
Low Methane Mines	54		100,557,100		100,557,100			100,557,100	37,877,000	191.32	2.65
High Methane and Outburst Mines	3		32,585,400		32,585,400			32,585,400	1,816,600	62.00	17.94
Open-Pits											
Totals	57		133,142,500		133,142,500			133,142,500	39,693,600	253.32	3.35
Jiangxi Province											
Low Methane Mines	8		10,307,100		10,307,100			10,307,100	3,050,600	19.61	3.38
High Methane and Outburst Mines	15	8	100,033,300	11,514,500	111,547,800	8,000,000	3,514,500	103,547,800	3,811,400	212.23	29.27
Open-Pits											
Totals	23	8	110,340,400	11,514,500	121,854,900	8,000,000	3,514,500	113,854,900	6,862,000	231.84	17.76
Anhui Province											
Low Methane Mines	7		30,603,500		30,603,500			30,603,500	4,824,700	58.23	6.34
High Methane and Outburst Mines	17	5	293,657,100	9,820,700	303,477,800	7,418,300	2,402,400	296,059,500	22,377,400	577.39	13.56
Open-Pits											
Totals	24	5	324,260,600	9,820,700	334,081,300	7,418,300	2,402,400	326,663,000	27,202,100	635.62	12.28
Zhejiang Province											
Low Methane Mines											
High Methane and Outburst Mines	11		28,013,700		28,013,700			28,013,700	906,700	53.30	30.90
Open-Pits											
Totals	11		28,013,700		28,013,700			28,013,700	906,700	53.30	30.90
Jiangsu Province											
Low Methane Mines	20		51,637,400		51,637,400			51,637,400	15,744,100	98.24	3.28
High Methane and Outburst Mines	2		12,095,700		12,095,700			12,095,700	1,096,400	23.01	11.03
Open-Pits											
Totals	22		63,733,100		63,733,100			63,733,100	16,840,500	121.25	3.78

TABLE C-2. 1994 METHANE EMISSIONS FROM CHINA'S KEY STATE-RUN COAL MINES, BY PROVINCE

Heilongjiang Province											
Low Methane Mines	24		39,904,100		39,904,100			39,904,100	23,543,400	75.92	1.69
High Methane and Outburst Mines	32	4	436,600,600	13,467,300	450,067,900		13,467,300	450,067,900	15,242,100	856.29	29.53
Open-Pits	1		1,248,740		1,248,740			1,248,740	738,900	2.38	1.69
Totals	57	4	477,753,440	13,467,300	491,220,740		13,467,300	491,220,740	39,524,400	934.59	12.43
Jilin Province											
Low Methane Mines	24		13,833,600		13,833,600			13,833,600	4,645,400	26.32	2.98
High Methane and Outburst Mines	18	1	111,365,400	1,556,000	112,921,400		1,556,000	112,921,400	5,903,600	214.84	19.13
Open-Pits											
Totals	42	1	125,199,000	1,556,000	126,755,000		1,556,000	126,755,000	10,549,000	241.16	12.02
Liaoning Province											
Low Methane Mines	10		17,316,200		17,316,200			17,316,200	3,512,800	32.95	4.93
High Methane and Outburst Mines	30	15	393,823,400	142,171,000	535,994,400	126,716,200	15,454,800	409,278,200	23,791,300	1,019.78	22.53
Open-Pits	3		37,950,150		37,950,150			37,950,150	7,697,800	72.20	4.93
Totals	43	15	449,089,750	142,171,000	591,260,750	126,716,200	15,454,800	464,544,550	35,001,900	1,124.93	16.89
Nei Mongol Autonomous Region											
Low Methane Mines	26		30,137,890		30,137,890			30,137,890	13,429,600	57.34	2.24
High Methane and Outburst Mines	4	?	71,034,500		71,034,500	0		71,034,500	3,654,300	135.15	19.44
Open-Pits	5		18,883,200		18,883,200			18,883,200	8,430,000	35.93	2.24
Totals	35	0	120,055,590	0	120,055,590	0	0	120,055,590	25,513,900	228.42	4.71
Shanxi Province											
Low Methane Mines	39		244,526,800		244,526,800			244,526,800	66,943,200	465.23	3.65
High Methane and Outburst Mines	24	20	680,270,700	115,237,200	795,507,900	101,854,400	13,382,800	693,653,500	37,474,000	1,513.52	21.23
Open-Pits	1		38,328,650		38,328,650			38,328,650	10,501,000	72.92	3.65
Totals	64	20	963,126,150	115,237,200	1,078,363,350	101,854,400	13,382,800	976,508,950	114,918,200	2,051.67	9.38
Hebei Province											
Low Methane Mines	36		72,981,000		72,981,000			72,981,000	29,741,300	138.85	2.45
High Methane and Outburst Mines	15	9	176,982,000	19,250,500	196,232,500	14,171,700	5,078,800	182,060,800	12,368,000	373.35	15.87
Open-Pits											
Totals	51	9	249,963,000	19,250,500	269,213,500	14,171,700	5,078,800	255,041,800	42,109,300	512.20	6.39
TOTAL - 20 PROVINCES			4768251010	561284200	5329535210	395196300	166087900	4934338910	468671400	10140	
TOTAL HIGH GAS MINES	318										
TOTAL RECOVERY SYSTEMS		131									

TABLE C-3. 1993 SPECIFIC EMISSIONS OF LOCAL MINING AREAS THAT ARE CONSIDERED BY MOCI TO BE HIGH-GAS

REGION	LOCAL MINING AREA	PROVINCE	AVERAGE SPECIFIC EMISSIONS (m3/ton)
NORTH			
	Lingshan	Hebei	23.81
SOUTH			
	Tongxin	Guizhou	50.20
	Lewei	Sichuan	27.72
	Yarong	Sichuan	28.06
	Longmenshan	Sichuan	23.46
	Shangrao	Fujian	14.00
	Gannon	Jiangxi	19.86
	Wutong	Anhui	14.95
	Xuanjing	Anhui	51.73
	Ningzhen	Jiangsu	12.81
	Yilil	Jiangsu	16.63
	Puxi	Hubei	15.71
MOCI does not consider the coal mines in these LMA's to be key state-run mines, and therefore emissions from these mines are not included in Tables C-1 and C-2			

TABLE C-4. HIGH GAS CMAs IN CHINA AND THEIR AVERAGE SPECIFIC EMISSIONS

REGION	PROVINCE	COAL BASIN	CMA	# MINES	# MINES	1993 COAL	SPECIFIC EMISISONS (m3/ton)		1994 TOTAL METHANE (10^3m^3):	
				(94FUSHUN)	(1991 JP)	PRODUCTION (Tons)	AVERAGE	SOURCE	LIBERATED	DRAINED
Northeast	Heilongjiang	Sanjiang-Mulinghe	Jixi		15	11,644,200	29.84	JP		
Northeast	Heilongjiang	Sanjiang-Mulinghe	Shuangyanshan		9	10,015,500	15.77	JP		
Northeast	Heilongjiang	Sanjiang-Mulinghe	Qitaihe		6	10,060,100	19.18	JP		
Northeast	Heilongjiang	Sanjiang-Mulinghe	Hegang		2	13,130,700	16.17	JP		
PROVINCE	**TOTAL**			**32**	**32**	**72,270,000**	**29.53**		**450,070**	**13,470**
Northeast	Jilin	Jiaohe-Liaoyuan	Liaoyuan		10	3,979,000	16.36	JP		
Northeast	Jilin	Yilin-Yitong	Shulun		5	3,803,800	22.63	JP		
Northeast	Jilin	Yanbian	Huichun		3	1,610,100	15.52	JP		
Northeast	Jilin	Hongyang-Hunjiang	Tonghua		10	3,809,300	18.25	JP, CII		
PROVINCE	**TOTAL**			**18**	**28**	**24,240,000**	**19.13**		**112,920**	**1,560**
Northeast	Liaoning	Nanpiao	Nanpiao		1	1,954,200	12.29	JP		
Northeast	Liaoning	Hongyang-Hunjiang	Yantai		2	NA	22.35	JP		
Northeast	Liaoning	Fuxin	Fuxin		13	12,698,700	29.08	JP		
Northeast	Liaoning	Donhua-Fushun	Shenyang		8	4,410,500	26.18	JP		
Northeast	Liaoning	Donhua-Fushun	Fushun		3	8,579,400	31.58	JP		
Northeast	Liaoning	Songliao	Tiefa		5	1,024,100	12.73	JP		
Northeast	Liaoning	Nanpiao	Beipiao		4	2,177,600	24.57	JP, CII		
PROVINCE	**TOTAL**			**30**	**35**	**52,590,000**	**22.53**		**535,990**	**142,170**
North	Hebei	Taixing-Shandou	Fengfeng		5	10,370,000	21.28	JP		
North	Hebei	Chengde	Xinglong		4	1,050,000	14.65	JP, CII		
North	Hebei	Jingtang	Kailuan		1	17,604,800	12.00	CII		
							15.82	JP		
North	Hebei	Jingtang	Babaoshan		2	290,000	21.77	CII		
North	Hebei	Xuanwei	Xiahuayuan		3	630,000	28.00	JP		
PROVINCE	**TOTAL**			**15**	**15**	**63,400,000**	**15.87**		**196,230**	**19,250**
North	Shandong	Guangfang	Zibo		2	5,061,700	14.66	JP		
PROVINCE	**TOTAL**			**3**	**2**	**68,030,000**	**17.94**		**32,590**	**0**
North	Jiangsu	Lunan	Yangchang		2	609,400	13.97	JP		
North	Jiangsu	Xuhuai	Xuzhou		2	13,103,000	13.16	JP		
PROVINCE	**TOTAL**			**2**	**4**	**25,060,000**	**11.03**		**12,100**	**0**
North	Anhui	Huainan	Huainan		7	11,498,500	12.00	CII		
							18.41	JP		
North	Anhui	Xuhuai	Huiabei		6	14,232,100	12.00	CII		
							11.45	JP		
PROVINCE	**TOTAL**			**17**	**13**	**36,130,000**	**13.56**		**303,480**	**9,820**
North	Henan	Qinshui	Jiaozuo		8	3,799,600	19.97	JP		
North	Henan	Taixing-Shandou	Hebi		7	4,671,500	15.73	JP		
North	Henan	Yuxi	Pingdingshan		4	17,147,800	NA			
North	Henan	Yuxi	Yima		3	8,609,600	10.84	JP		
North	Henan	Yuxi	Xinmi		2	NA	8.79	JP		
PROVINCE	**TOTAL**			**29**	**24**	**92,790,000**	**16.21**		**314,630**	**23,530**

TABLE C-4. HIGH GAS CMAs IN CHINA AND THEIR AVERAGE SPECIFIC EMISSIONS

North	Shanxi	Qinshui	Yangquan		9	10,476,900	25.95	JP, CII		
North	Shanxi	Daning	Datong		4	31,754,600	21.42	JP		
North	Shanxi	Daning	Xuangang		3	2,062,100	11.81	JP		
North	Shanxi	Qinshui	Xishan		2	14,127,700	12.35	JP		
North	Shanxi	Qinshui	Yinying Mine			1,203,000	NA			
North	Shanxi	Qinshui	Jincheng		1	10,320,600	19.00	CII		
PROVINCE	**TOTAL**			**24**	**19**	**306,560,000**	**21.23**		**795,510**	**115,240**
North	Shaanxi	Ordos	Tongchuan		3	4,721,600	17.08	JP		
North	Shaanxi	Jinshaan	Hancheng		3	3,462,800	16.48	CII, JP		
North	Shaanxi	Ordos	Cuijiagou		2	863,100	10.32	JP		
PROVINCE	**TOTAL**			**10**	**8**	**33,630,000**	**25.83**		**161,280**	**4,720**
North	Inner Mongolia	Daqingshan	Baotou		6	1,904,500	45.50	JP, CII		
PROVINCE	**TOTAL**			**4**	**6**	**55,140,000**	**19.44**		**71,030**	**0**
North	Ningxia	Zhuohe	Shitanjing		3	6,005,800	12.48	CII, JP		
North	Ningxia	Zhuohe	Shizuishan		1	2,560,800	14.27	JP		
PROVINCE	**TOTAL**			**6**	**4**	**13,720,000**	**14.69**		**92,550**	**13,080**
South	Zheijiang	Suzhe-Wanbian	Changguang		9	1,027,600	27.64	JP		
PROVINCE	**TOTAL**			**11**	**9**	**1,380,000**	**30.90**		**28,010**	**0**
South	Jiangxi	Pingdong	Fencheng		5	2,000,300	28.55	JP, CII		
South	Jiangxi	Pingdong	Yinggangling		5	505,300	37.86	JP		
South	Jiangxi	Jiyou	Pingxiang		3	2,741,400	30.62	JP		
South	Jiangxi	Pingdong	Leping		?	1,082,900	18.86			
PROVINCE	**TOTAL**			**15**	**13**	**21,040,000**	**29.27**		**111,550**	**11,510**
South	Hunan	Lianshao	Lianshao		7	2,360,100	37.88	JP, CII		
South	Hunan	Chenzi	Baisha		4	1,676,800	23.20	JP, CII		
South	Hunan	Chenzi	Zixing		3	2,142,400	22.04	JP		
PROVINCE	**TOTAL**			**31**	**14**	**40,750,000**	**30.91**		**103,200**	**2,430**
South	Sichuan	Chuannon-Qianbei	Furong		7	2,394,700	26.72	JP		
South	Sichuan	Chuannon-Qianbei	Nantong		7	2,208,600	36.83	JP		
South	Sichuan	Chuannon-Qianbei	Songzao		5	2,696,400	47.99	JP		
South	Sichuan	Chuannon-Qianbei	Zhonglianshan		2	613,800	58.38	JP		
South	Sichuan	Huayingshan-Yongrong	Yongrong		7	1,501,800	37.65	JP		
South	Sichuan	Huayingshan-Yongrong	Tianfu		5	1,345,900	50.40	JP		
South	Sichuan	Huayingshan-Yongrong	Huayingshan		?	669,800	26.07	CII		
South	Sichuan	Dukou-Chuxiong	Dukou *		1	NA	10.78	JP		
South	Sichuan	Guangwang	Guangwang		1	1,667,200	17.04	JP		
PROVINCE	**TOTAL**			**43**	**35**	**79,350,000**	**48.30**		**618,650**	**152,960**
South	Guizhou	Liupanshui	Liuzhi		7	1,454,100	51.31	JP		
South	Guizhou	Liupanshui	Shuicheng		7	4,122,200	33.74	JP		
South	Guizhou	Liupanshui	Panjiang		5	5,014,000	20.42	JP		
PROVINCE	**TOTAL**			**19**	**19**	**45,290,000**	**37.12**		**416,560**	**48,500**

TABLE C-4. HIGH GAS CMAs IN CHINA AND THEIR AVERAGE SPECIFIC EMISSIONS

South	Yunnan				?					
PROVINCE	**TOTAL**			**5**		**24,020,000**	**19.65**		**35,280**	**0**
South	Guangxi	Nanning	Nanning		?	226,200	19.69	CII		
South	Guangxi	Guizhong	Hongmao		?	810,100	24.48	CII		
PROVINCE	**TOTAL**			**NA**		**11,960,000**	**NA**		**NA**	**NA**
South	Guangdong	Yuebei	Meitian		?	920,400	41.83	CII		
South	Guangdong	Yuebei	Quren		?	1,084,200	16.33	CII		
South	Guangdong	Guangzhou	Maoming		?	118,600	11.72	CII		
PROVINCE	**TOTAL**			**NA**		**9,510,000**	**NA**		**NA**	**NA**
Northwest	Gansu	Zhongqilian	Yaoji		1	2,718,100	14.49	JP		
Northwest	Gansu	Jingyuan-Jingtai	Jingyuan		1	3,350,800	11.25	JP		
PROVINCE	**TOTAL**			**4**	**2**	**18,060,000**	**37.17**		**33,180**	**3,050**
Northwest	Xinjiang	S. Junggar Basin	Uramqi			2,166,600	16.00	CII		
Northwest	Xinjiang	Talimu Basin	Guala Mine			NA	15.24	CII		
Northwest	Xinjiang	Talimu Basin	Tiema Mine			NA	22.56	CII		
Northwest	Xinjiang	Talimu Basin	Baojishan Mine			NA	NA	CII		
Northwest	Xinjiang	Chaidamu Basin	Lucaoshan Mine	0		NA	27.25	CII		
PROVINCE	**TOTAL**			**0**		**23,920,000**			**NA**	**0**
GRAND TOTAL				**318**	**281**				**4,424,810**	**561,290**
There are 12 local mine areas (LMAs) that do not appear on this table, which are considered by MOCI to be high gas mines. They are listed separately in Table C-3 (Appendix C) of this report.										
NOTE: Emissions data for CMAs in Guangxi and Guangdong Provinces from CII, 1995; No total emissions data are available for these provinces										
Average specific emissions from JP data calculated using arithmatic average of all high gas mines within a given CMA										

APPENDIX D

PROVISIONAL REGULATIONS AND RULES FOR THE MANAGEMENT OF EXPLORATION AND DEVELOPMENT OF METHANE

Provisional Regulation and Rules For the Management of Exploration and Development of Coalbed Methane

Editor: *According to " Law of Mineral Resources in the People's Republic of China" and Reply from the State Planning Commission on management of exploration and development of coalbed methane, the Ministry of Coal Industry formulated and issued the " Provisional Regulation and Rules for the Management of Exploration and Development of Coalbed Methane" in April, 1994.*

Chapter 1 General Principle

Article 1 This Regulation is formulated in accordance with the " Law of Mineral Resources in the People's Republic of China " and relevant regulations issued by the State Council, with an objective to maintaining rational development and utilization of coalbed methane resources, strengthening the management of exploration and development of coalbed methane resources and ensuring that the exploration, planning, design and mining operation of coal resources will not be affected by the exploration and development of the coalbed methane.

Article 2 Coalbed methane is a kind of resource associated and co—generated with coal in the form of gas, which is an excellent clean energy and raw material for chemical industry. The state enjoys the ownership of all coalbed methane resources and encourages the exploration and development of coalbed methane resources.

Article 3 Agreement from the legal persons of the related coal mine enterprises and approval by the Ministry of Coal Industry must be obtained before the exploration and development of the coalbed methane resource in mining areas of production or under construction. For the exploration and development of coalbed methane in mining areas under state plans, the Ministry of Coal Industry should be solicited for advice and opinions.

Article 4 The state shall exercise the right to make unified planning for the exploration and development of coalbed methane and while the management work shall be performed at different levels.

The Ministry of Coal Industry shall supervise and manage the exploration and development of coalbed methane according to the principles of comprehensive exploration and development and reasonable distribution in conjunction with unified planning, comprehensive exploration, comprehensive evaluation of coal resources.

Departments in charge of coal industry work in provinces, autonomous regions and municipalities under the direct jurisdiction of the central government shall be responsible for formulating and implementing the exploration and development planning of coalbed methane in the respective area and shall exercise the right to supervise and manage the exploration and development of coalbed methane in accordance with this Regulation.

Article 5 The Ministry of Coal Industry shall perform the following responsibilities in the exploration and development of coalbed methane:

1. Formulating national plan of exploration and development of coalbed methane;
2. Reviewing and approving coalbed methane exploration plans;
3. Reviewing and approving coalbed methane development projects and issuing production license for coalbed methane development;
4. Supervising, inspecting and managing exploration, development and production of coalbed methane;
5. Coordinating the relationships between exploration and development of coalbed methane and the exploration and mining of coal.

Article 6 Any disputes in relation to the exploration and development of coalbed methane and exploration and development of coal shall be settled by the Ministry of Coal Industry through consultation with the departments concerned and / or with the people's governments of provinces, autonomous regions and municipalities under the direct jurisdiction of the central government. If such consultation fails to reach an agreement, such dispute shall be filed to the comprehensive planning department under the State Council for final verdict.

Article 7 The project proposal, feasibility study reports and preliminary designs for the exploration and development of coalbed methane shall be reviewed and approved by the departments in charge of coal industry in the provinces, autonomous regions and municipalities under the central government before submitting to the Ministry of Coal Industry for review and approval.

Article 8 The State encourages introduction of foreign funds and advanced foreign technology to explore and develop coalbed methane.

All projects for the exploration and development of coalbed methane with foreign funds and foreign and overseas advanced technology shall be reviewed and approved by the Ministry of Coal Industry whose responsibilities shall include:

1. Approving and defining the area for overseas cooperation, delineating blocks for co—operation, defining forms of co — operation and approving the master planning for the development of coalbed methane with foreign input.

2. Sponsoring negotiations between domestic enterprises and foreign enterprises, signing and implementing letters of intent and contracts for joint exploration and development of coalbed methane.

3. Within the areas assigned for co—operation with foreign partners, no enterprises or organizations shall be allowed to engage in activities for exploration and development of coalbed methane or sign economic co-operation agreements with foreign enterprises for the exploration and development of coalbed methane in such areas unless special approval has been obtained from the Ministry of Coal Industry.

Article 9 The state encourages and fully supports positive introduction of modern development technologies and equipment and intensified scientific research for coalbed methane development by relying on scientific and technological progress for continuos improvement of the development level.

Chapter 2 Coalbed Methane Exploration

Article 10 The comprehensive exploration evaluation work for coalbed methane resources in mining areas, of which master feasibility study reports, master planning and overall development plan have already been approved by the planning organizations under the State Council and by the Ministry of Coal Industry and in the key national mining areas where pre-investment studies are under way shall be implemented after the approval by the Ministry of Coal Industry and no registration for the exploration of coalbed methane in these areas shall be processed.

The department in charge of coal industry in each province, autonomous region and municipality under the direct jurisdiction of the central government shall have the power to approve the exploration of coalbed methane in the local mining areas and shall file such approval to the Ministry of Coal Industry.

Article 11 All the information for the exploration of coalbed methane shall be submitted to the Ministry of Coal Industry. The Ministry of Coal Industry shall review and approve the findings of geological exploration of coalbed methane.

Article 12 For the additional exploration of coalbed methane in mining areas or within the coal properties, the extent of coalbed methane reserves with content of over 8 cubic meters of methane per ton of coal and the location of coalbed methane should be clearly defined and in each coal property at least one borehole should be selected for in—situ measurements of permeability, strata stress, temperature at the bottom of borehole and in coal seams as well as other parameters in order to make evaluation of coalbed methane reserves which shall be submitted.

Article 13 In any boreholes where coalbed methane outburst is encountered, such borehole should be regarded as exploration wells where regular measurements of pressure, flow, temperature and other parameters should be taken and analysis and assays should be made to determine the composition and contents which shall be used as the basis for evaluation of coalbed methane reserves. In the event of such matters, the departments in charge of coal industry in the related provinces, autonomous regions and municipalities under the central government should be notified.

Article 14 Trial extraction options must be prepared before trial extraction of coalbed methane in any exploration wells is conducted in the course of geological exploration. Such trial extraction should not exceed half a year. The option and time — frame for such trial extraction should be approved by the department in charge of coal industry in the respective provinces, autonomous regions and municipalities under the central government.

Chapter 3 Coalbed Methane Development

Article 15 All feasibility study reports and general planning of mining areas and feasibility study reports of coal mines prepared after the issuance of this Regulation should include the planning of coalbed methane development.

Article 16 The initiatives from local governments at all levels and enterprises as well as foreign businessmen should be brought into full play and joint development and utilization of coalbed methane should be encouraged.

Article 17 For coalbed methane production, license of coalbed methane development and production must be obtained. The Ministry of Coal Industry shall formulate a separate management rules for coalbed methane production license.

For the development and production of coalbed methane in the area of state—owned key coal mines, coalbed methane production license can be issued only by the Ministry of Coal Industry with the agreement from the said mines and with the peliminary review by the departmnts in the respective provinces, autonomous regions and municipalities under the central government.

For the development and production of coalbed methane in the areas of local coal mines, coalbed methane production license shall be issued upon the agreement by the said local mines and approval by the department in charge of coal industry in provinces, autonomous regions and municipalities under the central government. Such issuance should be filed to the Ministry of Coal Industry.

Article 18 In the development of coalbed methane on coalfields, continuos and stable development policy should be followed under the guidance of cost effectiveness with less input and more output.

The development and utilization of coalbed methane must be preceded by clear delineation of resources and assured source of users of coalbed methane, which shall be planned and arranged in the scientific procedure of coalbed methane production for the maximized utilization of coalbed methane. Advanced and effective technology should be employed to maximize coalbed methane output and production period, to achieve high rate of extraction and to yield the optimum techno — economic benefits.

Article 19 The design and development of coalbed methane projects must be fit into the design and production requirements of coal mines without affecting normal mining operation in coal mines due to extraction of coalbed methane.

In order to improve the design of coalbed methane development projects, all the designs submitted to coal industry authorities for review and approval should be evaluated by relevant technical department.

Article 20 The implementation of the construction projects for the development of coalbed methane must be based on the approved design to achieve unified organization and completion of the projects and associated facilities within the shortest possible period. For coal mines where methane is drained from the underground and utilized, the existing methane drainage facilities should be taken into consideration for reasonable utilization of these facilities when preparing designs of methane recovery from the surface.

Article 21 Advanced and highly efficient construction techniques should be employed to achieve complete project construction including gas extraction, gas supply, gas cleaning and utilization. The project construction shall conform to the relevant regulations of environmental protection.

Article 22 Upon the completion of all project items of coalbed methane development, acceptance inspection shall be performed according to the relevant project quality standards. The designed target should be achieved within the shortest possible time after the gas wells are put into production.

Article 23 Coalbed methane research and monitoring work should be strengthened in the course of coalbed methane development in order to timely ascertain the behavior of coalbed methane and to make adjustment in different mining levels so as to ensure smooth replacement of gas wells for stable and consistent gas supply for a long period.

Chapter 4 Development of Coalbed Methane and Development of Coal

Article 24 The exploration and development of coalbed methane should be subordinated to the development and production of coal.

Article 25 Coal production enterprises shall not be held liable for losses suffered by coalbed methane exploration and development enterprises due to surface subsidence or due to other reasons as a result of coal development.

Article 26 If the original design should be modified by coal production enterprises due to changes of geological structure and variation of coal seams, new approval should be obtained from the authority which approved the original design. If such modification will affect the exploration and development of coalbed methane, the coal production enterprise which made this modification should send official notice half a year in advance to the affected enterprise of coalbed methane exploration and development in order to allow the affected party for emergency measures. Coal production enterprises shall not be held liable for any economic losses as a result of such modification.

Article 27 Coalbed methane development and production enterprises should make economic compensation to coal production enterprises if the latter suffer economic losses due to exploration and development of coalbed methane.

Article 28 Coal enterprises and coalbed methane enterprises in the same region should establish a close co-operation relationship, adhere to the principle of mutual benefit and mutual understanding and correctly handle the relation between coal mining and coalbed methane extraction. They should exchange develepent plans and necessary drawings.

Article 29 All coalbed methane wells (including exploration test wells and production wells) must be cemented or sealed according to relevant regulations without leaving any hidden danger to the coal mining operation. No steel tubes or any other objects which may affect coal mining operation should be left in coal seams. For those objects which cannot be removed, their precise spatial locations must be provided to coal mining departments.

Chapter 5 Supplementary Articles

Article 30 The departments in charge of coal industry in provinces, autonomous regions and municipalities under the direct jurisdiction of the central government shall in accordance with this Regulation and the actual conditions in the respective locality formulate implementation procedures which shall be filed to the Ministry of Coal Industry.

Article 31 All enterprises which started coalbed methane exploration, development and production activities before the issuance of this Regulation shall complete registration and necessary formalities in accordance with this Regulation within one year.

Article 32 This Regulation shall be interpreted by the Ministry of Coal Industry.

Article 33 This Regulation shall be effective upon the date of issuance.

APPENDIX E

FOR MORE INFORMATION

FOR MORE INFORMATION...

For more information on coalbed methane recovery experiences, project potential, or program activities and accomplishments, contact:

Coalbed Methane Program Manager

US Environmental Protection Agency
Mail Code 6202J
Atmospheric Pollution Prevention Division
401 M Street, SW
Washington, DC 20460

Telephone: 202 233-9468
Facsimile: 202 233-9569
Internet: schultz.karl@epamail.epa.gov
Automated Faxback: Call 202 233-9659 and enter #1740

Selected list of EPA Coalbed Methane Outreach Reports:

- USEPA (U.S. Environmental Protection Agency). **Finance Opportunities for Coal Mine Methane Projects: A Guide to Federal Assistance.** Office of Air and Radiation (6202J). Washington, D.C. August 1995.

- USEPA (U.S. Environmental Protection Agency). **Finance Opportunities for Coal Mine Methane Projects: A Guide for Vest Virginia.** Office of Air and Radiation (6202J). Washington, D.C. August 1995.

- USEPA (U.S. Environmental Protection Agency). **Finance Opportunities for Coal Mine Methane Projects: A Guide for Southwestern Pennsylvania.** Office of Air and Radiation (6202J). Washington, D.C. EPA-430-R-95-008. June 1995.

- USEPA (U.S. Environmental Protection Agency). **Economic Assessment of the Potential for Profitable Use of Coal Mine Methane: Case Studies of Three Hypothetical U.S. Mines.** Office of Air and Radiation (6202J). Washington, D.C. EPA-430-R-95-006. May 1995.

- USEPA (U.S. Environmental Protection Agency). **Identifying Opportunities for Methane Recovery at U.S. Coal Mines: Draft Profiles of Selected Gassy Underground Coal Mines.** Office of Air and Radiation (6202J). Washington, D.C. EPA-430-R-94-012. September 1994.

- USEPA (U.S. Environmental Protection Agency). **The Environmental and Economic Benefits of Coalbed Methane Development in the Appalachian Region.** Office of Air and Radiation (6202J). Washington, D.C. EPA-430-R-94-007. April 1994.

- USEPA (U.S. Environmental Protection Agency). **Opportunities to Reduce Anthropogenic Methane Emissions in the United States. Report to Congress.** Office of Air and Radiation (6202J). Washington, D.C. EPA-430-R-93-012. October 1993.

- USEPA (U.S. Environmental Protection Agency). **Anthropogenic Methane Emissions in the United States: Estimates for 1990. Report to Congress.** Office of Air and Radiation (6202J). Washington, D.C. EPA-430-R-93-003. April 1993.

- USEPA (U.S. Environmental Protection Agency). **Options for Reducing Methane Internationally - Volume 1: Technological Options for Reducing Methane Emissions.** Washington, D.C. EPA 430-4-93-006 A. July 1993.

- USEPA (U.S. Environmental Protection Agency). **Options for Reducing Methane Internationally - Volume 2: International Opportunities for Reducing Methane Emissions.** Washington, D.C. EPA 430-R-93-006 B. October 1993.

- USEPA (U.S. Environmental Protection Agency). **A Guide for Methane Mitigation Projects: Gas to Energy at Coal Mines.** Draft. February 1996.