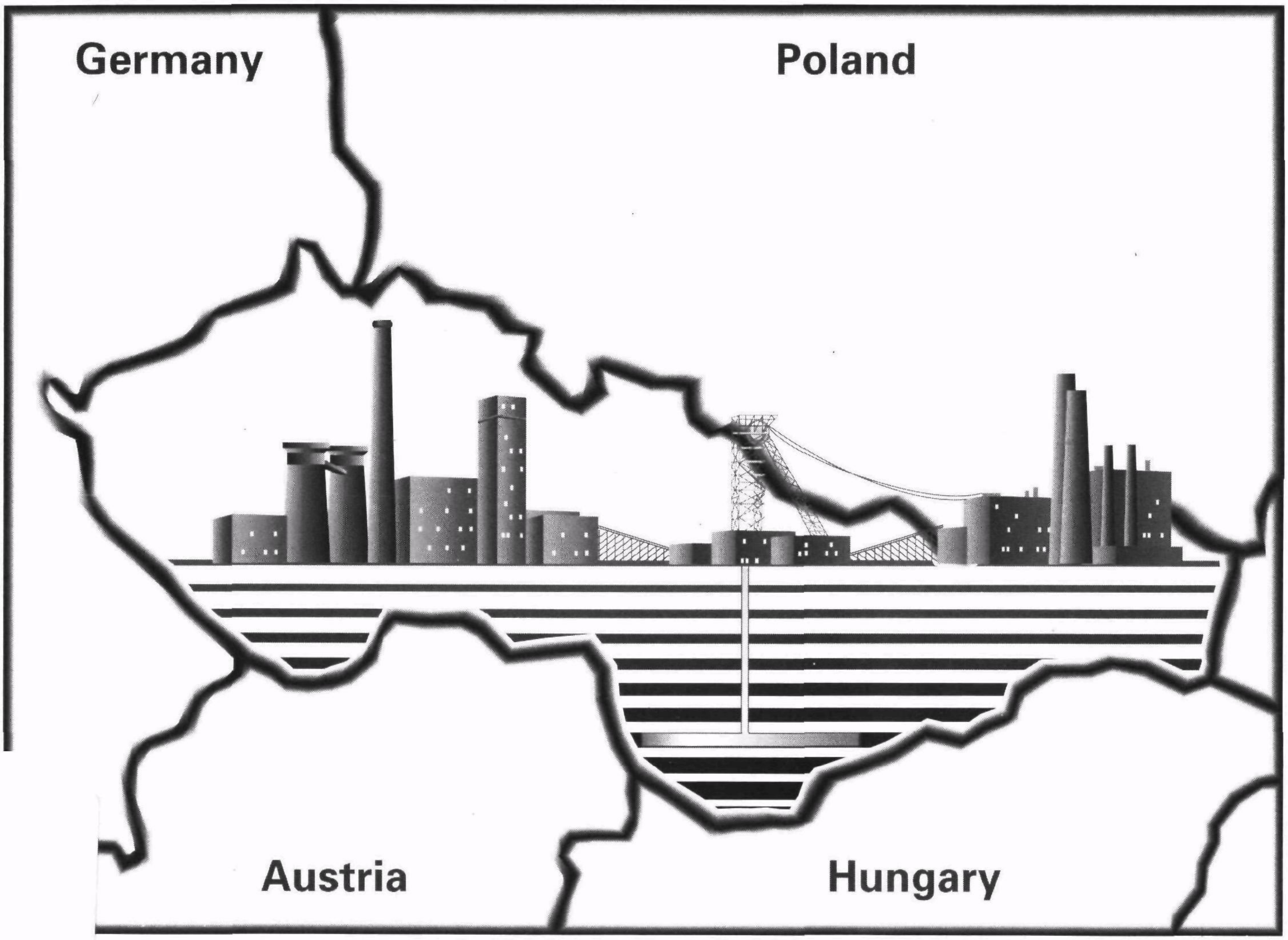
United States
Environmental Protection
Agency

Air and Radiation
(ANR-445)

EPA/430/R-92/1008
October 1992

Assessment of the Potential for Economic Development and Utilization of Coalbed Methane in Czechoslovakia



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EPA/430/R-92/1008

ASSESSMENT OF THE POTENTIAL FOR ECONOMIC DEVELOPMENT AND UTILIZATION OF COALBED METHANE IN CZECHOSLOVAKIA

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ACKNOWLEDGEMENTS

The U.S. EPA gratefully acknowledges the work of Raven Ridge Resources, Inc. under EPA Contract 68-D9-0068.

The efforts of the many reviewers of drafts of this report are also appreciated. The U.S. EPA is indebted to the following Czechoslovakian institutions and individuals for their gracious assistance in the preparation of this report.

Ministry for Economic Policy and Development of the Czech Republic

Federal Ministry of Economy, Department of Energy Policy

Ministry of the Environment of the Czech Republic

DPB Paskov, a.s.
Zdeněk Vavrušák, Director
Dr. Georges Takla, Deputy Director

OKD, a.s.

Officials of the Staříč, Dardon, and ČSM Collieries

Ostrava Mining University

SMP Gas Storage Facility, Štramberk

Nová Hut Metallurgical Plant

VUPEK Institute for Research

Czech Gas Company

SEVEn The Energy Efficiency Center

SUMMARY

INTRODUCTION

This report presents an assessment of Czechoslovakia's coalbed methane resources commissioned by the U.S. Environmental Protection Agency. The study evaluates the potential for coalbed methane development and utilization within Czechoslovakia, and its impact on the country's environmental and energy needs.

This study assesses the coalbed methane resource potential of Czechoslovakia, focusing on the coalbed methane resources of the Ostrava-Karviná Mining District, the largest active mining region in the country. Methane recovery in coal mining areas is emphasized because methane emitted to the atmosphere as a result of mine operations represents the loss of a valuable energy resource, and because it is a greenhouse gas affecting the global climate.

KEY FINDINGS

- **Coalbed methane is an abundant domestic natural gas resource with excellent potential for increased development and utilization in Czechoslovakia. Coal mining operations vent tremendous amounts of methane to the atmosphere.**

  -- Coalbed methane reserves contained in balance coal reserves of active mining concessions in the Ostrava-Karviná Mining District (OKR) of Czechoslovakia are estimated to be between 10 and 70 billion cubic meters. This estimate may be conservative in that it does not include methane contained in coal seams deeper than 1200 m. The total coalbed methane resource associated with all coal mine concessions in the OKR is estimated to be between 50 and 370 billion cubic meters.

  -- Methane resource estimates were not prepared for other Czechoslovakian hard coal basins due to lack of data on emissions or gas content of the coal. However, these basins may also contain substantial methane resources.

  -- Large volumes of coalbed methane are liberated by coal mines each year, representing a serious waste of energy. It is estimated that about 524 million cubic meters of methane are liberated as a result of mining operations each year in the OKR alone, and that only 125 million cubic meters (24 percent) of this gas are utilized.

- **There appear to be many opportunities for Czechoslovakian mines to develop profitable projects to expand the recovery and use of coalbed methane. These mines have numerous options with respect to both recovery and utilization technologies.**

  -- Using demonstrated technologies, it appears likely that Czechoslovakian mines could recover and use 50 percent or more of the methane liberated by mining.

- Additional recovery could be achieved by employing an integrated approach to methane recovery, including drainage prior to, during, and after mining, and, where feasible utilizing low methane concentration ventilation air as combustion air in power plants. If such an approach were used within the active concessions, 80 to 90 percent of the methane that would be liberated and otherwise lost by mining operations could be recovered.

- **Economic problems will worsen as domestic energy production continues to decline, the demand for imported energy increases, and imported energy costs increase to meet world energy prices. A new source of domestic energy would reduce economic burdens.**

  - The contribution of natural gas to Czechoslovakia's energy fuel mix is likely to increase as the use of brown coal and lignite decreases, and as domestic coal production decreases due to the closing of mines.

  - Ninety-five percent of all natural gas consumed in 1991 was imported, and import costs are rising rapidly to meet world prices. Czechoslovakia has limited conventional natural gas resources and needs to develop its unconventional gas resources if it is to reduce dependence on imports.

  - Considering the status of the energy economy described above, Czechoslovakia would benefit from development of a "new" domestic gas resource: coalbed methane.

- **The value of recovering and using large amounts of coalbed methane will become even more significant because of recently enacted environmental legislation.**

  - Under the 1991 Hydrocarbons Law, it appears that fines for emission of methane to the atmosphere could be imposed in 1992. Initially, the fines are set at a level of $14 U.S./thousand cubic meters. By 1997, however, the fines will increase to $47 U.S./thousand cubic meters. At the current level of emissions in the OKR, these fines could cost coal mines an estimated $5.6 million U.S. in 1992. Even when the reduction in emissions expected to result from the planned closure of several mines is taken into account, the fines could reach $11.6 million U.S. annually by 1997.

- **The development of coalbed methane could make important contributions to Czechoslovakia's energy economy as well as benefiting the local and global environment.**

  - Czechoslovakia will likely continue reducing its dependency on coal, coke oven gas, and town gas in order to reduce the environmental problems their use creates. This will provide welcome reductions in pollutants, but could increase the country's dependence on imported energy. Aggressive utilization of coalbed methane could permit Czechoslovakia to achieve its environmental goals and increase domestic production of clean burning energy.

  - Aggressive coalbed methane development and utilization would also decrease methane emissions dramatically, which has important implications for the global climate. Methane is a potent greenhouse gas. In addition, it contributes to tropospheric ozone formation and may contribute to stratospheric ozone depletion.

-- Coalbed methane could be used to generate both steam and electricity, displacing the use of hard coal and lignite. Coalbed methane can also be transported by pipelines directly to end users, replacing the town gas and coke oven gas currently being used. Displacement of hard coal, lignite, town gas or coke oven gas would improve local air quality.

-- Increased mine productivity would result from increased methane drainage, improving the economic viability of hard coal mines. Mine revenues might be further enhanced through joint ventures with gas production companies.

RECOMMENDATIONS

- **An aggressive program of coalbed methane development and utilization should be pursued in Czechoslovakia in order to help the nation achieve its economic and environmental goals.**

  -- At mining operations, an integrated approach to methane recovery should be evaluated and, where economically feasible, implemented.

  -- All utilization options for coalbed methane should be evaluated to ensure that efficient uses for the gas are developed. This evaluation should include the assessment of using or enriching gas that is contaminated with mine air during the production process.

- **Facilitating the rapid development of coalbed methane will require the concerted effort of Czechoslovakian federal and republic governments, international development agencies, foreign governments, and private industry.**

  -- Information about coalbed methane resources should be disseminated within Czechoslovakia. The coalbed methane clearinghouse in Katowice, Poland should be expanded to a regional facility encompassing Czechoslovakian coalbed methane information.

  -- Training programs should be developed for government and industry personnel to raise awareness of coalbed methane and the techniques and technology for development and utilization. This training should include technical, economical, and regulatory components presented as seminars, workshops, fellowships, and trade missions.

  -- The applicability of several methane recovery approaches should be assessed at OKR mines, and the opportunity to both increase gas quantities and improve gas quality (concentration) should be evaluated. This evaluation could be performed by methane drainage consultants, working in conjunction with OKR mine experts.

  -- A study of the potential for methane use in power generation in the OKR is recommended. The study could recommend appropriate modifications to existing facilities, and/or development of new facilities. An important aspect of this study would be an assessment of the feasibility of using mine ventilation air as combustion air in nearby boilers.

  -- The feasibility of enriching low-methane gas (30 to 50 percent methane) to pipeline quality (90 percent methane) should be evaluated. If enrichment proves technically and economically feasible, opportunities for using gas recovered from mine methane drainage systems could increase substantially.

-- It may be desirable to evaluate the potential for increasing the underground gas storage capacity of the OKR, as the ability to store coalbed methane to allow for seasonal fluctuations in demand could make it more economical to use. Mines in the OKR slated for closure should be studied as potential sites for gas storage, modeling them after similar facilities at Perrones-Lez-Binche in Belgium.

-- The federal and republic governments should give priority to coalbed methane development and utilization when developing new energy policies. Policies should be based on an assessment of the potential environmental, socioeconomic, and infrastructure impacts of coalbed methane development.

-- Potential markets for methane produced by active coal mines should be assessed, and the investments required to bring this gas to market identified.

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CHAPTER 1

COALBED METHANE IN CZECHOSLOVAKIA'S ENERGY ECONOMY

1.1 INTRODUCTION

Large amounts of methane are released to the atmosphere from coal mines in Czechoslovakia. Czechoslovakia is among the top ten nations emitting methane from coal mining; about 400 million cubic meters of methane are emitted annually from the mines of the Ostrava-Karviná Mining District alone.

These methane emissions represent the loss of a valuable resource and have a deleterious effect on the earth's atmosphere. Methane has a number of atmospheric impacts that represent threats to the environment. It is a potent greenhouse gas, second in importance only to carbon dioxide. In addition, it tends to increase tropospheric ozone and smog formation, and may also contribute to stratospheric ozone depletion (Kruger, 1991).

Inefficient use of energy, declining resources of hard coal, the need to reduce dependence on low-quality brown coal and lignite, and increasing dependency on imported oil and gas have created a critical need for new indigenous energy sources in Czechoslovakia. In addition, because they are faced with severe environmental problems from the mining and burning of coal, Czechoslovakian officials want to reduce dependence on coal and use more natural gas, nearly all of which is currently imported from the former Soviet Union. This would clearly help them meet environmental goals, but the rising cost of imported natural gas will severely constrain this endeavor.

Czechoslovakia faces other serious economic challenges. During the early 1980's, the nation was able to reduce foreign debt so that it is now relatively low compared with that of Poland or Hungary. In doing so, however, the country went without vital acquisitions of Western technology. This technology is now necessary to help Czechoslovakia compete with more advanced economies, and a deficit of more than $550 million U.S. has been incurred with Western countries since 1990. Meanwhile, the country can no longer rely on inexpensive energy from the former Soviet Union, because of the dissolution of the Council of Mutual Economic Assistance (CMEA). Czechoslovakia, which is heavily dependent on imported energy, has thus been abruptly forced to pay market prices for oil and gas.

For the reasons suggested above, it appears that increased development of Czechoslovakia's coalbed methane resource would address environmental concerns, while providing additional options for an affordable natural gas supply.

1.2 THE ENERGY SECTOR IN CZECHOSLOVAKIA

1.2.1 OVERVIEW

Energy Consumption and Production

Coal provides about 56 percent of Czechoslovakia's primary energy demand (Figure 1), mostly from domestic production. Czechoslovakia is more dependent on brown coal and lignite than any other nation in Europe; it accounts for approximately 63 percent of all coal consumed in Czechoslovakia. Brown coal is widely recognized an undesirable fuel due to its low heating value and high content of sulfur and ash. However, its abundance has made it the primary fuel source for industrial and power generation needs. At the present rate of extraction, reserves of brown coal and lignite are being depleted by 3 percent per year. Some authorities expect them to be exhausted before 2010 (EIU, 1991), although others predict that Czechoslovakia will be able to continue producing brown coal and lignite until 2040 (Couch et al, 1990).

Production of hard coal has been steadily decreasing during the past decade. As the planned closure of uneconomic mines proceeds during the next few years, production is expected to decline dramatically. In fact, the government plans to reduce hard coal production by up to 40 percent by the year 2000.

Consumption of conventional natural gas has been increasing in response to declining coal production, but known domestic reserves of oil and natural gas are small, as discussed in Section 1.2.2. Annual domestic oil production accounts for less than 1 percent of the amount consumed in Czechoslovakia; gas production, less than 7 percent. The remaining oil and gas is imported, mostly from the Commonwealth of Independent States (CIS; formerly the Soviet Union). The country's main oil supply, which comes from the CIS, has been cut by nearly half since early 1990. This reduction in supply has caused the cost of oil- and gas-based energy to double. Gas supplies are also unsteady, and energy costs are continuing to rise dramatically (Daviss, 1991).

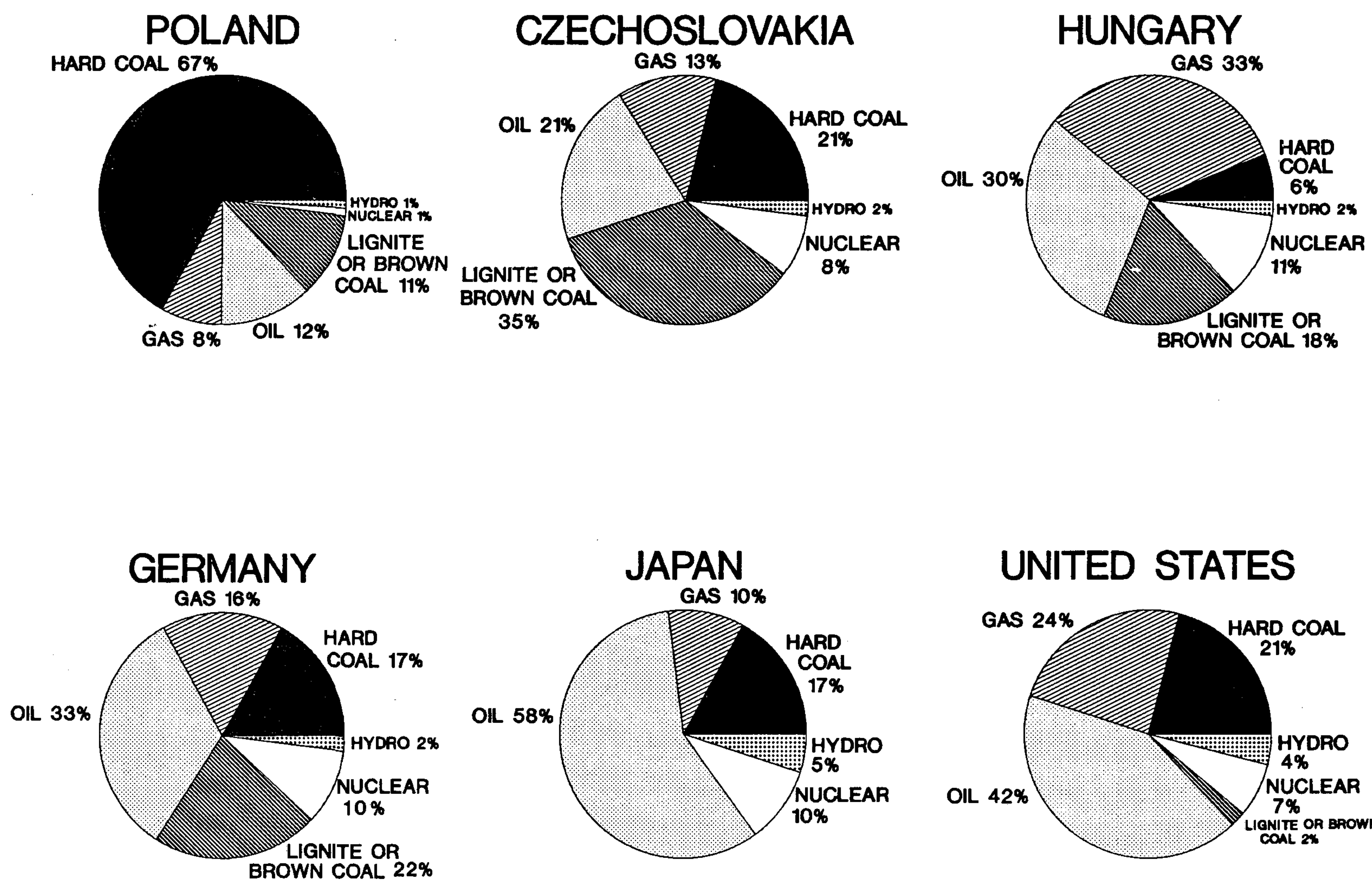
As of 1989, nuclear power accounted for 28 percent of all electricity generation in Czechoslovakia (EIU, 1991). There are eight 440 MW nuclear reactors in Czechoslovakia, two of which are currently shut down and may be decommissioned in 1995. Four additional plants are under construction. There is also a reactor which has been permanently shut down since 1979 because of accidents. Long term problems are associated with the storage and disposal of spent fuel from this reactor, and from nuclear units presently in operation or under construction. There is also some concern about the adequacy of monitoring and safety management.

Sectoral Energy Demand

Czechoslovakia's final energy demand in 1990 was 2.058 exajoules[1] (EJ) (UNECE, 1991a). Sectoral end use is divided into three categories: Industry (including manufacturing, mining, and construction), Domestic (which includes households, agriculture and commercial enterprises) and Transportation (rail, road, water, and air). In 1990, the domestic sector used 0.821 EJ and industrial sector used 1.104 EJ. Together they accounted for 94 percent of the energy consumed in Czechoslovakia (Figure 2). The

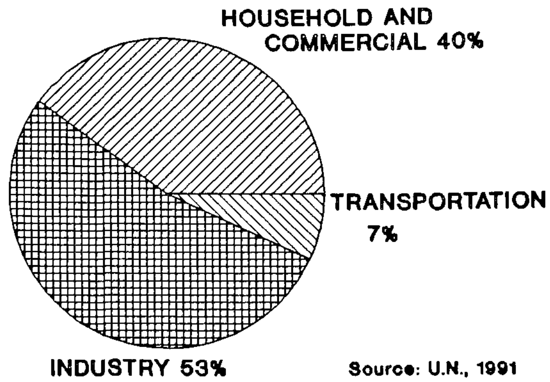
[1] 1 EJ = 0.948 quadrillion BTU = 0.948 X 10^{15} BTU

FIGURE 1. FUEL MIX OF SELECTED COUNTRIES, 1989



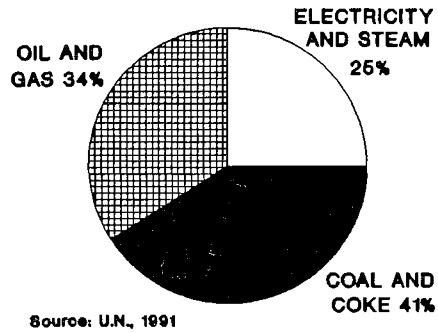
Source: U.S. DOE EIA, 1991; UNECE, 1991c transportation sector accounted for the remaining 7 percent of energy consumed (0.133 EJ). The large share of energy consumed by the industrial sector reflects the national emphasis placed on heavy industry, coupled with low energy efficiency.

FIGURE 2. ENERGY DEMAND BY SECTOR, 1990



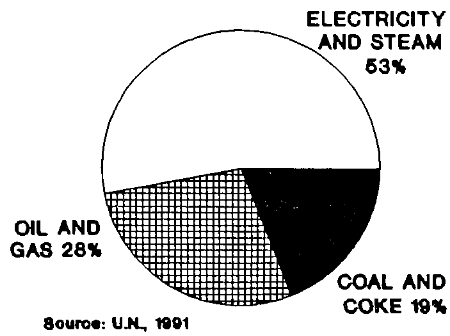
As shown in Figure 3, about 41 percent of the domestic sector's energy in 1990 was derived directly from coal and coke. Indirect use of coal via electricity and steam generation accounted for 25 percent of domestic energy demand, and oil and gas fuels comprised the remaining 34 percent. The United Nations Economic Commission for Europe (UNECE, 1991a) forecasts that through 2010 domestic consumption of energy via direct combustion of coal and coke will decrease relative to consumption of electricity, steam, oil, and gas. The UNECE forecast also assumes that nuclear energy will contribute more to electricity generation than it does at present.

FIGURE 3. DOMESTIC SECTOR ENERGY SOURCES, 1990



Most of the energy used by the industrial sector is also derived directly or indirectly from coal, as shown in Figure 4. In 1988, about 53 percent of the energy consumed by industries was derived indirectly from coal in the form of electricity and steam; 19 percent was generated directly from coal and coke, mostly for steel production. The remaining 28 percent was derived from gas and oil, most of which was imported. According to a UNECE forecast, by 2010, direct consumption of coal will account for only 12 percent of the total energy consumed by the industrial sector. The UNECE forecasts that oil and gas will account for 35 percent of the energy consumed by the industrial sector; gas comprises by far the largest portion of that percentage. In order for industry to shift to gas, however, it will be necessary for Czechoslovakia to either increase domestic gas production or increase imported natural gas. In addition, expenditures will be necessary in order for industries to convert existing facilities for natural gas use, and for building pipelines to transport gas to industrial facilities.

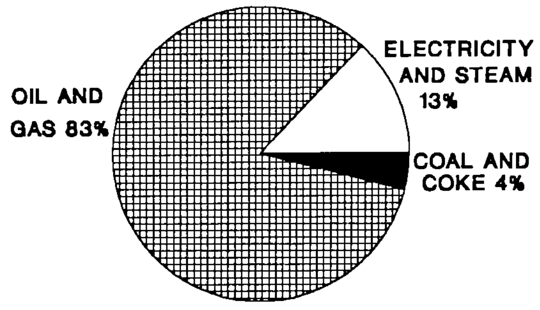
FIGURE 4. INDUSTRIAL SECTOR ENERGY SOURCES, 1990



The transportation sector (Figure 5) is fueled primarily by oil (82 percent), nearly all of which is imported; natural gas contributes 1 percent to the fuel mix for a total oil and gas share of 83 percent. Thirteen percent of the energy used by the transportation sector is generated indirectly from coal as steam and

(UNECE, 1991a). Czechoslovakia must continue to import large amounts of oil to meet the demands of the transportation sector.

FIGURE 5. TRANSPORTATION SECTOR ENERGY SOURCES, 1990



1.2.2 PRIMARY ENERGY SOURCES IN CZECHOSLOVAKIA

Coal: The Dominant Fuel

Czechoslovakia relies heavily on coal for its primary energy production. As shown in Figure 1, coal accounted for over 55 percent of Czechoslovakia's fuel mix in 1989. Brown coal and lignite represented 35 percent of the fuel mix, and production of these lower ranked coals exceeded hard coal production by about four times. The coalfields of Czechoslovakia are indicated in Figure 6.

More than 83 million tons[2] of brown coal and lignite were produced in Czechoslovakia in 1990 (Table 1). Ninety-three percent of this was brown coal produced in the North Bohemia Brown Coal Basin, located in the northwestern part of the country near the German border (Figure 6); most of this coal is produced by open cast methods. The remainder was lignite produced near the Czech-Slovak border southeast of Brno, and in Slovakia west of Banská Bystrice; most of the lignite in these areas is mined underground. The brown coal basin east of Česke Budějovice has not been exploited, and the extent of its resources is not known.

As shown in Table 1, brown coal and lignite consumption has declined steadily in the past five years. The overall view from within Czechoslovakia is that brown coal and lignite production and consumption will continue to decrease largely as a result of environmental pressure, but also as a result of falling demand brought about by a decrease in heavy industry, as well as increasing prices. However, the rate at which demand will continue to decline depends on whether other forms of energy will be available to meet Czechoslovakia's needs.

Hard coal is produced from the Ostrava-Karvina Mining District (OKR) of the Upper Silesian Coal Basin; the Central Bohemian Coal Basins, which contain the Kladno District west of Prague, and the Plzen District; the Trutnov District of the Lower Silesian Coal Basin; and the Boskovice Trough west of Brno (Figure 6). The Ostrava-Karvina District has the highest output, producing 19.7 million tons (90 percentof Czechoslovakia's total hard coal production) in 1990. Total hard coal production in Czechoslovakia in 1990 was 21.9 million tons.

As shown in Table 1, hard coal consumption has declined in recent years, largely due to lower demand for coke as a result of changes in the metallurgical industry. Hard coal production has declined steadily in the past decade. Czechoslovakia exports coking coal, primarily to Austria, Germany, and Hungary. Until recently, the only coal it imported was non-coking coal (from Poland and the CIS). In 1991, however, both coking and non-coking coal were imported.

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[2]Throughout this report, "tons" refers to S.I. (metric) tons. The term "million" (10^6) is used, rather than the S.I. prefix "mega-", because it is familiar terminology in the international mining and energy industry.

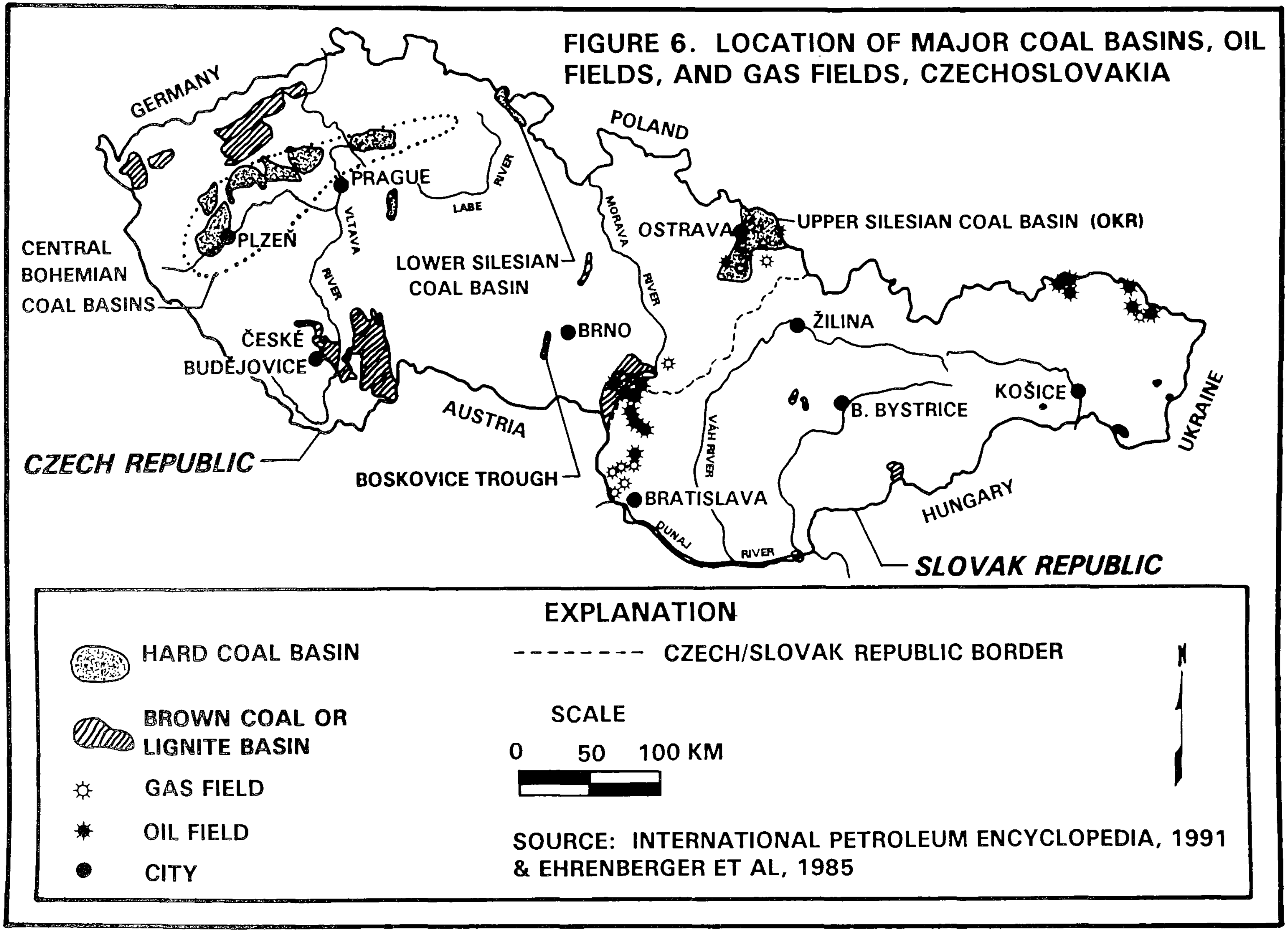

FIGURE 6. LOCATION OF MAJOR COAL BASINS, OIL FIELDS, AND GAS FIELDS, CZECHOSLOVAKIA

TABLE 1. COAL PRODUCTION AND CONSUMPTION IN CZECHOSLOVAKIA (MILLION TONS)

YEAR	BROWN COAL AND LIGNITE		HARD COAL	
	PRODUCTION	CONSUMPTION	PRODUCTION	CONSUMPTION
1980	96.0	93.8	28.4	29.8
1981	96.4	94.1	27.5	28.9
1982	99.0	96.0	27.5	29.6
1983	100.5	99.9	26.9	29.0
1984	102.9	99.6	26.4	28.3
1985	100.4	97.5	26.2	28.2
1986	99.9	99.2	25.7	28.1
1987	97.0	95.8	25.7	28.1
1988	98.4	95.2	25.5	28.1
1989	92.3	91.9	25.1	27.4
1990	83.7	82.5	21.9	25.3
1991 (Estimated)	85.2	82.5	21.0	23.7

Sources: U.S. DOE Energy Information Administration (1982-1991)
United Nations (1982-1990)
Ministry for Economic Policy and Development of the Czech Republic (MEPDCR) (1991)
Couch et al (1990)
Czechoslovakian Federal Ministry of Economy (1991)

Oil

Czechoslovakia produces only about 442 tons[3] of oil per day, mostly from the Vienna Basin southeast of Brno (Figure 6). Reserves are estimated at about 2.6 million tons (International Petroleum Encyclopedia, 1991).

Although production has been fairly steady in recent years, it represents only about 1 percent of the oil consumed in Czechoslovakia. The sharp decrease in oil consumption in 1990 (Table 2) does not reflect a decrease in demand, but rather a reduction in supply from the CIS. Czechoslovakia is now seeking new sources of oil, and deliveries of 100,000 tons per month from the Middle East started along the Adria pipeline through Yugoslavia in January 1991.

[3] 1 ton of oil = 6.780 barrels

TABLE 2. OIL PRODUCTION AND CONSUMPTION IN CZECHOSLOVAKIA (THOUSAND[4] TONS)

YEAR	OIL PRODUCTION	OIL CONSUMPTION
1980	108	20,800
1981	88	20,300
1982	88	17,900
1983	93	20,300
1984	95	18,600
1985	153	18,400
1986	211	18,000
1987	158	17,900
1988	153	17,800
1989	162	17,800
1990	140	13,500

Sources: Gustavson Associates (1990)
U.S. DOE Energy Information Administration (1982-1991)
Czechoslovakian Federal Ministry of Economy (1991)

In September, 1991, the Ministry for Economic Policy and Development of the Czech Republic (MEPDCR), the Ministry of Economy of the Slovak Republic, and the Slovak Geological Office issued an invitation to companies, both foreign and domestic, to participate in the first open bidding round for petroleum exploration and production in the Bohemian Massif and West Carpathians, the area located in and around the Vienna Basin. The resulting exploration should help increase domestic oil and gas production, but Czechoslovakia is expected to remain heavily dependent on imported oil.

Natural Gas

Natural gas production in Czechoslovakia was negligible until about 1955. Gas production is primarily located in the Vienna Basin (southeast of Brno), with lesser amounts produced in the easternmost part of the country, and near Ostrava.

Although natural gas production has increased during the past decade, Czechoslovakian fields are producing at maximum capacity (696 million cubic meters in 1990) and proven conventional reserves

[4] The term "thousand" (10^3) is used throughout this report, rather than the S.I. prefix "kilo-", because it is familiar terminology in the international energy and mining industry

are estimated to be only 14 billion cubic meters[5] (UNECE, 1991b), equal to the present annual gas demand (Table 3). Therefore, Czechoslovakia will have to continue importing most of the natural gas it consumes. In 1990, 95 percent of the conventional gas used was imported from the CIS, and it is expected that this percentage will increase as brown coal consumption is reduced and hard coal production declines. The Deputy Minister of Fuel and Energy has prepared energy forecasts through the year 2005. Under the most favorable scenario, which assumes the success of the country's economic reform program, Czechoslovakia is projected to import 21 billion cubic meters of conventional gas by 2005 (Platts Oilgram News, 1991).

The heavy dependence on imported natural gas has adverse economic implications for Czechoslovakia.The CIS, sole supplier of natural gas to Czechoslovakia, was charging $120 US per thousand cubic meters in November 1991, and they are continuing to raise gas prices. Moreover, the CIS can be an unreliable gas exporter, as exemplified in the CIS' unexpected reneging on a contract to deliver gas to Poland. This incident, which took place January 1992, forced Polish industries dependent on natural gas to sharply curtail consumption and output until the contract could be renegotiated. Unlike Poland, however, the main gas pipeline coming from the CIS to Central and Western Europe passes through Czechoslovakia so it is unlikely that such an abrupt halt in gas deliveries to Czechoslovakia could occur. Still, the long-term reliability of gas deliveries from the CIS to Czechoslovakia is uncertain, and Czechoslovakia is looking for other potential gas suppliers, such as Algeria, Norway, and the Netherlands (Oil and Gas Journal, 1991a). Afghanistan has recently approached Czechoslovakia offering to sell them gas via a pipeline to the gas grid of the CIS.

Another alternative gas source being examined by Czechoslovakia is its indigenous coalbed methane resources. Development of these resources could be a significant boost to domestic gas production, as discussed in later chapters.

1.2.3 THE NATIONAL ENERGY STRATEGY

Czechoslovakia's energy economy is in the midst of a complex transition. The 1991 decision of the former Soviet Union to demand payment for fuel at world prices and in hard currency has caused energy costs per unit of gross national product to increase sharply. Improvements in energy efficiency will help relieve growing energy shortages, but it is also necessary to have a comprehensive energy strategy, and to develop the nation's most attractive domestic resources.

Since its inception in 1990, the current government has been working on energy sector management and reform. The highlights of the government strategy involve developing market economy structures, adjusting energy prices, emphasizing clean-burning, efficient electric power technologies, and expanding nuclear power (UNECE, 1991a).

Implementing market-oriented energy policies will require that energy production, sales, and trade take place within self-sustaining enterprises. At present, the government still plays a major role in enterprises involved in producing and distributing energy. It is anticipated that privatization of these enterprises will eventually take place, but it is unlikely that they will be privatized within the next few years.

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[5] The term "billion" is used throughout this report, rather than the S.I. prefix giga-, because it is common terminology in the international energy and mining industry. 1 billion cubic meters = 35.3 billion cubic feet = 0.035 trillion cubic feet.

TABLE 3. NATURAL GAS PRODUCTION AND CONSUMPTION IN CZECHOSLOVAKIA (MILLION CUBIC METERS)

YEAR	GAS PRODUCTION	GAS CONSUMPTION
1980	341	9,010
1981	392	8,940
1982	429	9,460
1983	378	9,580
1984	505	10,070
1985	478	11,290
1986	699	12,080
1987	708	12,570
1988	730	11,820
1989	750	12,660
1990	696	13,960

Sources: Gustavson Associates (1990)
U.S. DOE Energy Information Administration (1992-1991)
Czechoslovakian Federal Ministry of Economy (1991)

There is broad agreement that the historical price structure of Czechoslovakian energy resources has been low in comparison to other industrialized nations and that this structure has resulted in significant internal price distortions. Major pricing reform is therefore underway in each of the energy sectors of the country. In the long run, tradeable energy resources will be priced at comparable international levels (Huddleston, 1991). Pricing reform is important not only within individual energy sectors, but also in its impacts on industrial output, employment, trade, government finance, and environmental conditions.

One aspect of Czechoslovakia's plan to emphasize clean-burning, efficient electric power technologies is using less brown coal and lignite. In addition, research on using gasification of coal for power generation is underway, and Czech and Slovak utilities have been attempting to secure loans to install flue gas desulfurization and electrostatic precipitator technologies in coal-fired power plants (Eastern European Energy Report, 1991). Scrubbers for removal of sulfur dioxide and nitrogen oxides are virtually non-existent on the country's power plants, and it is estimated that two-thirds of Czechoslovakia's power plants will have to be refurbished or retrofitted with pollution control equipment.

According to the UNECE (1991a), for the next 15-20 years, one of the main targets of Czechoslovak energy policy is a vast international cooperative effort to improve existing nuclear technologies and develop new ones, in conformity with international agreements on safety standards for the operation of plants and disposal of wastes. The objective is a capacity of about 12 GW by 2005, more than a threefold increase from present levels. However, construction of new nuclear power stations has been delayed by planning and organization difficulties, and rising costs connected with increased safety requirements (EIU, 1991).

Czechoslovakia's energy program also calls for an increase in natural gas consumption, particularly in the residential and commercial sectors.

1.2.4 THE ROLE OF COALBED METHANE

In the future, Czechoslovakia seeks to rely less upon domestic coal and more upon other, cleaner-burning energy sources to meet its growing energy needs. Accomplishing this goal without developing new domestic gas resources will be very difficult, however, because Czechoslovakia's domestic resources of oil and conventional natural gas are much too small to meet present, let alone increased, demand; and, because it is difficult for Czechoslovakia to pay for the amount of fuel it currently imports, let alone the increased amount that will be necessary as coal production and use declines. Thus, Czechoslovakia would benefit from the development of an affordable and environmentally sound domestic energy source, such as coalbed methane.

Coalbed methane production should help Czechoslovakia achieve its environmental goals in an economically sustainable manner. Substantial reserves of coalbed methane are projected to lie in and around the hard coal mines of Czechoslovakia. In addition, more than 520 million cubic meters of methane are liberated by mining each year, three-fourths of which is wasted through emissions to the atmosphere. Good opportunities exist for increased recovery and utilization of methane from coal mines in Czechoslovakia, as well as development of the resource independent of mining. A comprehensive program of mine methane drainage and utilization, combined with methane development in areas lying beyond the mines, could supply enough energy to significantly reduce the need for imported natural gas--even with the assumption that demand for natural gas will rise sharply in the future.

Unutilized, coalbed methane is an environmental liability acting as a potent greenhouse gas. Utilized, it is a remarkably clean fuel. The burning of methane emits virtually no sulfur or ash, and only about 32 percent of the nitrogen oxides, 45 percent of the carbon dioxide, and 43 percent of the volatile compounds emitted by coal burning (Oil and Gas Journal, 1991b; U.S. EPA, 1986). Coalbed methane can be substituted for hard coal in local power plants through cofiring or direct combustion in existing boilers, reducing foreign imports of energy coal, and reducing regional imports of increasingly expensive electricity. In instances where coalbed methane would be used to displace coal, coke oven gas, or town gas, it would improve the regional, as well as global, air quality.

In addition to national economic benefits of reduced imports of natural gas, coalbed methane drainage and utilization improves profitability of coal mines. With aggressive methane drainage, less money would be spent on installation and maintenance of large ventilation fans and other safety measures, and a waste product would be converted to a useable and marketable energy source (Dixon, 1987). Methane drainage could also increase mine productivity by reducing the down time associated with high methane levels. Coalbed methane drainage also reduces the potential for methane explosions, improving safety conditions for miners.

CHAPTER 2

COALBED METHANE RESOURCES OF CZECHOSLOVAKIA

2.1 INTRODUCTION

Coalbed methane has traditionally been viewed as a mine safety hazard, requiring dilution to safe non-explosive levels. For this reason, most coal mines throughout the world simply vent large amounts of methane in low concentrations to the atmosphere. In many mines, however, ventilation alone is insufficient to maintain safe mining conditions, and additional degasification techniques, including in-seam drilling, have been developed. Many of Czechoslovakia's coal mines have high methane concentrations, and degasification techniques have been used in these mines for many years to ensure safety.

An estimate of the magnitude of the coalbed methane resource in Czechoslovakia is necessary to evaluate its development potential. Because coalbed methane development has not begun aggressively, however, much of the data required to develop a detailed resource assessment is not yet available. For example, there is currently no data available on actual measured gas contents and other characteristics of Czechoslovakian coals that would affect both the magnitude of the resource and its recoverability. Nevertheless, assumptions based on similar coals have allowed reasonable preliminary estimates to be made.

The following sections describe the available data on Czechoslovakia's coal resources, present estimates of coalbed methane resources, and discuss some of the key factors related to the recoverability of the resource. Most of the data on which this discussion is based was provided by MEPDCR, and by mining enterprises that have collected data for purposes of producing coal and maintaining mine safety.

Until more detailed data is available, these estimates should be considered preliminary. Mining experience in Czechoslovakia and the available data indicate that the coalbed methane resource is large. Given the lack of key types of information, however, it is clear that more detailed data collection activities are warranted to better assess Czechoslovakia's coalbed methane resource and identify the most promising production locations.

2.2 COAL RESOURCES

As outlined in Chapter 1, hard coal is produced from four basins in Czechoslovakia, the locations of which are shown in Figure 6. Characteristics of the basins are summarized in Table 4. As the table shows, the Ostrava-Karviná District of the Upper Silesian Coal Basin (USCB) is the largest hard coal producing region in Czechoslovakia, and most of the mining activity is concentrated in this basin. A more detailed description of each basin is provided below.

2.2.1 THE UPPER SILESIAN COAL BASIN (OSTRAVA-KARVINÁ DISTRICT)

Introduction

The Czechoslovakian portion of the Upper Silesian Coal Basin, which extends into Poland, is more commonly referred to as the Ostrava-Karvina District (OKR[6]); its location is shown in Figure 6. Coal mining began in the OKR in 1782; workings originating as early as the 1840's are still being mined. Presently, coal is produced from 14 mine concessions (15 produced coal in 1991, but the Šverma mine closed in January 1992).

TABLE 4. SUMMARY OF COAL BASIN CHARACTERISTICS, CZECHOSLOVAKIA (1990)

CHARACTERISTIC	OSTRAVA-KARVINA DISTRICT OF USCB	CENTRAL BOHEMIAN BASINS		TRUTNOV DISTRICT OF LSCB	BOSKO-VICE TROUGH
		KLADNO	PLZEN		
Basin Area (km^2)	1,200	100	70	50	20
Documented Coal Resources (Million Tons)	11,797	443	57	314	13
Number of Active Mine Concessions	15	2	2	2	1
1990 Coal Production (Thousand Tons)	19,735	1,308	255	459	140
Methane Liberated, 1990* (Million m^3)	524.1	N/A	N/A	0.8*	N/A
Sources:	MEPDCR (1991) DPB Paskov (1991)				

* Stated amount of methane liberated in Trutnov District may represent a year other than 1990

[6] The Czechoslovakian abbreviation "OKR" is used in this report because use of the literal English abbreviation, OKD, would cause it to be confused with OKD, a.s., the enterprise which controls all but one of the mine concessions in the Ostrava-Karvina District.

Mining depths in the OKR range from 480 to 1100 meters (m). Upper Carboniferous formations contain the 3,800 m thick productive series, which includes 255 coal seams, about 120 of which are considered workable (Dopita and Havlena, 1972). The total thickness of the coal seams is approximately 150 m.

Geologic Setting

Predominant tectonic characteristics of the OKR are shown in Figure 7. In the west-central part of the district, two principal structural features (Michálkovice and Orlová) form a boundary between two distinct tectonic styles. The Michálchovice and Orlová features are in some places manifested as thrust faults, and in other places manifested as sharp synclinal folds. West of these principal fold/fault features, structural features consist primarily of south-southwest/north-northeast trending folds, with east-west (and southeast-northwest) trending normal faults prevailing over north-south trending faults.Thrust faults are also present. In contrast, east of the Michálkovice and Orlová fold/fault features, structural features consist of north-south trending faults roughly equal in number to east-west (and east-southeast/west-northwest) faults. In this area, major grabens are present and thrust faults are absent.

The general stratigraphy of the basin is shown in Figure 8. The oldest coal-bearing formation is the Ostrava Formation (Namurian A and B). It is characterized by a predominance of fine-grained siltstones, sandstones, and mudstones interbedded with 168 coal seams, each averaging 73 cm thick. All four members of the Ostrava Formation are coal bearing, but the oldest members (Petřkovice and Hrušov) tend to be most productive. The formation is believed to have been deposited in a coastal plain environment (Dopita and Havlena, 1972).

The Karviná Formation (Namurian B and C, and Westphalian A) overlies the Ostrava Formation. It is characterized by a predominance of coarse-grained sandstones and conglomerates interbedded with 87 coal seams averaging 120 cm thick. The formation was deposited in a terrestrial (rivers and lakes) environment.

While coalbeds in both the Ostrava and Karviná Formations are currently mined, present and planned mining activity emphasizes Karviná coalbeds. All three members of the Karviná Formation are mined, but the Saddle Seams Member is especially productive. According to Dopita (1988), during the late 1980's more than 36 percent of all coal mined in the OKR was from the Saddle Seams Member, and this percentage is forecast to increase in the future.

On average, OKR coal contains 0.6 percent sulfur, 15 percent ash, 3.5 percent moisture, 23 percent volatile matter, and has a heating value of 25.5 MJ/kg. OKR coal rank ranges from high volatile bituminous to anthracite; approximately 73 percent of the coal is of coking quality.

Coal Resources

Total coal resources in the OKR are estimated at 16 billion tons, contained in 64 deposits. As of 1991, fifteen of the deposits were considered "developed" (i.e., with active mines or mines under construction); the remaining 49 are "undeveloped" (i.e., have never been or are not currently being mined). As shown in Table 5, nearly three-fourths of the coal resources in the basin are documented (identified), and more than 40 percent are classified as mineable balance resources (the term "balance" represents coal thickness, quality and depth criteria defined in Table 5).

FIGURE 7. TECTONIC MAP OF THE UPPER SILESIAN COAL BASIN (OSTRAVA-KARVINÁ MINING DISTRICT), CZECHOSLOVAKIA

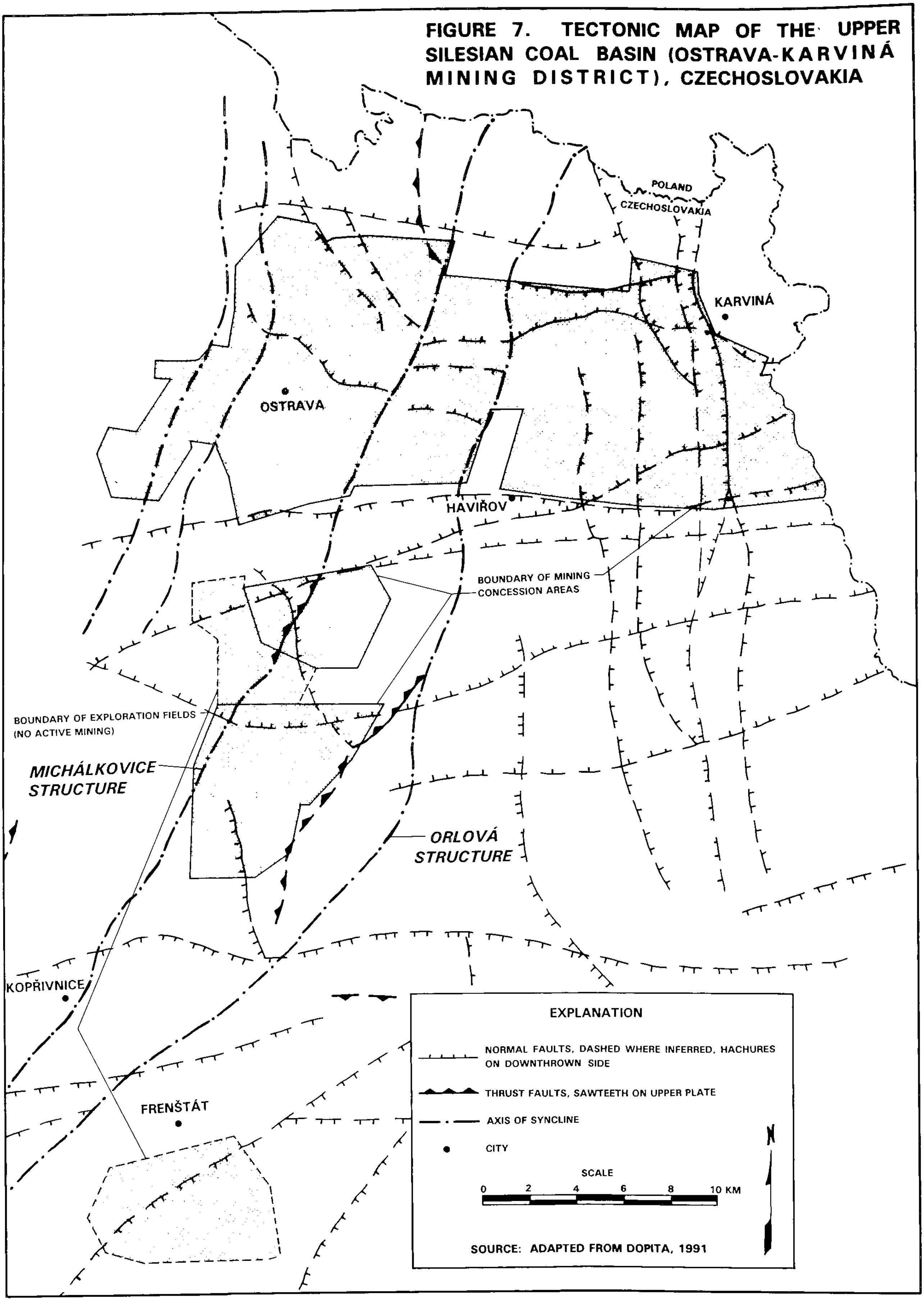

FIGURE 8. STRATIGRAPHIC CORRELATION OF COAL BEARING FORMATIONS, CZECHOSLOVAKIA

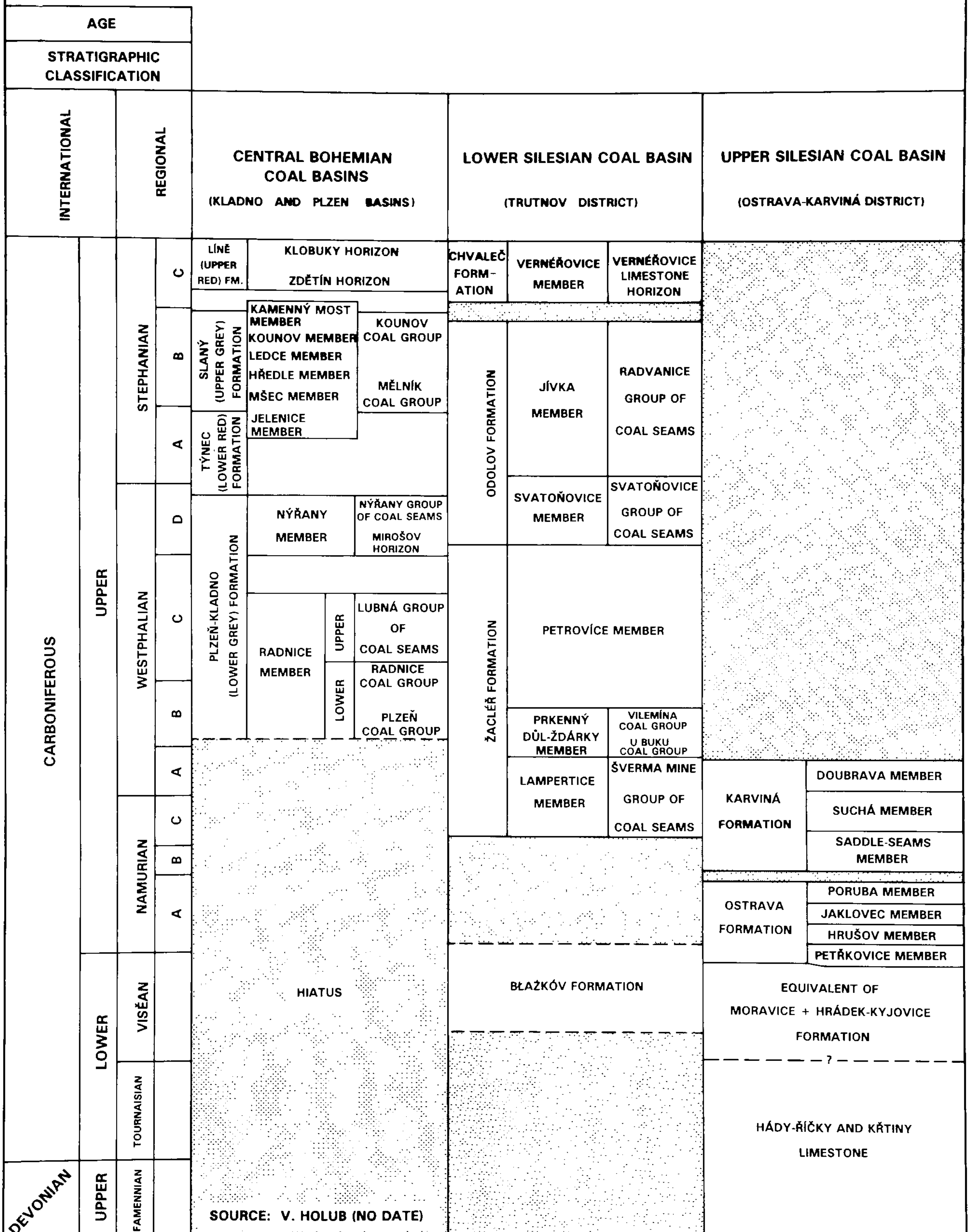

TABLE 5. HARD COAL RESOURCES OF THE OSTRAVA-KARVINÁ DISTRICT, 1990 (IN MILLION TONS)

DOCUMENTED[7] (IDENTIFIED) RESOURCES	
IN DEVELOPED DEPOSITS (ACTIVE MINES)	
Balance Reserves (seams more than 40 cm thick, ash less than 60%, depth above 1200 m)	
Mineable	2,008.1
Non-Mineable (unfavorable geologic and/or safety conditions)	1,036.6
Non-Balance Resources (do not meet thickness, ash, and depth criteria above)	782.8
TOTAL DEVELOPED DEPOSITS	**3,827.5**
IN UNDEVELOPED DEPOSITS (INCLUDING INACTIVE MINES)	
Balance Reserves (seams more than 40 cm thick, ash less than 60%, depth above 1200 m)	
Mineable	4,913.7
Non-Mineable (unfavorable geologic and/or safety conditions)	1,165.9
Non-Balance Resources (do not meet thickness, ash, and depth criteria above)	1,891.0
TOTAL IN UNDEVELOPED DEPOSITS	**7,969.9**
TOTAL DOCUMENTED RESOURCES (DEVELOPED + UNDEVELOPED)	11,797.4
TOTAL PROGNOSTIC[8] (UNDISCOVERED) RESOURCES	4,320.0
TOTAL RESOURCES (TOTAL DOCUMENTED + TOTAL PROGNOSTIC)	**16,118.1**

Source: MEPDCR, 1991

[7] "Documented" coal resources include resources classified as A, B, C_1, and C_2 by the Czechoslovakian government. In U.S. terminology, these are equivalent to "identified" resources, which include measured, indicated, and inferred resources.

[8] "Prognostic" coal resources include resources classified as P_1 and P_2 (formerly called D_1 and D_2) by the Czechoslovakian government. In U.S. terminology, these are equivalent to "undiscovered" resources, which include hypothetical and speculative resources.

Coal Production

The locations of OKR coal mines and mine concessions are shown in Figure 9. Coal production in 1990 was 19.7 million tons, which represents more than 95 percent of the total hard coal production in Czechoslovakia. Production declined more than 10 percent between 1989 and 1990, however, because of rising extraction costs and lower demand.

Table 6 provides data on the coal minlng concessions[9] of the OKR, including 1990 coal production, resources, and depths. The table also lists the starting date of production at the mine concessions. Four of the mine concessions are in the process of closure or are expected to close by 1995, and the Šverma mine concession closed in January 1992. These closures are resulting from unprofitability and reduction of subsidies. Nearly all of the coal in the OKR is mined from longwall faces, mostly by mechanized methods.

All of the mining concessions except for ČSM are owned by OKD, Inc., a state enterprise. ČSM became independent of OKD near the end of the 1980's, and ČSM management is thus able to make its own decisions regarding mining policy and procedures. While no longer controlled by OKD, ČSM is still a state-run enterprise, although plans for privatization have been made.

Methane Liberation

Coals of the Karviná and uppermost Ostrava Formations tend to be the gassiest in the OKR, and they are equivalent to formations with high gas contents in the Polish part of the Upper Silesian Coal Basin.

Data provided by the mine drilling and safety enterprise Důlni Průzkum a Bezpečnost (DPB), indicate that 524 million cubic meters of methane were liberated from the 15 mine concessions operating in the OKR in 1990 (Table 7). In 1989, about 494 million cubic meters of methane were liberated from these mines; this is an approximation, however, because complete ventilation data for 1989 was not available. Table 7 also shows the amount of methane used by OKR mines in 1990. Nearly 126 million cubic meters, or 24 percent of the liberated methane, was being used rather than emitted to the atmosphere in 1990. Note the distinction between "liberation" and "emission": liberated methane is that released from the coal, whether or not it is utilized; emissions, in the strict sense, refer to liberated methane that has not been utilized and therefore enters the atmosphere.

A number of factors suggest that the amount of methane liberated, as reported by DPB, is accurate. Methane volume and concentration is monitored at all mines. Methane content is monitored at the face, throughout the entryways, at the intersections of entryways, in the ventilation shaft itself, and at the surface of the ventilation shaft. Measurements are recorded on a regular basis.

As gob areas are sealed off, a gas drainage pipe is placed in the barrier and is connected to the drainage system; in this way, methane liberated from gob areas is accounted for. During all shifts, a person is stationed at the barrier where the gob is sealed off, and his sole function is to measure the concentration of methane in the pipeline coming from the gob area. In addition, the concentration of methane flowing through all other degasification pipelines is measured at regular intervals, and methane concentrations and volumes are carefully measured at the degasification stations on the surface.

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[9] Note that a mining concession may contain more than one mine. For example, the Darkov mining concession contains the Barbara mine, the Gabriela mine, and the Darkov mine.

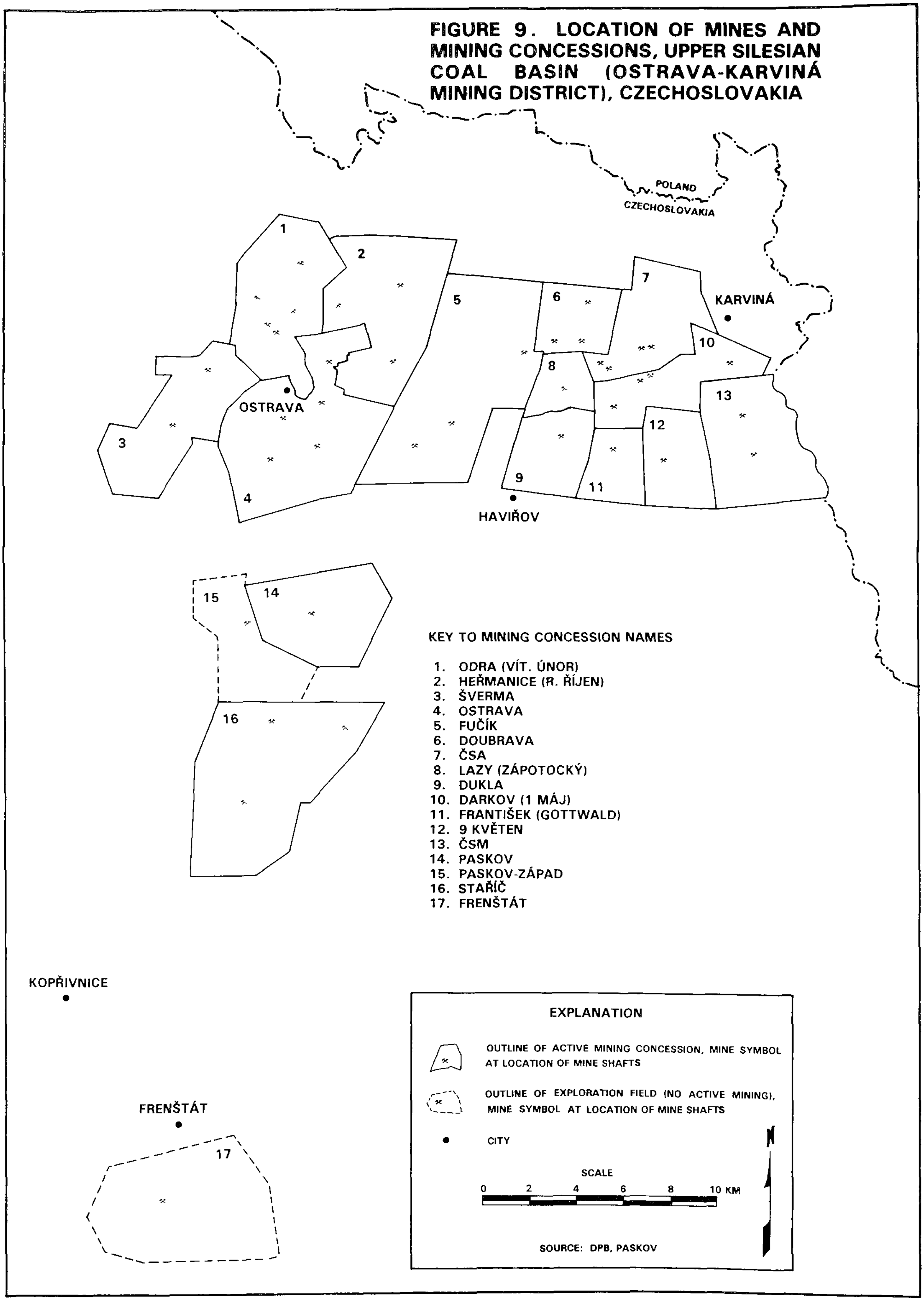


FIGURE 9. LOCATION OF MINES AND MINING CONCESSIONS, UPPER SILESIAN COAL BASIN (OSTRAVA-KARVINÁ MINING DISTRICT), CZECHOSLOVAKIA

TABLE 6. KEY CHARACTERISTICS OF MINE CONCESSIONS IN THE OSTRAVA–KARVINA DISTRICT (1990)

MINE CONCESSION	AVERAGE MINING DEPTH (m)	PRO-DUCTION BEGAN (YEAR)	DOCUMENTED COAL RESOURCES IN ACTIVE MINES (MT): BALANCE[1] RESOURCES: MINE-ABLE	NON-MINE-ABLE	TOTAL	NON-BALANCE[2] RESOURCES	TOTAL RE-SOURCES	COAL PRODUC-TION (kT)	CH4 LIBER-ATED (Mm³)	m³ CH4 PER TON COAL MINED
CONCESSIONS WHOSE MINES ARE EXPECTED TO REMAIN OPEN										
CSA	795	1852	193.1	190.6	383.7	66.4	450.0	1761.5	68.3	38.8
CSM	770	1968	214.3	242.6	457.0	75.0	532.0	1911.9	62.4	32.6
STARIC	750	1970	226.6	43.3	269.9	83.4	353.3	1288.5	59.0	45.8
DARKOV (1 MAJ)	683	1852	324.0	158.7	482.7	99.9	582.6	2945.9	58.3	19.8
PASKOV	740	1967	168.4	43.6	212.1	47.4	259.5	720.0	25.9	35.9
DUKLA	850	1907	54.6	24.8	79.4	21.6	101.0	1769.3	20.6	11.6
DOUBRAVA	730	1856	186.4	98.9	285.3	34.1	319.4	1293.4	18.5	14.3
9 KVETEN	600	1961	72.2	38.4	110.5	18.2	128.7	1137.4	17.6	15.5
LAZY (ZAPOTOCKY)	640	1848	112.1	52.5	164.6	32.7	197.3	1998.2	16.4	8.2
FRANTISEK (GOTTWALD)	800	1911	44.7	16.3	61.0	20.8	81.8	715.3	13.6	19.0
CONCESSIONS WHOSE MINES ARE IN THE PROCESS OF BEING CLOSED OR ARE LIKELY TO BE CLOSED BY 1995										
OSTRAVA	840	1840	83.5	34.9	118.3	42.2	160.5	957.7	46.1	48.1
HERMANICE (R. RIJEN)	660	1843	127.7	28.4	156.2	58.6	214.7	496.0	43.0	86.8
ODRA (VIT. UNOR)	580	1849	60.1	40.1	100.2	47.6	147.9	852.3	31.1	36.4
FUCIK	725	1871	48.0	7.7	55.6	110.9	166.6	1281.1	30.0	23.4
SVERMA (closed Jan. 1992)	850	1892	92.4	15.8	108.2	24.1	132.2	606.2	13.3	21.9
TOTALS (SUM OF ALL CONCESSIONS)			2008.1	1036.6	3044.7	782.8	3827.5	19734.7	524.0	

[1] This category includes only coal from seams greater than 40 cm thick, with ash content less than 60%, found at depths less than 1200 m.

[2] This category includes coal not meeting thickness, ash content, and depth requirements specified in ([1]) above.

TABLE 7. 1990 METHANE EMISSION DATA FROM MINE CONCESSIONS OF THE OSTRAVA–KARVINA DISTRICT (IN MILLION CUBIC METERS). SOURCE: DPB (UNDERGROUND EXPLORATION AND SAFETY ENTERPRISE)

MINE CONCESSION	DIST–TRICT	METHANE LIBERATED BY MINING: BY VENTI-LATION	METHANE LIBERATED BY MINING: BY DRAIN-AGE[2]	METHANE LIBERATED BY MINING: TOTAL LIBERATED	DRAINED METHANE UTILIZED: BY MINE	DRAINED METHANE UTILIZED: BY IN–DUSTRY	DRAINED METHANE UTILIZED: TOTAL UTILIZED	METHANE EMITTED TO ATMOSPHERE	% OF TOTAL LIBERATED METHANE DRAINED	% OF DRAINED METHANE UTILIZED	% OF TOTAL LIBERATED METHANE UTILIZED	% SHARE OF TOTAL METHANE LIBERATED
CONCESSIONS WHOSE MINES ARE EXPECTED TO REMAIN OPEN												
CSA[1]	KARVINA	57.79	10.53	68.32	0.00	10.42	10.42	57.90	15.42	98.87	15.25	18.95
CSM	KARVINA	42.78	19.59	62.36	19.59	0.00	19.59	42.78	31.40	99.96	31.41	17.30
STARIC	OSTRAVA	28.83	30.19	59.02	12.56	15.47	28.03	31.00	51.15	92.81	47.48	16.37
DARKOV (1 MAJ)	KARVINA	35.50	22.79	58.29	7.06	15.02	22.08	36.21	39.09	96.86	37.88	16.17
PASKOV	OSTRAVA	16.38	9.50	25.88	6.19	1.37	7.56	18.32	36.69	79.62	29.21	7.18
DUKLA	KARVINA	12.28	8.27	20.55	0.00	6.69	6.69	13.86	40.24	80.85	32.56	5.70
DOUBRAVA	KARVINA	11.84	6.69	18.52	0.00	6.26	6.26	12.26	36.09	93.57	33.80	5.14
9 KVETEN	KARVINA	11.89	5.73	17.62	5.55	0.00	5.55	12.08	32.53	96.82	31.48	4.89
LAZY (ZAPOTOCKY)	KARVINA	11.12	5.24	16.36	4.95	0.00	4.95	11.42	32.02	94.33	30.22	4.54
FRANTISEK (GOTTWALD)	KARVINA	10.31	3.29	13.60	2.29	0.90	3.19	10.41	24.19	96.67	23.43	3.77
SUBTOTAL		238.73	121.81	360.53	58.19	56.13	114.30	246.23	33.78	93.84	31.70	100.00
CONCESSIONS WHOSE MINES ARE IN THE PROCESS OF BEING CLOSED OR WILL BE CLOSED BY 1995												
OSTRAVA[1]	OSTRAVA	43.12	2.99	46.11	1.48	0.96	2.44	43.66	6.47	81.88	5.30	28.20
HERMANICE (R. RIJEN)	OSTRAVA	34.35	8.69	43.04	0.00	7.52	7.52	35.52	20.19	86.51	17.47	26.33
ODRA (VIT. UNOR)[1]	OSTRAVA	27.58	3.48	31.06	0.94	0.41	1.35	29.71	11.22	38.67	4.33	19.00
FUCIK	OSTRAVA	25.88	4.11	29.98	0.18	0.00	0.18	29.80	13.69	86.51	0.62	18.34
SVERMA[1] (Closed Jan. 1992)	OSTRAVA	13.29	0.00	13.29	0.00	0.00	0.00	13.29	0.00	0.00	0.00	8.13
SUBTOTAL		144.21	19.26	163.47	2.60	8.89	11.49	151.98	11.78	59.66	7.03	100.00
TOTAL (ALL CONCESSIONS)		**382.94**	**141.07**	**524.01**	**60.79**	**65.02**	**125.79**	**398.21**	**26.92**	**89.17**	**24.01**	**100**

[1] Ventilation data from ventilation department, rather than degasification department

[2] Drained methane is that which is recovered from the coal seams via boreholes.Only methane recovered via drainage is utilized. As shown in the column titled "% of Drained Methane Utilized", 89.17% of the methane recovered from OKR mines in 1990 was utilized.

At all mines that have a methane drainage program, both the mine concession's ventilation department and its degasification department (responsible for underground methane drainage) monitor the amount of methane liberated by ventilation. For the ČSM, Ostrava, Odra, and Šverma mine concessions, the methane ventilation data shown in Table 7 reflects measurements made by the ventilation department. For these four concessions, the ventilation department's data is more complete than the degasification department's, because each of these four concessions has one or more mines from which methane is not drained, and therefore no ventilation measurements are made by the degasification department. All mines in the remaining eleven concessions have methane drainage programs, and for those eleven concessions, the ventilation data shown in Table 10 reflects measurements by the degasification department.

Figure 10 is a contour map of methane liberated per ton of coal mined in the OKR; data was gridded and contoured using the Kriging method, which is described in Appendix A. It is evident from this map that coal in the western side of the district liberates more methane per ton of coal mined than coal in the eastern side of the district. The structural style changes across the Orlová-Michálkovice fold/fault feature; on the eastern side most of the displacement is through block faulting, whereas displacement on the western side is by movement along overturned and thrusted folds. The overthrusting may form effective sealing, helping to trap the methane. Structural differences between the two sides of the feature are also manifested hydrologically; mines in the western, gassy area tend to have high water discharge, while discharge of water from mines in the eastern, less gassy area is lower (Appendix C). The overall trend of the contours is consistent with that mapped in Poland (Pilcher et al, 1991).

2.2.2 THE CENTRAL BOHEMIAN COAL BASINS

Introduction

The Central Bohemian Coal Basins, whose location is shown in Figure 6, contain two producing basins: the Kladno Basin, located 25 km west of Prague, and the Plzen Basin, located about 85 km southwest of Prague. The Central Bohemian Coal Basins also include several minor basins whose resources are unknown. Productive area of the Kladno District is approximately 100 km^2; the Plzen District has a productive area of about 70 km^2. Average seam depth is 529 m at Kladno, and 355 m at Plzen.

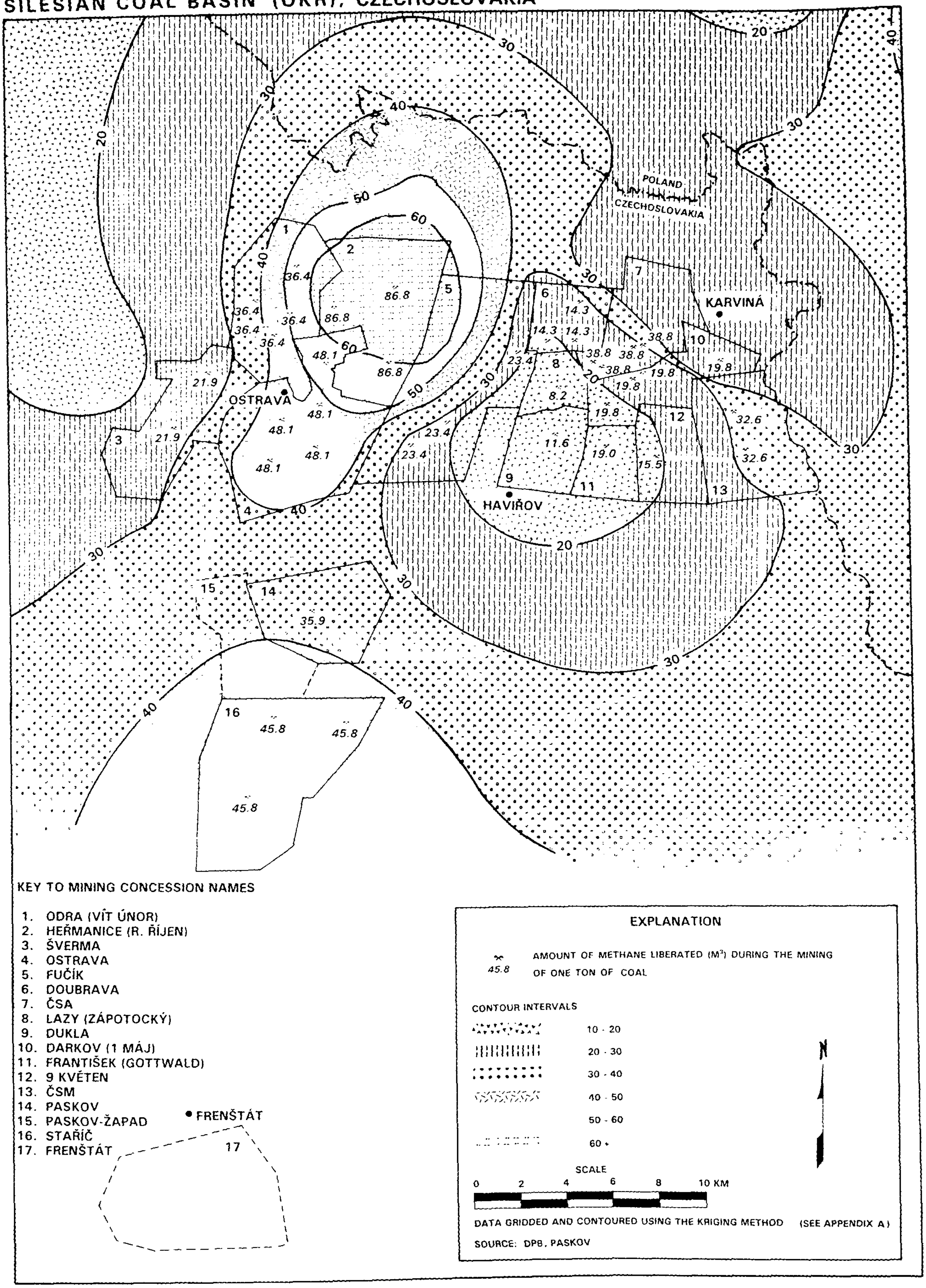
Geologic Setting

The main coal-bearing horizons in the Central Bohemian Coal Basins are of Carboniferous (Westphalian C and D, and Upper Stephanian) age. Stratigraphy is shown in Figure 8. Two formations are coal bearing (Ehrenberger et al, 1985), as described below:

1. Plzen-Kladno (Lower Grey) Formation (Westphalian C, partly D) composed mostly of sandstones and conglomerates, with lesser amounts of siltstones and claystones. This formation contains 3 coal zones, the most productive coalbed is the lowermost Radnice zone, containing 2 seams. The lower coal seam of the Radnice zone has a maximum thickness of 5 m, and a high ash content. The upper seam is more widespread and has an average thickness of 5-6 m.

2. Slaný (Upper Grey) Formation (Stephanian B) - composed of mostly sandstones and claystones. Coal of the Mělnik Group is unworkable, but the Kounov Group contains mineable seams, which rarely exceed 1 m in thickness.

FIGURE 10. CONTOUR MAP OF METHANE LIBERATED DURING MINING, UPPER SILESIAN COAL BASIN (OKR), CZECHOSLOVAKIA



The Kladno and Plzen Basins are tectonically similar to one another, and they were formed by the same series of events. Much of the faulting in these basins occurred during Permian (Saxonian) time, and the horst-and-graben tectonic pattern of the basins is shown in the tectonic map of the Plzen Basin (Figure 11). On average, seams mined in the Kladno Basin are 3.9 m thick and the coal contains 0.7 percent sulfur, 21 percent ash, and has an average heating value of 20.5 MJ/kg. Average thickness of mined seams in the Plzen Basin is 1.5 m, and the coal averages 0.4 percent sulfur, 39.8 percent ash, and only 16.7 MJ/kg heating value. Moisture content in both basins varies widely, from 6 percent to 25 percent, and coal rank ranges from subbituminous to low-volatile bituminous, with subbituminous coal predominating.

Coal Resources and Production

As shown in Table 8, coal production from the Central Bohemian Coal Basins totalled 1.6 million tons in 1990, only 7 percent of Czechoslovakia's hard coal production. Roughly 84 percent of coal produced from the Central Bohemian Coal Basins came from the Kladno Basin. Total documented resources of the basins are estimated at nearly 500 million tons, 89 percent of which is found in the Kladno District.

Mining began in the Kladno Basin around 1776, and while 9 major mine concessions have been delineated (Figure 12), only two of them (Libušín and Tuchlovice) are presently being mined. Production decreased by 21 percent between 1988 and 1990, due to rising extraction costs and decreased demand. Mining costs are subsidized, and it is likely that subsidies will end in the future, resulting in mine closures.

TABLE 8. HARD COAL PRODUCTION AND RESOURCES OF THE CENTRAL BOHEMIAN COAL BASINS (IN MILLION TONS)

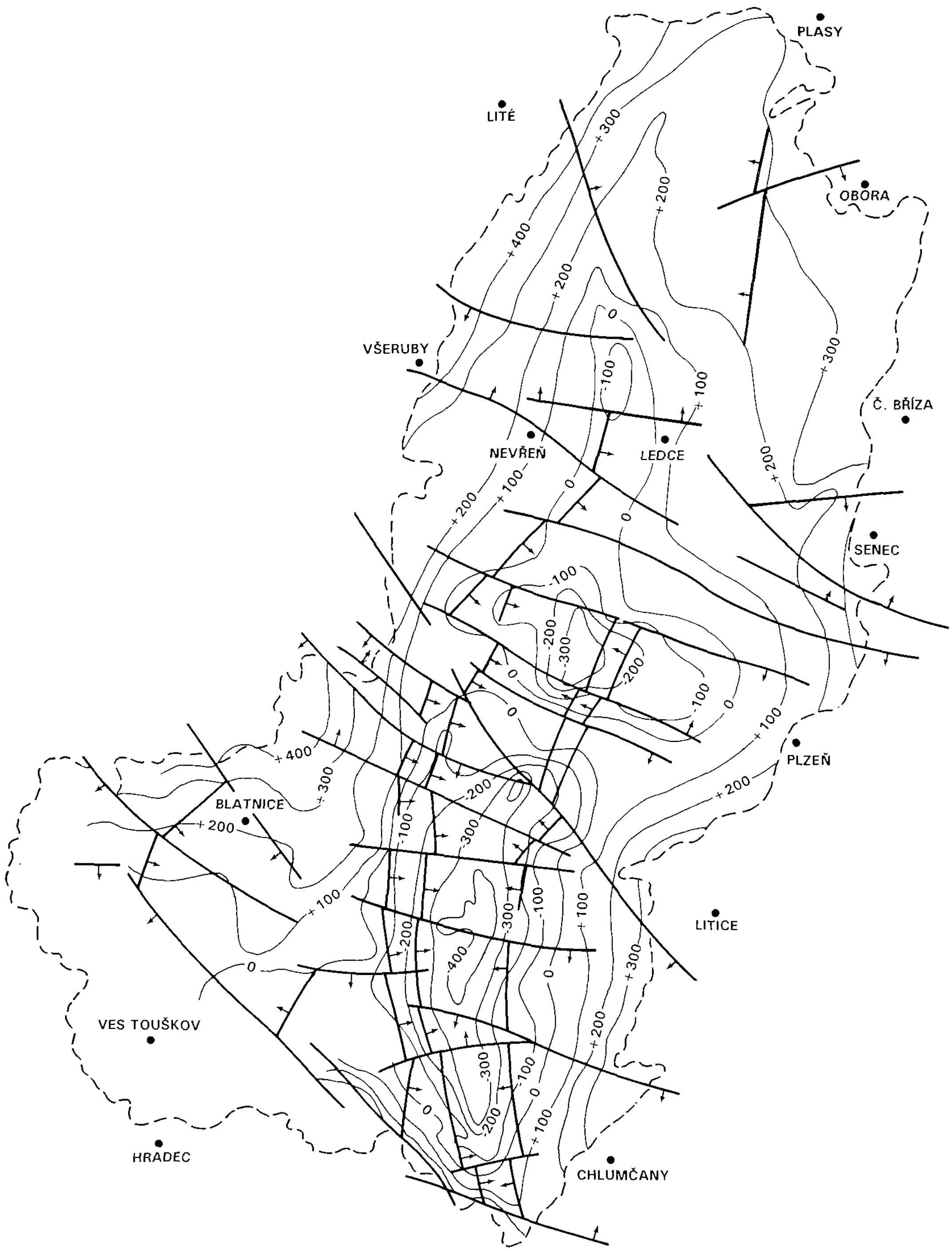
BASIN	1990 COAL PRODUCTION	DOCUMENTED RESOURCES	PROGNOSTIC RESOURCES	TOTAL RESOURCES
Kladno	1.31	443.03	571	1,014.03
Plzen	0.26	56.65	40	96.65
TOTAL	1.56	499.68	611	1,110.68
Source: MEPDCR, 1991				

Mining began in the Plzen Basin around 1793, and presently two concessions (Vejprnice and Dobřany) are operating. Production decreased by 31 percent between 1988 and 1990, primarily due to rising extraction costs and decreased demand. These Plzen mines are expected to be closed within the next few years. Non-mechanized longwall mining is the principal method used in both Kladno and Plzen.

Methane Liberation

The methane content of coal in the Central Bohemian Basins is generally considered to be low, and no methane emissions have been officially reported. Gas associated with coal in Kladno Basin mines is also reported to have a high carbon dioxide content (Koun, 1991). A joint venture between CenGaz Company and VKD (the state-owned mining enterprise at Kladno), to explore for coalbed methane at the inactive Slaný mine and other mine concessions in the Kladno Basin, was recently formed (MEPDCR, 1991). At time of publication, no information on the progress of this venture was available.

FIGURE 11. TECTONIC MAP OF THE PLZEŇ BASIN, CZECHOSLOVAKIA



EXPLANATION

NORMAL FAULT, ARROW ON DOWNTHROWN SIDE

BOUNDARY OF CARBONIFEROUS

+200 CONTOUR OF BASEMENT

• CITY

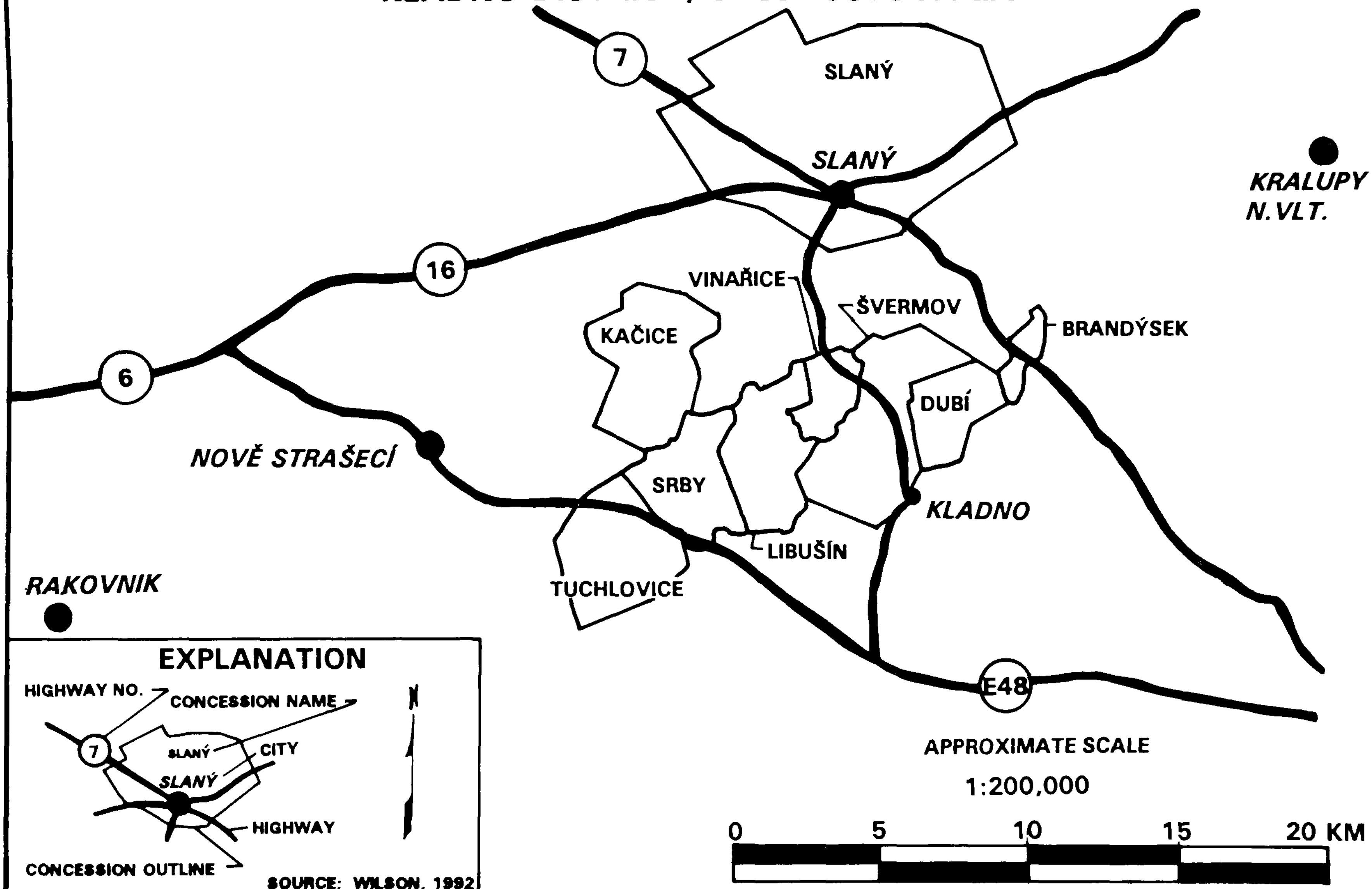
SCALE

0 2.5 5 7.5 10 KM

CONTOUR INTERVAL: 100 METERS

SOURCE: LOZEK AND PETRANEK, 1966

FIGURE 12. LOCATION OF MAJOR MINE CONCESSIONS, KLADNO DISTRICT, CZECHOSLOVAKIA



No problems with methane have been encountered in the Plzen Basin, and no emissions of methane from the basin's mines have been reported.

2.2.3 THE LOWER SILESIAN COAL BASIN (TRUTNOV DISTRICT)

Introduction

Only the southwestern limb of the Lower Silesian Coal Basin, whose location is shown in Figure 6, extends from Poland into Czechoslovakia, where it is known as the Trutnov District. The total area of the District is approximately 470 km^2, however the productive area is only about 50 km^2 (Ehrenberger et al, 1985).

Coal mining began in the Trutnov District (Figure 13) in the 1700's. Presently, coal is produced from 2 mine concessions. Trutnov District coal is high volatile to low volatile bituminous in rank; it is not suitable for coking (Ehrenberger et al, 1985). Average seam depth is 533 m.

Geologic Setting

The Lower Silesian Coal Basin originated as a large intermontane trough, trending northwest-southeast, in a late Paleozoic mountain range. The general stratigraphy of the Trutnov District is shown in Figure 8. Sedimentation in the district began with the Žacléř Formation (Westphalian A through C). The Žacléř Formation is composed of conglomerates, sandstones, minor siltstones, claystones, and coal beds. Near the town of Žacléř, it contains two coal groups, divided by thick strata. Here, the thickness of the Žacléř Formation reaches nearly 700 m; it decreases toward the southeast, and the amount of coal it contains also decreases.

Overlying the Žacléř Formation is the Odolov Formation (Westphalian D through Stephanian B), which has a total thickness of 1200 m and consists of two members:

> the Svatonovice Member, approximately 400 m thick, with 4 coal seams (2 of which are developed) in the upper part; and
>
> the Jívka Member, whose Radvanice Group includes 6 coal seams in a 100 to 150 m thick coal bearing interval.

Most of the coal resources in the Trutnov District are within seams of the Žacléř Formation. Only 24 seams in this formation are mined, each of them averaging about 1 m in thickness. The Odolov Formation is also mined; four coal seams occur in the Svatonovice Member, two of which are mined, and six coal seams occur in the Radvanice Member, two of which are mined. Mined seams in the Trutnov District average 1.2 m thick.

Coal Resources and Production

As shown in Table 9, coal production from the Trutnov District totalled 459 thousand tons in 1990, only 2 percent of all hard coal production in Czechoslovakia. Total documented resources of the basin are estimated at 314 million tons.

FIGURE 13. GEOLOGIC MAP OF THE TRUTNOV COAL DISTRICT, CZECHOSLOVAKIA

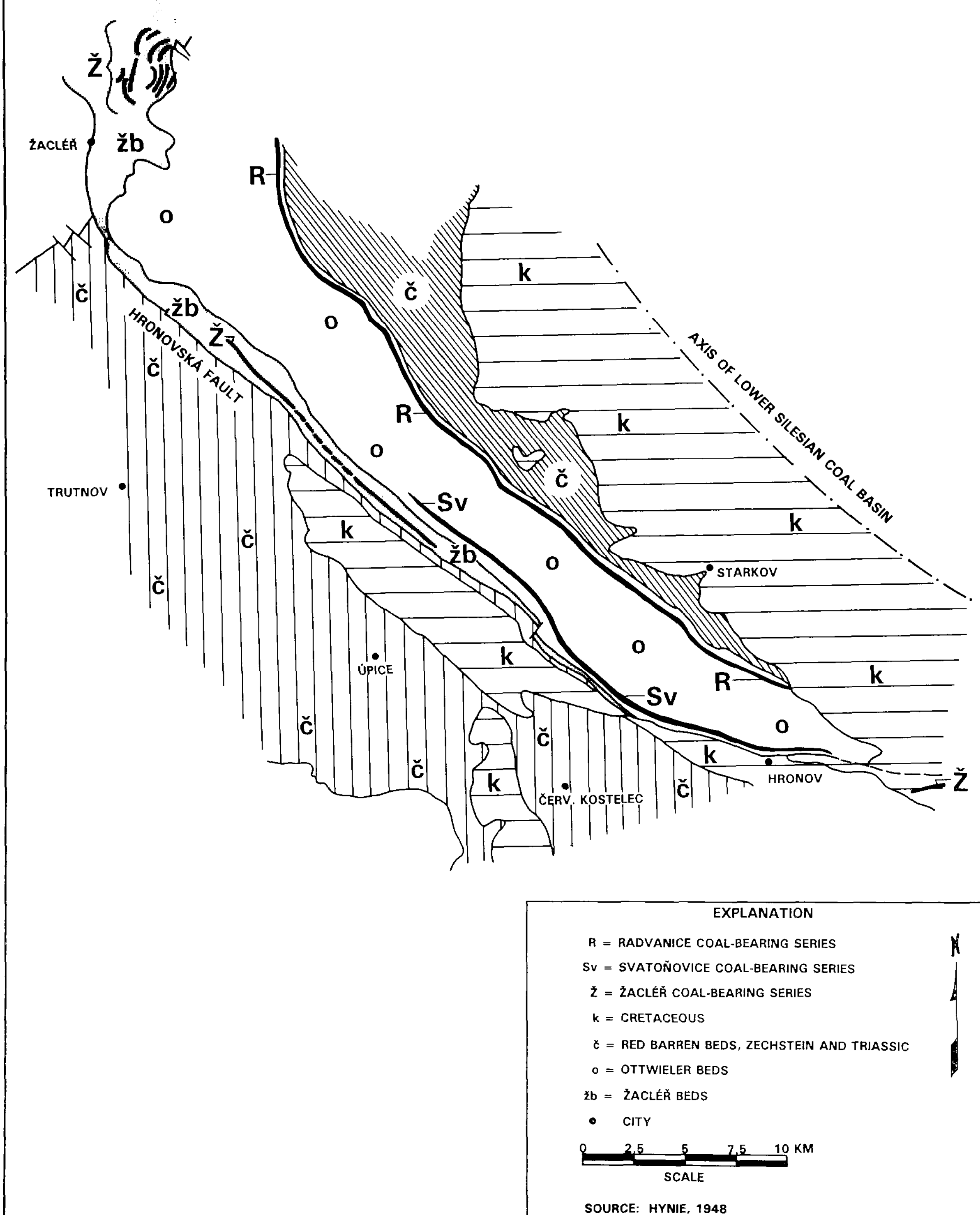


TABLE 9. HARD COAL PRODUCTION AND RESOURCES OF THE TRUTNOV DISTRICT (IN MILLION TONS)

1990 COAL PRODUCTION	DOCUMENTED RESOURCES	PROGNOSTIC RESOURCES	TOTAL RESOURCES
0.46	313.63	150	463.63
Source: MEPDCR, 1991			

Coal is presently produced from the Jan Šverma and Kateřina mining concessions; longwall mining is the principal method used. Production decreased by 31 percent between 1988 and 1990, and negotiations regarding restructuring or closure of these mines is underway. Coal mined from both concessions has high concentrations of radioactive elements, and new laws on disposal of radioactive waste will further reduce the economic viability of the mines (Koun, 1991). There are also other problems with coal quality; average sulfur content of coal mined from the Trutnov District is 1 percent, for example, average ash content is 45 percent, average moisture content 4.4 percent, and average heating value is only 16.2 MJ/kg.

Methane Liberation

It is reported that coal of the Trutnov District has a higher methane content than that of the Kladno District, and there is some data available on mining emissions. Apparently, no methane is utilized by the mines, and all is emitted to the atmosphere. Table 10 contains methane emission data for the Trutnov District received from the MEPDCR in 1991; the year in which these measurements were taken is not specified but it is assumed that the data is current as of 1990.

TABLE 10. METHANE AND CARBON DIOXIDE EMISSIONS FROM ACTIVE COAL MINES OF THE TRUTNOV DISTRICT

MINE	ANNUAL METHANE EMISSIONS (thousand m^3)	1990 COAL PRODUCTION (MT)	METHANE EMITTED PER TON COAL MINED	CARBON DIOXIDE EMISSIONS (thousand m^3)
JAN SVERMA	803.0	N/A		12,799.1
KATEŘINA	up to 36.5	N/A		2,646.3
TOTAL	up to 839.5	0.46	up to 1.8 m^3/ton	15,445.3
Source: MEPDCR, 1992				

This data indicates that the Trutnov District coal has a much higher carbon dioxide content than methane content. The presence of carbon dioxide appears to be related to northwest-southeast trending faults, where carbon dioxide from the underlying outgassing intrusions accumulates.

2.2.4 THE BOSKOVICE TROUGH

Introduction

The Boskovice Trough, also known as the Rosice Basin, is a narrow, north-northeast trending belt west of Brno in the Czech Republic (Figure 6). It is approximately 75 km long, and its productive area is approximately 20 km^2 (Ehrenberger, 1985).

Mining began in the Boskovice Trough in the 1850's. Presently, coal is produced from 1 mine concession. Coal rank is medium volatile and high volatile bituminous. Mining depth is around 500 m.

Geologic Setting

The Boskovice trough was formed during tectonic movements of the Asturian Orogeny, which occurred in Late Carboniferous time. The trough is filled by material transported from rising regions of the Bohemian Massif. Sedimentation began in latest Carboniferous (Stephanian) time and extended through the Early Permian. The sequence consists of a basal conglomerate, overlain by sandstones, siltstones, claystones, coal beds, marlstones, and carbonates.

Three coal beds, all dated as uppermost Stephanian, occur in the above described sequence. The uppermost seam is the most widespread; its thickness is usually between 3 and 4 meters, but reaches 10 meters in places; average thickness of mined seams is 3.1 meters. Coal beds dip 40-50 degrees, except in the southern part of the basin where dip is less.

Coal mined from the Boskovice trough averages 2.7 percent sulfur, 47.3 percent ash, 2.8 percent moisture, and has an average heating value of 16.8 MJ/ton.

Coal Resources and Production

Coal production from the Boskovice Trough totalled 140 thousand tons in 1990, which was less than 1 percent of hard coal produced in Czechoslovakia. Total documented resources of the basin are estimated at 26 million tons. Estimates of prognostic resources were not available.

Coal is presently produced from the Jindřich mining concession. Production decreased by 41 percent between 1988 and 1990, and all mining in the Boskovice Trough is expected to cease by the end of 1992.

Methane Liberation

Methane outbursts have been reported in mines of the Boskovice Trough, but no methane emissions data was available. Apparently, no utilization of coalbed methane is taking place.

2.3 COALBED METHANE RESOURCE ESTIMATES

Preliminary estimates suggest Czechoslovakia's coalbed methane resources are large. Ideally, resource estimates should be based on gas content measurements of Czechoslovakian coals. Because such data are currently unavailable, two alternative resource estimation methodologies are used in this report. The first approach is based on specific emissions, and the second approach is based on measured gas contents from coals in nearby Polish mining concessions. As more detailed information becomes available, these estimates can be refined and improved.

2.3.1 ESTIMATES ACCORDING TO SPECIFIC EMISSIONS

"Specific emissions" refers to the volume of methane liberated per unit weight of coal mined during a given time period, commonly expressed in m^3 per ton. The resulting values are estimates of the methane contained in the coal bearing package, rather than just the potential target coal seams. Therefore, unless specific emissions values are adjusted to account only for methane contained in the target coal seams, resource estimates may be inflated.

Table 11 shows the methane resources associated with active OKR coal mining concessions, estimated according to methods A through E. Method A calculates methane resources by multiplying the unadjusted specific emissions for a given mining concession, by the coal reserves contained in that concession, thereby potentially including the methane contained in the entire rock package. Methods B and C adjust these values by assuming that the gas contained in target coal seams in the OKR ranges from 10 percent (Method B) to 65 percent (Method C) of that contained in the entire rock package. The basis for this assumption is explained below.

Diamond et al (1991) reported that approximately 90 percent of the gas liberated into the mine workings during mining of the Upper Kittaning coalbed in Pennsylvania (the Northern Appalachian Basin) emanates from coal seams overlying the target coal seam, and from strata down dip. Researchers at the Skochinsky Institute (1992) in Russia report that the gas contained by coal seams and thin intervening partings ranges from 10 percent to 65 percent in various mining districts of the Donetsk Basin of Ukraine and Russia, and that the remaining gas--ranging from 35 to 90 percent of emissions--is emitted from non-coal rocks. The primary cause of disparity between the two observations is lithologic differences between the two coal bearing intervals that were studied, suggesting that this variable depends on the lithologic and structural characteristics of a specific basin, or even more localized regions within a given basin.

Using unadjusted specific emissions can cause the coalbed methane resource to be overestimated if adjacent coal seams that were included in the coal resource estimate are the source of some of the methane that is emitted into the mine workings during mining. The coalbed methane resource would be "double counted" because the weighted average of the gas liberated during mining would include the gas from the adjacent mineable seams and the target seam, but would not consider that some of the methane would be depleted from some of the coal resource. In the OKR this factor is minimized due to the fact that during exploitation of the coal reserves, mining of coal bearing intervals usually proceeds from top to bottom of the sequence, and the structural continuity caused by caving and development of the gob area is in an upward direction, away from unmined coal resources.

The same resource estimation methods are used in Table 12, which summarizes the estimated methane resources contained in active mining concessions, as well as those contained in undeveloped coal deposits, inactive mines, and in prognostic (undiscovered) coal deposits.

TABLE 11 . ESTIMATED METHANE RESOURCES ASSOCIATED WITH COAL MINING CONCESSIONS IN THE OKR (1990)

		ESTIMATED METHANE RESOURCES (MILLION CUBIC METERS) CALCULATED ACCORDING TO:									
		A). SPECIFIC EMISSIONS		B). 10 PERCENT OF SPECIFIC EMISSIONS		C). 65 PERCENT OF SPECIFIC EMISSIONS		D). ASSUMED GAS CONTENT (4.4 m^3/T)		E). ASSUMED GAS CONTENT (23.0 m^3/T)	
MINE CONCESSION	SPECIFIC EMISSIONS (m^3 / TON)	BALANCE RESERVES[1]	TOTAL DOCUMENTED RESERVES[2]	BALANCE RESERVES	TOTAL DOCUMENTED RESERVES	BALANCE RESERVES	TOTAL DOCUMENTED RESERVES	BALANCE RESERVES	TOTAL DOCUMENTED RESERVES	BALANCE RESERVES	TOTAL DOCUMENTED RESERVES
CONCESSIONS WHOSE MINES ARE EXPECTED TO REMAIN OPEN											
CSA	38.8	14,882	17,455	1,488	1,746	9,673	11,346	1,688	1,980	8,825	10,351
CSM	32.6	14,905	17,352	1,491	1,735	9,688	11,279	2,011	2,341	10,510	2,236
STARIC	45.8	12,363	16,183	1,236	1,618	8,036	10,519	1,188	1,555	6,208	8,126
DARKOV (1 MAJ)	19.8	9,550	11,527	955	1,153	6,208	7,493	2,124	2,563	11,101	3,399
PASKOV	35.9	7,622	9,325	762	933	4,954	6,062	933	1,142	4,878	5,968
DUKLA	11.6	922	1,173	92	117	600	762	349	444	1,826	2,322
DOUBRAVA	14.3	4,085	4,574	409	457	2,655	2,973	1,255	1,405	6,562	7,346
9 KVETEN	15.5	1,712	1,994	171	199	1,113	1,296	486	566	2,542	2,960
LAZY (ZAPOTOCKY)	8.2	1,348	1,616	135	162	876	1,050	724	868	3,786	4,538
FRANTISEK (GOTTWALD)	19.0	1,160	1,555	116	156	754	1,011	268	360	1,403	1,881
CONCESSIONS WHOSE MINES ARE IN THE PROCESS OF BEING CLOSED OR ARE LIKELY TO BE CLOSED BY 1995											
OSTRAVA	48.1	5,697	7,728	570	773	3,703	5,023	521	706	2,722	3,692
HERMANICE (R. RIJEN)	86.8	13,552	18,634	1,355	1,863	8,809	12,112	687	945	3,592	4,939
ODRA (VIT. UNOR)	36.4	3,653	5,390	365	539	2,375	3,503	441	651	2,306	3,401
FUCIK	23.4	1,302	3,898	130	390	846	2,534	245	733	1,280	3,831
SVERMA (closed 1 / 92)	21.9	2,372	2,899	237	290	1,542	1,884	476	582	2,488	3,041
TOTALS (ALL CONCESSIONS)		95,126	121,303	9,513	12,130	61,832	78,847	13,397	16,841	70,027	88,032

[1] Refers to methane resources associated with balance coal reserves. Balance coal reserves contain seams greater than 40 cm thick, with ash content less than 60%, and must be at depths less than 1200 m.

[2] Refers to methane resources associated with documented coal reserves. Documented coal reserves = balance + non-balance reserves; non-balance reserves are those not meeting thickness, ash content, and depth criteria specified in ([1]) above

TABLE 12. ESTIMATED METHANE RESOURCES OF THE OSTRAVA-KARVINÁ DISTRICT (IN BILLION CUBIC METERS)

	A. SPECIFIC EMISSIONS[1]	B. 10% OF SPECIFIC EMISSIONS	C. 65% OF SPECIFIC EMISSIONS	D. ASSUMED GAS CONTENT (4.4 m^3 / T)	E. ASSUMED GAS CONTENT (23.0 m^3 / T)
I. DOCUMENTED[2] METHANE RESERVES (In Mine Concessions Active as of 31 Dec. 1991)					
Ia). In Coal of the Balance Resource Classification					
Mineable	64.0	6.4	41.6	8.8	46.2
Non-Mineable	31.1	3.1	20.3	4.6	23.8
Subtotal	**95.1**	**9.5**	**61.9**	**13.4**	**70.0**
1b). In Coal of the Non-Balance Resource Classification					
	26.2	2.6	17.0	3.4	18.0
TOTAL DOCUMENTED METHANE RESERVES					
	121.3	**12.1**	**78.9**	**16.4**	**88.0**
2. PROGNOSTIC[2] METHANE RESOURCES					
2a) . In Coal of Undeveloped Deposits (Including Inactive Mines)					
	252.6	25.3	164.2	35.1	183.3
2b). In Coal Deposits Classified as Prognostic (Undiscovered)					
	136.9	13.7	89.0	19.0	99.4
TOTAL PROGNOSTIC METHANE RESOURCES					
	389.5	**39.0**	**253.2**	**54.1**	**282.7**
TOTAL METHANE RESOURCES (TOTAL DOCUMENTED + TOTAL PROGNOSTIC)					
	510.8	**51.1**	**332.1**	**70.5**	**370.7**

[1] Specific emission value is 37.1, based on a weighted average of the specific emissions values for each mining concession listed in Table 11.

[2] The term "documented methane reserves", as used here, denotes those associated with active (as of 1991) mining concessions. "Prognostic methane resources" denotes those associated with a) coal resources in undeveloped documented coal deposits (including inactive mining areas) or b) coal resources officially categorized as prognostic.

2.3.2 ESTIMATES ACCORDING TO ASSUMED GAS CONTENTS

Typically, the coalbed methane resources of a coal basin are assessed by multiplying the amount of coal in different sections of the basin by the gas content of the coal in each section. The coal gas content is determined from desorption tests performed on coal samples from these various sections of the basin. Ideally, therefore, the coalbed methane resources of Czechoslovakia would be assessed using gas content data from coal desorption tests performed on numerous samples collected throughout the OKR and other Czechoslovakian basins.

However, as noted previously, desorption data indicating gas contents of Czechoslovakian coals is currently unavailable. Coal gas content data from nearby concessions in the Polish part of the Upper Silesian Coal Basin was used instead. Coal gas contents obtained from 17 Polish mining concessions ranged from 4.4 to 23.0 m^3 per ton. It is assumed that this range of gas contents is reasonably similar to coal gas contents in the OKR, as the coals are of the same rank. Therefore, as shown in Tables 11 and 12, coal resources of the OKR were multiplied by 4.4 m^3 per ton and 23.0 m^3 per ton in methane resource estimation methods D and E, respectively.

The reliability of using this range of assumed gas contents is limited by two factors. First is the obvious limitation associated with attempting to estimate coal resources of the OKR using coal gas contents from sources outside of the OKR. The second limitation involves the technique used for coal gas content estimates in Poland, which may not adequately account for gas lost from coal samples prior to sealing in desorption canisters. The reliability of coal gas content estimates is affected by the technique used to collect coal samples, and by the methodology used for estimating the amount of in-situ gas contained by the coal.

A coal gas content estimate comprises three components: the gas that is desorbed and measured, the gas that is not desorbed and remains in the coal (residual gas), and the unmeasured gas that desorbs during the time that elapses from the moment the coal sample is cut from the seam, until the moment it is sequestered in an airtight container. This latter component is called "lost gas". Generally, in developing an estimate of the coalbed methane resources contained in a coal field, only the measured gas and the unmeasured lost gas are considered. Residual gas is, by definition, not likely to be produced during the coal or methane extraction processes, so it is not considered to be of commercial importance, nor is it a potential source of methane emissions during mining. It is likely, however, that some of the residual gas is emitted during coal handling and crushing operations prior to combustion.

Difficulties arise in estimating the amount of lost gas, and many techniques have been proposed. Any technique that is to be used with confidence must provide a volume correction factor that accounts for the amount of gas that is likely to desorb at a specific rate under the temperature and pressure conditions extant at the time of sampling. Gas contents used in this report were calculated according to Polish methodology, which uses a constant volume correction factor. Because the same volume correction factor is used for every coal sample, it does not take into account regional variations in temperature or pressure gradients, which are usually significant, nor does it account for the significant changes in temperature or pressure that the sample is exposed to as it travels uphole during core retrieval. If temperature or pressure gradients are large, they can greatly increase the amount of lost gas, which in turn influences the gas content of the coal. For example, laboratory experiments comparing desorption rates vs. coal depth have been performed in Raven Ridge Resources' laboratory. These experiments have shown that, at a geothermal gradient similar to that of the OKR and adjacent Poland, under constant pressure the rate of desorption increases 1.3 times for each 700 m of depth, during the first minute of desorption. The constant volume correction factor used in estimating gas contents in Poland would not account for this significant increase in the desorption rate. Therefore, the assumed gas contents used for resource estimation in this report may be too low and may underestimate the size of the coalbed methane resource.

2.3.3 DISCUSSION OF COALBED METHANE RESOURCE ESTIMATES

Using the specific emissions method adjusted as described in Section 2.3.1, and the assumed gas contents as described in Section 2.3.2, the coalbed methane resource of the OKR is estimated to be 51 to 371 billion m^3, of which 12 to 88 billion m^3 are documented (associated with active mining concessions) and 39 to 283 are prognostic, as shown in Table 12. Appendix B compares these resource estimates with estimates from other Carboniferous coal basins.

It is assumed that the coalbed methane resource of the OKR is within the range reflected in this preliminary resource estimate. Moreover, this resource estimation methodology may underestimate Czechoslovakia's total coalbed methane resources for several reasons:

- First, these methane resource estimates are based on official coal resource estimates, developed as part of mining resource assessments. It is unlikely that they account for coals buried deeper than 1500 m, which is beyond the economic and technological limits of mining in the OKR. There may be more deeply buried coals that contain large amounts of gas in the OKR, however. Coalbed methane is being produced from coal seams and associated sandstone reservoirs in the Piceance Basin of western Colorado, USA at depths up to 2600 m, which suggests that exploration and development of deep resources of coalbed methane in Czechoslovakia should be attempted.

- Second, no resource estimates were prepared for other Czechoslovakian basins, such as the Kladno Basin and Lower Silesian Basin (Trutnov District), which may also contain significant amounts of gas.

- Third, the upper limit of the resource estimate is based on a coal methane content that may not account for lost gas, as discussed in Section 2.3.2 above.

Assessment of coalbed methane resources in Czechoslovakia could be improved by obtaining accurate gas content measurements and estimates of producibility from coals of the OKR and other coal basins. Ideally, this would involve drilling boreholes at selected sites and analyzing the resulting geological, geophysical, and geochemical data. Data that would be collected and analyzed from such a program would include: horizontal and vertical variations in permeability, lateral variations in gas content, hydrologic parameters, lateral continuity of the coals, and estimates of the gas contained in adjacent lithologies.

2.3.4 THE RECOVERABILITY OF COALBED METHANE

The amount of coalbed methane that can be recovered is, to a large extent, determined by natural characteristics of the coal-bearing rock package, including the geologic conditions in which it presently exists. For the most part, these natural characteristics cannot be altered by technological efforts. The primary factor that may limit production of methane from a coalbed is the coal's matrix permeability, which is its capacity to transmit fluids along the pore spaces. Matrix permeability of the Carboniferous coals found in European basins is low, but in some cases, post-depositional structures such as fractures or cleats may serve as natural pathways along which the methane can be transported. In this case, the matrix permeability is not increased, but accessibility to pores within the coal is improved. Likewise, stimulation techniques used to increase productivity of methane from the coalbed do not create permeability, but simply enhance access to the pore space, linking the borehole to naturally occurring permeability.

Successful recovery depends on the coalbed's natural capacity for gas production, and the design and implementation of stimulation and completion techniques appropriate to the conditions. It is difficult to estimate the amount of gas that will be recovered from a coalbed methane deposit without some prior experience in similar geologic conditions. Many companies expect to recover at least 30 to 35 percent of the in-place reserves. However, a study in the Black Warrior Basin of Alabama shows that in one case the methane contained in the coal had been drained after ten years of production (Diamond et al, 1989). Unfortunately, until exploration and production of methane from the Upper Silesian Coal Basin proceeds, recoverable reserves can only be estimated by comparison with other basins having similar geologic characteristics.

CHAPTER 3

COALBED METHANE RECOVERY AND UTILIZATION POTENTIAL IN CZECHOSLOVAKIA

3.1 COALBED METHANE RECOVERY

Reducing the concentration of methane in mine ventilation gas is a prime safety concern of coal mines throughout the world. This can be accomplished by increased ventilation, which can involve adding additional ventilation shafts or increasing the size of the fans, or by decreasing the amount of gas contained in the coal through methane drainage. As the amount of methane liberated per ton of coal mined increases, the capacity of the ventilation system must also increase. As shown in Table 6, this ratio is high for those mine concessions which liberated the greatest amounts of methane. Experience elsewhere has shown that there are economic limits to the amount of methane that can be removed from ventilation systems alone. However, there are no economic benefits to simply ventilating methane in a region where natural gas is imported for use. In addition, the Czech Ministry of Environment, in accordance with the recently enacted Hydrocarbons Law, plans to impose fines for coalbed methane emissions. Reportedly, the fines will go into effect sometime in 1992. The fine structure, based on a progressive increase of Czechoslovakian Korunas (Kcs[10]) per ton of methane emitted (assuming the specific weight of methane is 0.7 kg/m^3, or 95 percent methane concentration) is shown in Table 13. The individual mine concessions, rather than OKD, will be held accountable for emissions and imposed fines.

Table 7 shows that all mines in the OKR (except Šverma, which is now closed) are utilizing methane recovered by drainage; but, as of 1990, methane drainage recovered only 27 percent of the total methane liberated by mining. In addition, only 89 percent of the drained methane is currently utilized. Significantly more gas could be available for utilization with an integrated approach to drainage in conjuction with mining operations.

[10] Throughout this report, a 1991 conversion rate of 30 Czechoslovakian korunas to 1 U.S. dollar is used.

TABLE 13. PROPOSED FINE STRUCTURE FOR METHANE EMISSIONS

(Jaroš et al, 1991)

Year(s)	Fine for Methane Emissions	
	Kcs per ton CH_4	1991 $US per m^3 CH_4
1992-1993	600	$0.014
1994-1995	1200	$0.028
1996	1600	$0.037
1997	2000	$0.047

3.1.1 METHANE DRAINAGE METHODS

The predominant method of methane drainage from coal seams in the OKR is by means of upward-inclined boreholes drilled from the entryways into the strata above the coal seam to be mined. These boreholes range in length from 10 to 60 m, and the spacing of the boreholes is directly proportional to the amount of gas anticipated to be contained in the coals. This methane content value is indirectly derived based on the amount of methane liberated from the mined seam. (In contrast, the method for deriving gas content in the U.S. is direct laboratory measurement of the methane desorbing from the coal, and/or the amount of methane the coal is capable of adsorbing).

After the drainage boreholes are drilled, casing is placed in the holes and connected to an in-mine methane drainage pipeline system. The methane contained in the overburden is then drawn out by a system of pumps located at the surface. This process is started in advance of mining and is also used to drain the methane from the remaining gob.

The efficiency of gob drainage is dependent on effectively sealing the gob area. The quality of the drained gas, both from the boreholes as well as the gob, averages between 52 and 60 percent methane. Downward-inclined boreholes have been drilled in the past to drain methane from the underlying strata, but the boreholes filled up with water which was brought down from the surface for use in mining operations, and methane production was very low.

Another methane drainage method is used exclusively at the ČSM mine. An entryway is developed into a non-productive coalbed underlying the coal seam to be mined, and upward-inclined boreholes are drilled, intersecting several thin non-mineable coal seams between the entryway and the targeted seam. These boreholes are then connected to the methane drainage pipeline system and methane production is continued until no longer economic. When this method is combined with the previously described method, the overall efficiency increases to 65 percent.

3.1.2 OPTIONS FOR INCREASED RECOVERY

As stated previously, an integrated approach to mine drainage could maximize the recovery of methane within Czechoslovakia's mining concessions and improve mine profitability and safety. This approach could include recovery of methane before, during, and after mining, both from the surface and within the mine. Table 14 summarizes the four main methane recovery options and indicates the potential for recovery of each. If all methods of recovery were implemented and coordinated with mining activity, as much as 80-95 percent of the methane liberated could be recovered.

The Jim Walter Resources (JWR) mines in the Black Warrior Basin in Alabama, USA exemplify the economic success of an integrated mine drainage system. As increasingly gassy seams were encountered, it became uneconomic to increase the size of the ventilation fans. Moreover, even with larger fans, coal production would be limited to uneconomic levels unless drainage techniques were used. By initiating an integrated vertical and horizontal drilling and a post-mining gob methane drainage program, the mines were able to improve safety, increase productivity, and operate more profitably.

As an example, JWR No. 4 mine, which produces more than 2 million tons of coal annually, would have to double the air flow need for mine ventilation if it did not employ gob drainage. The additional ventilation shafts would cost an estimated $15 million US. The additional power to run them would cost $0.91 US per ton of coal, and many more underground airways would be required. JWR mine engineers state that this would not be feasible, either technically or economically. In addition to money saved as a result of the methane drainage program, proceeds from methane sales provide further revenue. JWR has sold more than 1.5 billion cubic meters of pipeline quality gas since 1983 (Dixon, 1990). Its methane recovery efficiency is currently 35-40 percent.

The optimal methane recovery program will be determined by many factors, including technical considerations such as mine safety requirements, gas quality and quantity, economic factors, regional energy needs, environmental objectives, and time considerations. Note that the recovery potential of Stages I through III is proven, but that Stage IV needs demonstration.

3.2 COALBED METHANE UTILIZATION

As shown in Table 7, nearly ninety percent of the coalbed methane drained from OKR mines in 1990 was utilized. Compared with many coal mining areas of the world, this is an excellent utilization rate. About half of the utilized gas is consumed by the mines, while the remaining half is sold to Northern Moravian Pipeline (SMP) for consumption by outside industries, including metallurgical plants and power plants. Only 27 percent of the total methane liberated from OKR mines is currently drained, however, and thus improved methane drainage could greatly increase the amount of coalbed methane available for utilization.

OKR mines presently use in-mine methane recovery (Stage II). It appears that implementation of vertical pre-mining methane recovery (Stage I) and post-mining methane recovery (Stage III) could increase gas recovery and would reduce the amount of methane emitted through the ventilation system. The quality of this gas is typically high and it is likely that this gas could be transported in existing natural gas pipelines.

While coalbed methane could be used as an alternative to hard coal, the most economical use of this resource would likely be as an alternative to natural gas, town gas and coke oven gas. The total amount of methane currently being utilized from drainage is 126 million cubic meters annually, which is significant considering the fact that currently, 241 million cubic meters of natural gas is consumed in the OKR annually. Of this only 23 million cubic meters is produced from local gas fields, and the rest (approximately 218 million cubic meters) is imported from the CIS annually. Thus, the nearly 400 million cubic meters of methane that is now being emitted annually to the atmosphere from coal mines could replace the natural gas imported into the region, and additional gas could be injected in the pipeline system to be utilized elsewhere in Czechoslovakia.

TABLE 14. METHANE RECOVERY AND UTILIZATION STRATEGIES (AFTER PILCHER ET AL, 1991; AND U.S/JAPAN WORKING GROUP ON METHANE, 1992)

METHOD	RECOVERY TECHNIQUES	SUPPORT TECHNOLOGIES	GAS QUALITY	USE OPTIONS	AVAIL-ABILITY	CAPITAL REQUIRE-MENTS	TECH-NICAL COM-PLEXITY	APPLI-CABILITY	CH_4 REDUC-TIONS
Vertical Pre-Mining Recovery **(Stage I)**	Vertical Wells Drilled from Surface	Advanced Surface Rigs, Compressors Pumps, and other support facilities	High Quality (32-37,000 kJ/m^3; above 90% CH_4)	Chemical Feedstocks, Power Generation Direct use by Industry/Residences	Currently Available	Medium/ High	Medium/ High	Technology, Finance, and Site Dependent	30-80 % of gas-in-place
In-Mine Recovery **(Stage II)**	In-mine Boreholes for Gas Recovery from Mined Seams and/or Roof and Floor Rock	In-Mine Drills, Compressors, Pumps, and other support facilities	Medium Quality (11-29,000 kJ/m^3; 30-80 % CH_4) to High Quality	Power Generation, Direct Use	Currently Available	Medium/ High	Medium/ High	Technology, Finance, and Site Dependent	40-45 % of gas remaining after comple-tion of Stage I
Post-Mining (Gob) Recovery **(Stage III)**	In-Mine Boreholes or Vertical Gob Wells	In-Mine Drills and/or Basic Surface Rigs, Compressors, Pumps, and other support facilities	Medium Quality	Power Generation, Direct Use	Currently Available	Low	Low	Widely Applicable Site Dependent	Up to 80% of gas remaining after comple-tion of Stage II
Ventilation Air Recovery **(Stage IV)**	Large ducts transport ventilation air to point of use	Surface Fans and Ducting	Low Quality (1-5% CH_4; usually below 1%)	Combustion Air for On-Site/Nearby Turbines and Boilers	Needs Demon-stration	Medium/ Low	Medium/ Low	Nearby Utilization Site Dependent	About 50% of gas remaining after comple-tion of Stage III
Integrated Recovery	Combined strategies	All Techniques	All Qualities	All Uses	I-III Now Available	Medium/ High	High	Combination of above	80-90% recovery

3.2.1 DIRECT INDUSTRIAL USE OPTIONS

Within the Ostrava-Karvina region, eight industrial consumers accounted for 90 percent of all the gas fuel (including natural gas, coke oven gas, propane-butane, and town gas) consumption in the region in 1987. These customers include metallurgical industries, automobile and rail car manufacturers, and heavy equipment manufacturers. A description of their gas use is shown in Table 15, and their approximate locations are shown in Figure 14. A breakdown of quantities of specific types of gas being used by these consumers in 1987 was not available; however, more specific information on consumption of gas delivered by SMP to the top four consumers was available for 1991. Because the last column (1991) refers only to gas delivered by SMP, coke oven gas values in this column do not include that which is produced on-site. The 1987 column includes coke oven gas produced on-site, therefore indicating total gas consumption, rather than only consumption of gas delivered by SMP.

Three industrial consumers (ZDB Bohumin, Nová Hut, and Vítkovice) have used coalbed methane, but in 1991, ZDB Bohumin was reportedly the only coalbed methane consumer. However, a coalbed methane pipeline directly connecting Nová Hut with Karviná-area coal mines is being constructed (Figure 15), and it is expected that by 1994 Nová Hut will use as much coalbed methane as the mines can supply. All of the consumers in Table 15 are served by conventional natural gas pipelines, and they represent opportunities for expanded use of coalbed methane.

3.2.2 POWER GENERATION OPTIONS

Currently, about 10 mines in the OKR use small amounts of coalbed methane in some of their boilers for heat generation, but other fuels (coal, coal waste rock, or conventional natural gas) are used in the majority of boilers at the mines. Aside from the use of boilers for heat production, most of the mines do not have their own power generation facilities. Exceptions are the ČSA power plant and the Odra power plant, both of which used coalbed methane to meet some of their power generation needs in 1991 (Table 16). Use of coalbed methane for power generation on a larger scale is under consideration by DPB and various mining and other industrial enterprises in the OKR. Possible options for using methane in power generation include cofiring coal and methane, converting boilers to intermittent use of methane, and use of methane in fluidized bed combustion, internal combustion engines, or gas turbines.

The locations of major coal fired power plants in Czechoslovakia are shown in Figure 16. Only two of these power plants, Detmarovice and Vojany, use hard coal while the remaining plants use brown coal. Both major (capacity greater than 200 MWe) and minor coal-fired power plants in the Ostrava region are listed in Table 16, and their locations are shown in Figure 14. If any of the methane recovered from OKR mines is not utilized by existing natural gas consumers, it could be practical to implement or increase coalbed methane use at these power plants, either by cofiring or by retrofitting boilers to use methane intermittently (seasonally) or year-round.

Referring to Table 16, note that, as of 1987, the Karviná, ČSA, and Odra plants were using some conventional natural gas and "other gas" in addition to coal or oil. "Other gas" refers to coalbed methane and/or coke oven gas; the 1987 data was not broken down according to quantities of specific gas types consumed. More specific data was available for 1991, indicating that the Karviná power plant used 11 million cubic meters of coalbed methane in addition to coal, the adjacent ČSA mine power plant used 15 million cubic meters of coalbed methane in addition to coke oven gas, and the Odra mine power plant used 1 million cubic meters of coalbed methane.

TABLE 15. LARGEST GAS FUEL CONSUMERS IN THE OSTRAVA-KARVINA REGION IN 1987 (Vupek, 1991; DPB, 1992)

COMPANY	INDUSTRY TYPE	TOTAL AMOUNT OF GAS[1] CONSUMED IN 1987 (TJ)	SHARE OF TOTAL GAS CONSUMED IN OSTRAVA-KARVINA REGION IN 1987 (%)	CONSUMPTION OF GAS DELIVERED BY SMP IN 1991
Vitkovice Ostrava	Metallurgical (Iron Manufacturer)	51,825.8	44.10	4,631 TJ (116 X 10^6 m^3) of conventional natural gas; 671 TJ (35 X 10^6 m^3) of coke oven gas
TZ Třinec	Metallurgical	38,076.2	32.40	4,028 TJ (101 X 10^6 m^3) of conventional natural gas
Nová Hut Ostrava	Metallurgical (Steel Manufacturer)	8,567.1	7.29	40.9 TJ (1.02 X 10^6 m^3) of conventional natural gas
ZDB Bohumin	Metallurgical (Iron Manufacturer)	4,030.9	3.43	966 TJ (24 X 10^6 m^3) of conventional natural gas; 706 TJ (37 X 10^6 m^3) of coke oven gas; 88 TJ (4 X 10^6 m^3) of coalbed methane
Tatra Koprivnice	Automobile Manufacturer	2,091.8	1.78	All conventional natural gas consumed is produced from nearby Příbor gas field
Vagonka Studenka	Rail Car Manufacturer	352.6	0.30	Some or all of gas consumed is conventional natural gas
Ostroj Opava	Mine Machinery Manufacturer	199.8	0.17	Some or all of gas consumed is conventional natural gas
Sigma Dolni Benesov	Manufacturer of Air Pumps	47.0	0.04	Some or all of gas consumed is conventional natural gas
TOTAL		**105,191.2**	**89.51**	**N/A**

[1] Undifferentiated; may include one or more of the following: natural gas, coke oven gas, propane-butane, town gas, or coalbed methane

FIGURE 14. GAS DISTRIBUTION NETWORK (SCHEMATIC), POWER PLANTS, GAS AND GAS STORAGE FIELDS, AND MAJOR GAS-CONSUMING INDUSTRIES IN THE OSTRAVA-KARVINÁ REGION

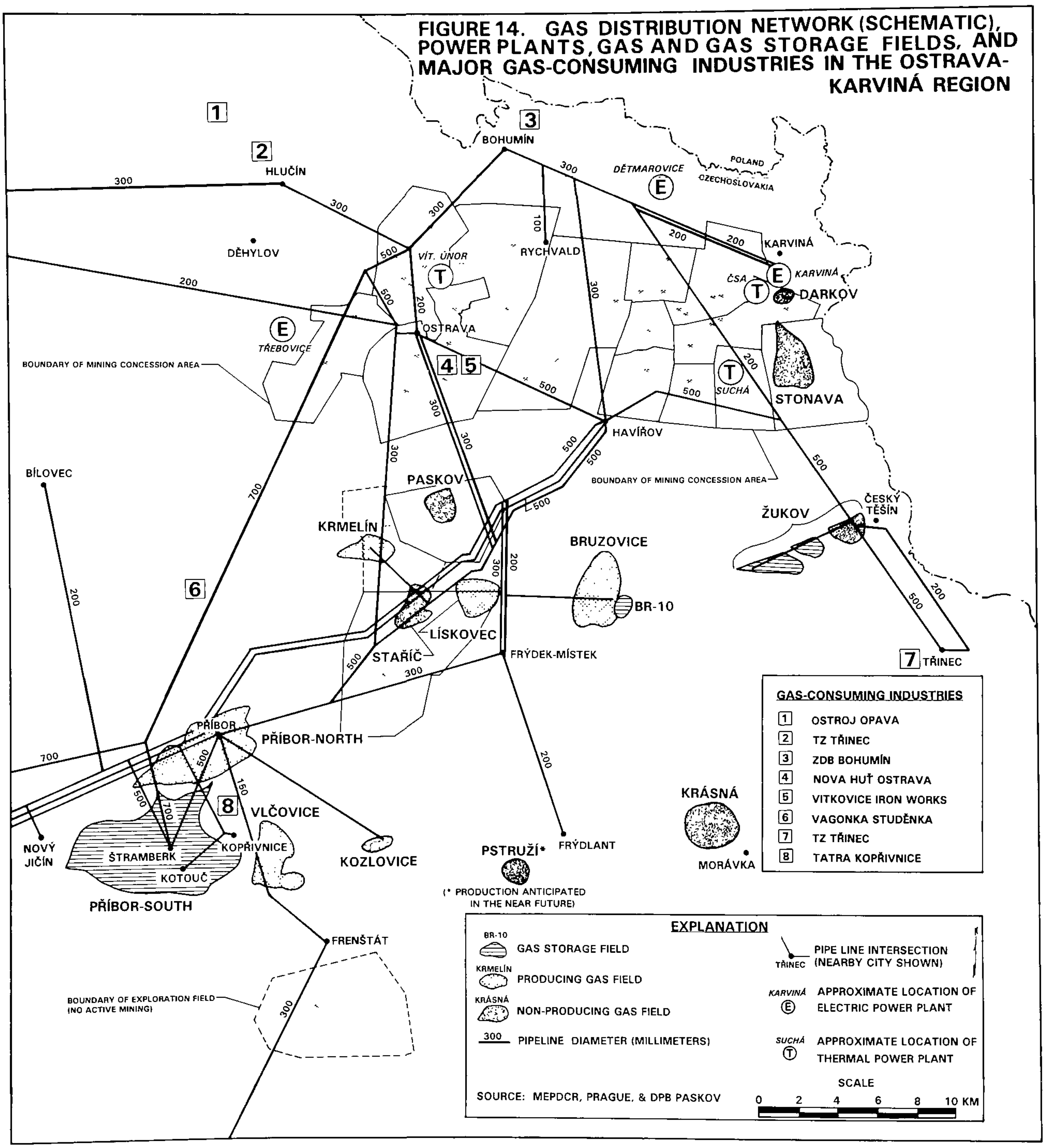


FIGURE 15. SCHEMATIC DRAWING OF COALBED METHANE AND COKE OVEN GAS PIPELINE SYSTEMS, OSTRAVA-KARVINÁ REGION

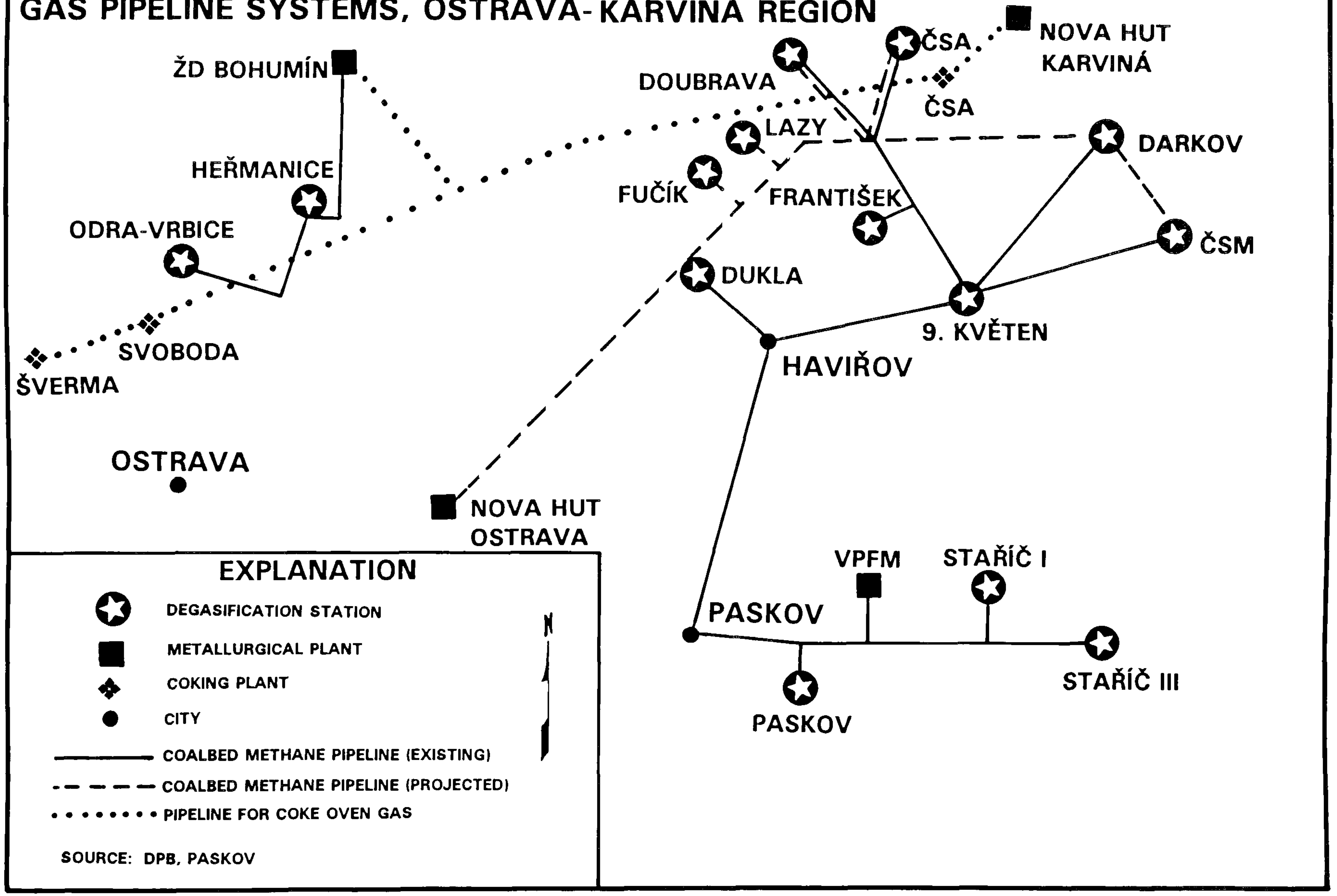


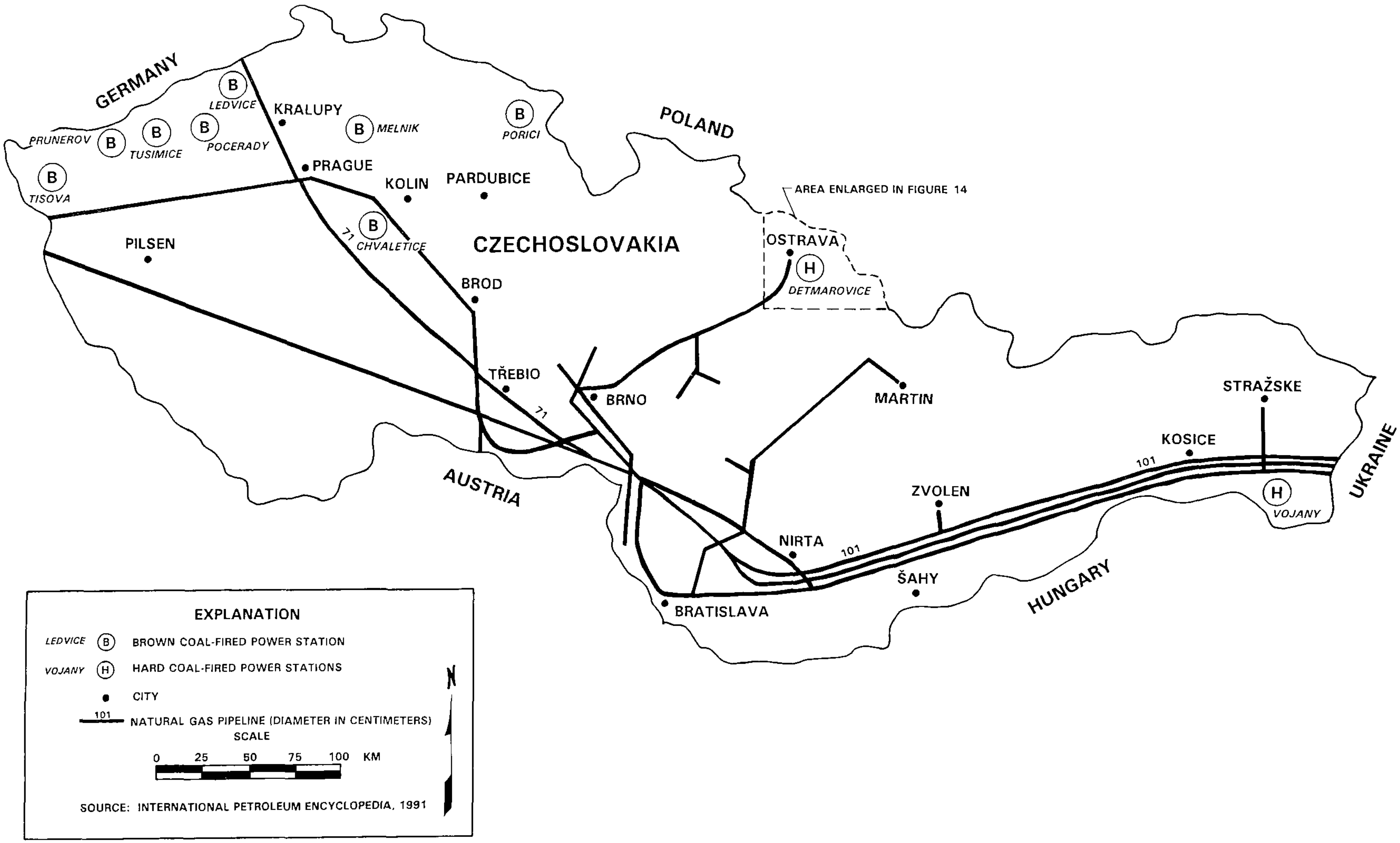
TABLE 16. ENERGY CONSUMPTION AND PRODUCTION OF POWER PLANTS IN THE OSTRAVA REGION

PLANT	YEAR PLANT WAS BUILT (APPROXIMATE)	INSTALLED CAPACITY (MWe)	1987 ELEC. OUTPUT (GWh/yr)	1987 THERMAL OUTPUT (TJ/yr)	1987 CONVEN-TIONAL NATURAL GAS USE (TJ)	"OTHER GAS" USE IN 1987 (COKE OVEN AND/OR COALBED METHANE)[1] (TJ)	1987 TOTAL FUEL INPUT (TJ)	ESTIMATED POTENTIAL CBM USE (COM-PLETE CONVERSION)[2] (Million m^3 per year)	ESTIMATED CBM REQ'D FOR 10% COFIRING[2] (Million m^3 per year)	TYPE(S) OF FUEL USED IN 1991	COMMENTS
DETMAROVICE	1976	800.0	3,038.6	859.1	0	0	32,765.4	1009.5	284.6	COAL	CONSISTS OF FOUR 200 MW PLANTS.
KARVINA	1950-1960	47.0	78.5	433.0	432.0	0	2,295.5	60.2[3]	20.1	COAL AND COALBED METHANE	USED 11 MILLION m^3 CBM IN 1991. CONSISTS OF THREE PLANTS NEAR MINES.
CSA MINE	N/A	24.0	85.3	2,281.8	69.2	500.2	4,457.1	96.3[3]	39.0	COKE OVEN GAS AND COALBED METHANE	USED 42 MILLION m^3 CBM IN 1991. USED 15 MILLION m^3 COKE OVEN GAS IN 1991.
SUCHA	N/A	12.0	72.1	2,372.1	0	0	3,284.7	101.8	28.7	OIL AND COAL	N/A
TREBOVICE	1935	80.0	251.2	4,794.8	0	0	8,668.7	269.8	75.9	COAL	WILL BE MODIFIED TO THERMAL PLANT SOON
ODRA MINE	N/A	10.5	51.2	2,415.6	1.5	1,051.3	3,252.4	100.1[3]	28.4	COALBED METHANE	BEING PHASED OUT, ENERGY USE IN 1991 MUCH LESS THAN IN 1987. USED 1 MILLION m^3 CBM IN 1991.
TOTAL			3,576.9	13,156.4	502.7	1,551.5	54,475.8	1690.9[3]	473.7		

[1] Specific type(s) of gas and their quantities not differentiated [2] Based on 1987 energy output [3] In addition to methane used annually as of 1991

Sources: Vupek, 1991; DPB, 1992

FIGURE 16. GAS DISTRIBUTION NETWORK AND APPROXIMATE LOCATION OF MAJOR COAL-FIRED POWER STATIONS IN CZECHOSLOVAKIA



The column in Table 16 titled "Estimated Potential CH_4 Use" shows the amount of methane the plant would consume daily if it were using methane as its only fuel (in the case of the Karviná, CSA, and Odra plants, values reflect the additional amount of methane that would be used, since these plants already consume methane). The values were derived by converting the total fuel input in terajoules to the equivalent volume of coalbed methane. Four percent was then added to that volume to account for efficiency drops that normally occur when coal or coal or oil boilers are retrofitted to use gas (Fay et al, 1986). However, it is important to note that new gas- or gas and coal-fueled combined-cycle systems (as opposed to modified existing coal-fired boilers) would have considerably higher efficiencies than conventional coal-fired boilers.

The estimates in Table 16 are illustrative, and it is important to bear in mind that feasibility and actual methane consumption will be site-specific. Before a project is initiated, more detailed data and engineering studies would be required. These estimates indicate that there is a large potential market for coalbed methane, however.

Cofiring With Natural Gas

Cofiring with gas has many potential benefits, including reduced sulfur dioxide emissions, greater fuel flexibility (allowing the utilization of lower cost, lower quality coal), improved plant capacity factor, and production of saleable fly ash. At some power plants in the United States, cofiring has reduced operating costs by hundreds of thousands or even millions of dollars per year (Vejtasa et al, 1991). In addition, if for any reason natural gas would no longer be available, the boiler could continue to operate entirely on coal.

The column "Estimated Gas Required For 10% Cofiring" in Table 16 reflects the daily volume of methane that would be consumed if 10 percent of the heat input were derived from natural gas. This was calculated by converting 10 percent of the total fuel input in terajoules to the equivalent volume of methane, and adding 0.7 percent to that volume to account for efficiency drops that normally result from cofiring. This slight decrease in efficiency is due to the increased flue gas moisture associated with firing gas as compared to coal.

Converting Boilers to Intermittent Use of Gas

Another potential option for methane consumption in power plants in the Ostrava-Karviná region is to retrofit boilers to burn gas intermittently with the hard coal. The idea of intermittent, rather than year-round gas use may be attractive because it is likely that most power plants will need to continue burning at least some coal in the event that there is not be enough coalbed methane to meet the year-round needs of the larger power plants. Intermittent gas use would allow the power plant to take advantage of low summer prices for methane, while maintaining the flexibility of being able to burn coal when gas is unavailable or more expensive.

Internal Combustion Engines

Internal combustion engines (IC engines) can generate electrical power utilizing medium to high quality coalbed methane. Typical capacities of IC engines range from several kilowatts to as much as 1 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 require medium-quality gas (30-80 percent methane) such as that produced by in-mine (Stage II) and post mining (Stage III) recovery.

IC engines are modular in design and require little specialized expertise to install and maintain. Due to their relatively small size, they can be relocated fairly easily as the gas supply is depleted. In addition, they can operate on medium quality methane from degasification systems. 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 for fluctuations in gas quality.

Recently, management at the Staříc mine has been considering utilizing IC engines which will burn coalbed methane for power generation at the mine. Engine size would be about 320 kW, so each engine would burn approximately 3,200 cubic meters of coalbed methane per day.

Gas Turbines

Gas turbine generators are generally used in the United States by electric utilities to provide power during peak demand times. As stated earlier, there are currently no gas turbines operating in the OKR. Instead, peak power demand is met by close monitoring and forecasting, and is regulated by stiff rate increases if the limit is exceeded. Given the environmental concerns associated with coal burning and the abundance of coalbed methane in the OKR, gas turbines may be an attractive alternative to coal-fired power generation. Gas turbines are more efficient, cost less to install, and are available in a large range of sizes. This allows for the addition of smaller increments of increased 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 good source of waste heat which can be utilized to generate steam in a heat recovery boiler. When this steam is used for process or district heating, this process is known as cogeneration. If this steam is used in a turbine generator for additional electrical power production, the system is known as a combined cycle. If the steam were injected into the hot gases flowing to the thermal turbine, the system would then be known as a steam injected turbine (STIG). All of these uses improve the thermal efficiency of the system.

Gas turbines fueled by coalbed methane recovered from gob areas have been successful in England, Australia, Germany, and China, and have undergone experimental use in the U.S. (Sturgill, 1991). In most of these cases the waste heat is being recovered from the turbine stack for use in an auxiliary thermal process. Gas turbines may soon be manufactured in Czechoslovakia by a joint venture company formed by Siemens and Škoda. This could eliminate the cost of importing them.

Gas turbine systems that can use coal or coal-based fuels have recently been developed. These systems are highly efficient, environmentally sound, and are ideal for situations where coal costs are lower than gas costs (Bajura and Webb, 1991).

3.2.3 VENTILATION AIR UTILIZATION OPTIONS

Currently, there are relatively few uses for the methane contained in mine ventilation air, due to its low concentration. Numerous studies have examined the possibilities of purifying this gas, but with currently available technology, the expense is too great. However, as technology progresses, it may eventually become economically feasible to enrich the gas contained in mine ventilation air using some of the methods discussed in Section 3.2.4.

At present, the best option for utilization of ventilation air appears to be as part of the fuel mixture in steam boilers or gas turbine generators. This ventilation air could supply all or most of the combustion air required, while the methane in the air would supply a portion of the needed fuel.

Ventilation Air Use in Coal-Fired Boilers

Preliminary technical feasibility analyses have indicated that ventilation air from a mine could probably be transported at the power plant through the existing boiler air ducts and coal circuits without modifying the stability or safety of the boiler operation (Energy Systems Associates, 1991; Bain, 1991). Methane contained in the ventilation air would readily be consumed in the boiler and deliver heat to the process. The percentage of heat would depend on the concentration of methane. With typical boiler efficiencies and air requirements, if the ventilation air contained 0.5 percent methane, it would supply approximately 7 percent of the boiler's energy, and ventilation air containing 1 percent methane would supply 14 percent of the boiler's energy.

In addition, if methane were used to generate a percentage of the boiler's energy, reducing the amount of coal required, the results would be less coal handling, lower pulverizer power requirements and maintenance costs, reduced furnace slagging, lower ash handling, and lower emission of particulates, sulfur dioxide, and nitrogen oxides (Pilcher et al, 1991).

Ventilation Air Use in Gas Turbines

The combustion air requirements of a gas turbine are correlated to its generating capacity. The combustion air required for simple cycle gas turbines is approximately 10 m^3/hr of air per kilowatt of installed turbine capacity. This calculation is based on manufacturer operating and design data for turbines in the 1 to 100 MW size range. Slightly lower air flows are required for the more complex combined cycle plants. This flow is about three times the flow required for steam boilers as a result of turbine cooling requirements. The turbine temperature should be sufficient to fully combust the methane in ventilation air, providing heat to the process.

At 0.5 percent methane, ventilation air would supply about 15 percent of the heat to the turbine. When the ventilation air contains 1 percent methane, approximately 30 percent of the turbine energy can be derived from this waste product. Obviously, this would significantly increase the appeal of a gas turbine operation.

Currently, there are no gas turbines operating in the Ostrava-Karviná Region. At one time, a gas turbine fueled by coalbed methane was reportedly utilized on a trial basis at the Darkov mine concession, but both the capital costs and maintenance costs were considered to be uneconomical. DPB officials believe that this may have been due in part to lack of familiarity with the equipment and procedures, and that future use of gas turbines should not be ruled out.

In order to assess the potential to use ventilation air, the following issues should be investigated (Pilcher et al, 1991):

- the number of ventilation shafts, flow rates, and volume of air leaving each shaft.
- the methane concentration in the ventilation air.

- the distance between the ventilation shafts and the mine power plants.
- detailed information on power plant characteristics, annual output, efficiency, and projected utilization.

The feasibility of using recovered ventilation air should be demonstrated. If it proves feasible, it should be included, when possible, in every mine's integrated methane drainage program. In cases where it is not feasible for either technical or economic reasons, aggressive Stage I-III methane drainage programs should be employed to reduce the amount of methane that is liberated by the ventilation systems. Studies indicate that with aggressive use of Stage I-III methane recovery systems, up to 85 percent of the methane could be recovered without use of ventilation air. Currently, most mines achieve efficiency of 20-30 percent, however.

3.2.4 GAS ENRICHMENT

Much of the gas currently recovered by mine methane drainage systems is not considered pipeline quality. Mining regulations require that gas with a methane concentration greater than 30 percent be recovered and transported to the surface via pipeline. Overall, the concentration of methane in recovery pipelines has decreased from 60 percent to 50 percent since 1974. Most of the gas vented after recovery has a methane concentration that ranges from 30 to 50 percent (herein referred to as low-methane gas). One mine-owned heat plant has used gas with concentrations of methane ranging from 33 to 38 percent, but most heat plants require gas quality to be at least 48 percent.

Presently, approximately 15 million m^3 of methane are recovered and then vented at the surface (about half of this methane is from mines that will be closed by 1995). The concentration of methane decreases as the life of an in-mine or gob gas well proceeds. If a more aggressive mine drainage and gob gas recovery program is pursued in the mines that are to remain open, the amount of recovered gas with methane concentrations below 50 percent will likely increase. However, volumes produced at any one location may remain relatively small.

Current research suggests that two types of gas enrichment technologies are best suited to small-scale applications (those which treat less than about 300,000 m^3 of gas per day), such as enrichment of mine drainage gas. These technologies are pressure swing adsorption and membrane gas separation.

Pressure Swing Adsorption

In this process, a molecular sieve is used to remove nitrogen or carbon dioxide from the feed gas stream. The process separates the gases by selectively adsorbing either the unwanted gases or the hydrocarbon gas under pressure, and subsequently placing a vacuum to the adsorbent bed, causing the adsorbed gas to be released. By alternately exerting pressure and placing a vacuum on the system, timing the pressure swing to take advantage of the rate at which the gases are selectively adsorbed, gas separation is achieved.

Presently available pressure swing systems use carbon molecular sieves. Another type of molecular sieve, zeolites, holds promise for gas separation applications. In the past, synthetic zeolites have been used for limited gas separation applications, and a recent research development project demonstrated that some species of naturally occurring zeolites perform at least as well as the carbon molecular sieve for separation of nitrogen and carbon dioxide from methane.

Membrane Gas Separation

Membrane gas separation is based on the differences in the diffusivities and solubilities of various gases within the membrane material. The relative rate at which different gases pass through the membrane is called the selectivity. A polymeric organic membrane system has been used for carbon dioxide removal, and the development of a membrane system to selectively remove nitrogen from natural gas is underway.

Membrane separation units have several features that make them attractive for gas separations. Within the basic unit itself, there are no moving parts, membrane units can be easily replaced, variations in flow rates can be easily accommodated and startup can be accomplished in a very short time.

Operating Costs

Cost comparisons among various processes are complex and situation dependent. Because these technologies do not have a long history, actual costs are not yet well established. However, the following cost approximations provide general guidelines.

To enrich a feed gas containing 70-80 percent methane to pipeline quality, operating costs range from approximately \$0.01/m^3 to \$0.04/m^3 for pressure swing adsorption systems, and from \$0.03/m^3 to \$0.09/m^3 for membrane gas separation systems (Sinor, 1992; Meyer et al, 1990). The cost of enrichment of lower-methane gas (30 to 50 percent methane) is not known and should be researched. It is important to bear in mind that, because this gas would otherwise be vented to the atmosphere, the cost of the feed gas is effectively zero, enhancing the economics.

3.2.5 GAS PIPELINE SYSTEMS IN CZECHOSLOVAKIA

Figure 14 shows the existing natural gas pipeline system in the Ostrava-Karviná region, which is maintained by SMP, and Figure 16 shows the major natural gas pipeline network of Czechoslovakia. As noted in Section 3.2.1, a pipeline system for coalbed methane is already in place in the Ostrava-Karviná region (Figure 15), as is a coke oven gas pipeline system. The existing coalbed methane and coke oven gas pipeline systems are operated by SMP, but the planned coalbed methane pipeline connecting Nova Hut' with Karviná-area coal mines will be operated by OKD. About 65 million cubic meters of coalbed methane were sold to SMP in 1990. This methane was in turn sold to various industrial consumers such as the ČSA power plant, the adjacent Karviná power plant, and the ZDB Bohumin ironworks and wire plant.

Coalbed methane that would be drained from the surface in advance of mining should be pipeline quality, and it may be possible to meet applicable quality standards with gob gas as well (as proven by the JWR mines). Pipeline quality gas could be injected directly into the natural gas pipeline system for transportation to end-users. Coke oven gas and the present concentrations of mine drainage gas both have very similar calorific values and as production of coalbed methane increases, DPB hopes to transport it via coke oven gas pipelines, eventually phasing out all transportation of coke oven gas.

3.2.6 FUEL SWITCHING WITH COALBED METHANE

Like conventional natural gas, coalbed methane is an environmentally acceptable fuel because when burned, it emits virtually no pollutants such as sulfur dioxide or particulates, and it emits much less carbon dioxide than coal and oil. Some fuels that coalbed methane could replace are:

Brown Coal

The use of brown coal for residential and commercial heating in the Ostrava region is a primary contributor to the current high sulfur dioxide and particulate levels in the region. The availability of coalbed methane may permit conversion of existing coal-fired hot water residential and commercial boilers to gas, reducing local pollution. Ninety percent of the sulfur dioxide emitted by coal consumption in Czechoslovakia results from burning brown coal, so any displacement of brown coal, whether in the Ostrava-Karviná region or other regions, would provide environmental benefits. Opportunities also exist at the OKR mines themselves, as in some cases brown coal is used for fuel in the mine boilers. Additional opportunities exist in residential and commercial heating the Ostrava-Karviná urban complex. Although it may not be cost-effective to transport coalbed methane from the OKR to distant consumers (eg. in the northwestern Czech Republic or in the Slovak republic), increased use of coalbed methane in the Ostrava-Karviná region would increase the amount of conventional natural gas for available for displacement of brown coal outside the region.

Town Gas

In some situations it may be practical to use coalbed methane as a substitute for town gas, a highly polluting form of energy. In Bohemia, a region in the western Czech Republic, 1.8 billion cubic meters of town gas were consumed in 1990 (Federal Ministry of Economy, 1992). Although there is currently no coalbed methane recovery from the nearby Central Bohemian Coal Basins, if proposed exploration is successful, coalbed methane could potentially replace some of the town gas consumed in Bohemia. In 1989, 45.7 million cubic meters of town gas were consumed in the Ostrava-Karviná region (Vupek, 1992). Coalbed methane recovered from OKR mines could potentially replace this resource.

Coke-Oven Gas

In 1990, 3.1 billion cubic meters of coke oven gas were consumed in the Ostrava-Karviná region (Federal Ministry of Economy, 1992), all of it by industries. Much of this coke oven gas was produced as a by-product of the conversion of coal to coke for use in metallurgical industries, and it is better to consume this coke oven gas rather than vent it. However, as coke and coke oven gas production decrease in response to the decline in heavy industry in the region (and nation), present consumers of coke oven gas will need to use an alternative gas fuel, and coalbed methane would be a much cleaner replacement.

The eastern Slovak Republic consumed 981 million cubic meters of coke oven gas in 1990 (Federal Ministry of Economy, 1992), most likely produced from metallurgical plants in the region. As in the Ostrava-Karviná region, it would not be beneficial to replace this gas with coalbed methane where the alternative to utilizing the coke oven gas would be to vent it. Furthermore, because the Slovak Republic has no known hard coal or coalbed methane resources, coalbed methane used for such displacement would have to be transported from the Czech Republic. Currently, the only pipeline between the eastern part of the Czech Republic and the eastern part of the Slovak Republic is the main high pressure line transporting imported natural gas the CIS westward to Czechoslovakia.

3.2.7 UNDERGROUND GAS STORAGE

Underground storage should be considered as part of any coalbed methane use strategy. With storage facilities, gas can be used as demand dictates. For example, gas produced when demand is low (such as during the summer) can be stored and used during periods of higher demand. This would relieve some of the dependency on natural gas purchased from the CIS.

In many gas producing areas of the world, including Czechoslovakia, underground storage of natural gas and other fuel gases is the most common means of storing gas to meet peak seasonal market requirements. Types of reservoirs preferred are porous reservoirs, including depleted oil and gas fields as well as aqueous reservoirs. Other sites used for storage are natural and manmade salt caverns and rock caverns. Underground gas storage was first utilized in the United States in 1916, and today there are more than 400 storage fields with a total capacity of over 228 billion cubic meters of gas, or almost half the annual U.S. gas consumption. In addition, utilization of underground gas storage is beginning to allow capitalization of spot gas market purchases, managing of transportation imbalances, handling of short-term standby supply needs, enhanced oil recovery, hedging on the gas futures market, and managing of marketing and production by producers (Thompson, 1991).

The development of underground storage of fuel gas began in Czechoslovakia in the early 1950's, but commercial utilization did not begin until 1965. The first facility was built near Přerov south of the Ostrava-Karviná region, specifically for town gas storage. There are currently at least seven active gas storage fields in Czechoslovakia, all in depleted natural gas reservoirs. They are: Lab, Hrusky, Štramberk, Žukov, BR-10, Lobodice, and Dolni Dunajovice. Present natural gas storage capacity of these fields is 2.4 billion cubic meters, not including the capacities for Žukov and BR-10. An additional 80 million cubic meters of town gas can be stored, primarily at Lobodice (Novotny & Plachy, 1990).

The Štramberk, Žukov, and BR-10 facilities are the only active gas storage facilities located near hard coal mining areas in the OKR (Figure 15). Of these three, Štramberk is the largest and oldest, with a current capacity of 760 million cubic meters. Presently, gas stored in this facility is purchased from the CIS. According to an agreement with the CIS, Czechoslovakia pays a reduced price for its gas imports in exchange for maintaining the pipeline across their country for gas moving from the CIS to Central and Western Europe. There are no pipelines linking Štramberk with the coal mines, and there are no compressors located at the storage facility because the CIS pipeline pressure is sufficient to inject the gas into the reservoir. Before this facility could be used for storage of coalbed methane, approximately 10 km of pipeline would have to be built and compressors would have to be installed. The estimated cost of installing the pipeline and compressors would be 15 million Kcs, or about $500,000 US in 1991 dollars. OKD hopes to increase the capacities of both Štramberk and Žukov. According to existing plans, the active gas storage capacity of Štramberk would increase from 320 million m^3 to at least 420 million m^3, at a cost of about 800 million Kcs, or about 27 million m^3.

In addition to expanding existing storage facilities, another option available in the OKR is that of gas storage in abandoned coal mines. Two abandoned mines have been utilized for imported natural gas storage at two locations in Belgium since the early 1980's. Criteria essential to the success of gas storage in abandoned coal mines have been identified (Moerman, 1982) as follows:

- The mine must be separated from adjacent workings by impermeable barriers.
- The overburden rock must be thick enough and preferably water-bearing, to secure a tight cap with no natural communication to the surface.

- The abandoned workings must be dry, no water should be flowing into the mine.

If a selected mine meets all of these criteria, the next step in development would be to identify and seal all openings (shafts and galleries). Pipes would need to be installed through some of these seals for future gas injection. In addition, the storage capacity of the mine and the maximum operating pressure would have to be determined. Finally, consideration must be given to the reaction of the rock mass to the gas, specifically, the ability of the unmined coal to adsorb any gas injected into to mine. This phenomena greatly enhances the ultimate storage capacity of the mine.

The Belgian mines using this technique are described as having an impermeable Miocene clay cap over the coal bearing strata, a water saturated zone overlying this cap, a well-understood geological setting, and structural isolation via faults. In addition, much of the gas stored in the Belgian facilities is actually stored in the remaining coal through adsorption, greatly increasing the current storage volume of the mine. These specific criteria also apply to the mine concessions in the OKR which are slated for closure in the near future (Section 2.2.1). At these mines, the Carboniferous is overlain by impermeable water saturated Miocene deposits and are bound on the east by the Michálkovice structure (Figure 7).

In assessing the economic feasibility of using abandoned mines for storage of coalbed methane, the cost of developing the facilities should be weighed against the costs of importing of natural gas from the CIS, and of venting coalbed methane to the atmosphere.

CHAPTER 4

THE ROLE OF COALBED METHANE IN CZECHOSLOVAKIA'S ENERGY ECONOMY

4.1 OVERVIEW

As described in Chapter 1, Czechoslovakia's energy economy depends heavily on lignite and brown coal for conversion to electrical and thermal energy. However, the proportionate use of fuel types within Czechoslovakia is in transition and will continue to be for some time. This transition was initiated in response to the movement of the Czechoslovakia toward a market oriented economy, and the breakup of the CMEA.

Although the end of the CMEA brought about a series of interrelated improvements in energy price rationalization and the shutdown of inefficient and uneconomic industries, the legacy of the CMEA is manifested in the structure of the economy (EIU,1991). This structural legacy is reflected in the:

- consumption of energy and raw materials per unit of GDP at a rate of about twice that in most western countries. This is a cause of widespread environmental degradation;
- reliance on supplies of CIS energy and raw materials exchanged, on a preferential and noncompetitive basis, for manufactured goods;
- the existence of a largely uncompetitive industrial structure that thrived within the CMEA but cannot compete in the open world market;
- foreign trade that is oriented toward the CIS and has not fully reoriented toward western economies.

4.2 THE ENERGY ECONOMY IN TRANSITION

Steps are being taken by the government of Czechoslovakia to mitigate lingering problems in the energy sector by a series of price reforms and a movement away from fixed prices and toward world prices. This price restructuring will be felt not only in the rationalization of imported energy prices but also in the price structure of internally produced energy (Hauptvogel, 1991). The impact of the purchase of imported energy fuels using hard currency at world market prices, has been felt throughout each of the energy use sectors. However, the most immediate and dramatic effects of these changes will be felt in the industrial sector.

Adjustments in the price structure of energy fuels consumed by the industrial sector will be accompanied by phased withdrawal of federal subsidies and closure of uneconomic industries. In addition, there is a concomitant reorganization of industry in response to the disappearing market for certain manufactured goods, which has resulted in lessened need for the past level of conversion of brown coal and lignite to electrical and thermal energy.

In response to the lessened need for coal conversion as the energy input to heavy industry, a proportionate decrease in coal extraction and processing is taking place, causing further shifts in the market for fuels. If modern energy efficient equipment is installed in the industrial, household and commercial sectors, the opportunity for even more dramatic changes in the mix of fuels consumed by Czechoslovakia will emerge. In anticipation of these opportunities, Czechoslovakia has developed the following energy policy goals (UNECE, 1991a) to add to the momentum of change in energy consumption:

- a substantial increase in the production of electricity using nuclear power facilities;
- the closure of non-profitable coal mines and sharply reduced domestic coal consumption;
- a substantial increase in natural gas consumption from the level of 1990 consumption, 13.3 billion cubic meters, to 15.1 in 1995, and 16.6 by year 2000.

Clearly, a program for rapid expansion of nuclear power facilities will require large capital investments, and as in many other parts of the world, it is likely to be delayed by public debate over the location of facilities and perceived dangers to the environment. In other words, this goal may not be achieved in the near-term.

Closing unprofitable mines is a logical step toward reducing subsidized and unprofitable energy production and consumption. As noted in Chapters 2 and 5, some coal mines have already been closed and others have been identified and will be closed shortly. It is expected that some additional down-scaling of operating mines is likely as the industrial sector is restructured.

Increasing the utilization of natural gas in Czechoslovakia will have a direct and rapid effect on the economy and environment. The breakdown of the CMEA and movement toward world market prices has caused the cost of imported natural gas consumed by Czechoslovakia in 1991 to increase by 350 percent over prices paid in 1990, and the cost is likely to continue to increase. The majority of the natural gas consumed is imported from the CIS. The stability of this supply has been a concern and the price will strain the financial security of the industrial consumers. Czechoslovakia is now looking into alternate suppliers with hopes of stabilizing supply and adding competition to the pricing system.

4.3 THE NATURAL GAS SUPPLY

As noted in Chapter 1, natural gas currently makes up 13 percent of the fuel mix, and its use is expected to increase. Given the closure of hard coal mines and the desire of the Czechoslovakian government to reduce the use of brown coal and lignite, the market for natural gas is likely to expand. However, the choices of supply of natural gas are limited to relatively small domestic reserves of conventional natural gas, increased importation of natural gas from the CIS, alternate supplies of conventional natural gas from western European or African sources, or domestic coalbed methane.

The UNECE Working Party on Gas (UNECE, 1991b) reports that the CSFR has 14 billion cubic meters proven reserves of natural gas and an additional 15 billion cubic meters of undiscovered (prognostic) reserves. Obviously, the annual use of natural gas is greater than the proven reserves, and additional supply sources will continue to be a necessity.

Over the next few years, the most likely source to supply the growing demand for natural gas will be the CIS. Although the supply is unstable, it has and will continue to supply the bulk of the imported natural gas to Czechoslovakia. As gas exploration and development moves progressively eastward within the CIS, the increased cost of transmission will be passed on to the consumer. Moreover, as the economics of gas supply undergoes change, there could arise the need for Czechoslovakia to seek additional gas suppliers among the EC, and to participate in some of the pipeline expansion projects in western Europe, which include new links between northern Europe and central and eastern Europe. The time required to plan finance, and execute these projects may further impact gas costs and the security of the gas supply. (UNECE, 1991b).

4.3.1 THE ROLE OF COALBED METHANE IN THE GAS SUPPLY

Coalbed methane development could provide the most timely and cost-effective alternative to increased importation of conventional natural gas. The total coalbed methane resources in the OKR are estimated to range from about 51 to 371 billion cubic meters. These resources comprise between 12 and 88 billion m^3 of documented reserves and between 39 and 283 billion m^3 of prognostic resources. Clearly, all of this methane is not recoverable, but even at a recovery factor of 30 percent the amount of domestic coalbed methane far exceeds conventional gas reserves. In addition, Czechoslovakian coal mines emit 400 million m^3 to the atmosphere annually. Much of the methane contained in the mineable reserves of coal will be emitted to the atmosphere if recovery and utilization is not increased.

At current world market gas prices of $145 US/1000 cubic meters, the 1990 mining emissions represent a loss of $58 million US annually. Even when the emissions reduction resulting from the planned closure of Ostrava-area mines is taken into account, about 246 million cubic meters will still be emitted annually, at a loss of about $36 million US annually.

Methane resources contained in the coal that is not likely to be mined are estimated to range from 45 to 325 billion m^3. These resources can be developed through stand-alone projects independent of mining, like much of the U.S. coalbed methane production. For example, in the Black Warrior Basin of Alabama, more than 2,100 wells produce coalbed methane, and most of them are unrelated to coal mining. In the San Juan Basin of the western U.S., unfavorable geological conditions prevent coal mining, yet more than 1,300 wells currently produce coalbed methane.

Additional assessment of the potential recovery of the coalbed methane resource in Czechoslovakia will require that a program for drilling and testing be planned and executed. The results should then be evaluated to further delineate the extent of the resource and its producibility. If the drilling program indicated 30 percent recoverability for the methane contained in coal not likely to be mined, the estimated gross value of these recoverable methane reserves would be between $2 billion and $14 billion U.S. The average world cost for discovery of new natural gas reserves is estimated to be $45.6 US per thousand cubic meters of reserves (UNECE, 1991b), so the cumulative cost of discovery of these reserves would be between $616 million and $4 billion US. The net undiscounted value of the unproduced gas would thus be between $1 billion and $10 billion US.

Czechoslovakia's coalbed methane resources could be rapidly developed, if appropriate incentives and market access are provided. Based on this initial analysis, it appears that the value of this resource can best be exploited by using it locally (i.e., in the Ostrava-Karviná region), or by storing it and using it seasonally to offset peak demand both within and outside of this region.

Development of coalbed methane resources in the Ostrava-Karviná region will have a positive impact on Czechoslovakia's energy economy by providing domestically available, high quality natural gas to industrial, commercial, and residential consumers, displacing imported natural gas. To optimize the value of this resource, a cost effective plan for development should include:

- utilization of the existing pipeline infrastructure
- construction of additional pipeline links to expand the regional market;
- expansion of storage facilities to provide reserves for peak demand periods

In addition, the environmental impacts will be significant. If Czechoslovakia is able to produce 1 billion cubic meters of coalbed methane annually by the year 2000, the environmental impacts could be as follows:

- A dramatic reduction in atmospheric mine methane emissions, thereby helping to mitigate global warming. If integrated methane recovery systems were used and 70 percent of the methane liberated by coal mining were recovered, methane emissions would be reduced to about 74 million cubic meters annually (this estimate takes into consideration the planned closure of the Ostrava-area mining concessions).

- Significant reductions in emissions of SO_2, NO_x, particulates, and CO_2. For example, 1 billion cubic meters of methane provides energy equivalent to about 1.3 million tons of OKR coal. Assuming an ash content of 15 percent, 1 billion cubic meters of methane could displace enough hard coal to reduce particulate emissions by about 195,000 tons annually. Displacement of brown coal, coke oven gas, or town gas with coalbed methane would also benefit air quality.

CHAPTER 5

CASE STUDIES

5.1 INTRODUCTION

There are currently fourteen operating mine concessions in the OKR. In proposing future coalbed methane recovery and utilization projects, it is useful to consider that, as stated in Section 2.2.1, four concessions, Ostrava, Heřmanice, Odra, and Fučik are either now in the process of closure, or their closure is likely by 1995. The Šverma concession was closed as of January 1992. Since the amount of methane being emitted from these mines is decreasing and will be zero in the near future, projects aimed at recovering and utilizing methane from these five mines are outside the goals of this study, although they may be of interest to other agencies or companies.

Some of the remaining 10 concessions could be subject to closure in the future, but at present such plans have not been announced. Methane is currently being recovered and utilized from all of these concessions, as shown in Table 10. Substantial opportunities still exist for increased methane recovery and utilization at these mine concessions, however. Of these ten concessions, the four which emit the most methane (ČSA, ČSM, Stařič, and Darkov) presently account for 47 percent of all methane liberated, and 42 percent of all methane emitted to the atmosphere annually from coal mining in Czechoslovakia. Based on their current and historical coal production (Table 6), it appears that at least three of these four concessions will remain open.

When the annual liberation and emissions of the five concessions to be closed are excluded, the top four emitters account for 68 percent of the methane liberated and emitted annually in Czechoslovakia. While all of the 10 concessions presently expected to remain open in Czechoslovakia are potential candidates for improved methane recovery, it seems that priority should be given to the top four emitters in order to achieve the most immediate reduction in methane emissions. A brief profile of each of these concessions follows.

5.2 ČSA CONCESSION CASE STUDY

5.2.1 PRESENT CONDITIONS

The ČSA mine concession is located in the northeastern part of the OKR near the city of Karviná (Figure 9). There are currently two mines operating within the ČSA concession, the Jan Karel mine which commenced operations in 1859 and has an average mine depth of 800 m, and the Jindřich mine which commenced operations in 1852 and has an average mine depth of 790 meters. The ČSA concession also has a coke plant and power plant on location.

Coal types within the concession are high volatile bituminous B and C with average seam thicknesses ranging from 1.5 to 5.5 m at the Jan Karel Mine, and 5 to 6 m at the Jindřich Mine. Coal production increased slightly from 1.64 million tons in 1988 to 1.76 million tons in 1990.

More methane is liberated from the ČSA concession than any other mining concession in Czechoslovakia. Emissions increased from approximately 40.5 million cubic meters annually in 1989 to 68.3 million cubic meters in 1990. In-mine (Stage II) and gob (Stage III) recovery methods are in use at the mine concession, but only 15 percent of the methane liberated by this concession is drained. In 1990, ČSA sold 10 million cubic meters of methane (99 percent of that recovered) to SMP for distribution to consumers, yet it purchased 22 million cubic meters of methane from SMP for use in its power plant. This mine concession emits the most methane to the atmosphere (57.9 million cubic meters in 1990). About 38 cubic meters of methane are liberated per ton of coal mined from the ČSA concession.

Methane from the mine has been used in its heating plant boilers, but consumption of the boilers is irregular and interrupted, possibly due to inadequate metering and control systems, resulting in emission of much of the methane to the atmosphere. The mine presently finds it more economical to use coal dust and coal waste rock in the boilers.

The current mineable balance coal reserves for the ČSA concession are 193 million tons, and total documented coal resources are 450 million tons (Table 6). The estimated methane reserves associated with the mineable balance coal reserves are 7.5 billion cubic meters, and 17.5 billion cubic meters of methane are associated with the total coal resource.

5.2.2 PROJECT TYPES

Mines of the ČSA concession are candidates for increased methane recovery via surface drilling (Stage I) and improved in-mine and gob drainage methods (Stages II and III). Furthermore, since the concession has a power plant, it may be a candidate for ventilation air use (Stage IV). In 1991, ČSA's thermal power plant used 42 million cubic meters of coke oven gas but only 14 million cubic meters of coalbed methane, both purchased from SMP. Any increase in methane production could offset the need for coke oven gas. As noted in Section 5.2.1, mine management reported that irregular and interrupted consumption by the boiler discouraged increased use of coalbed methane in the power plant. Improved metering and control systems could perhaps solve the problem. A large number of additional methane utilization opportunities exist outside of the mining enterprise, as described in Section 3.2.1.

Prior to initiating a pre-mine drainage program, it would be important to consider that water may be coproduced from pre-mine drainage wells (Appendix C). According to 1990 data supplied by the Dept. of Ecology of OKD, the ČSA mines pumped an average of 0.9 cubic meters of water for every ton of coal produced. The amount of total dissolved salts (presumably chlorides and sulfates) in this water averages 20,342 milligrams per liter (mg/l). This is highly saline; generally, water with a chloride and sulfate concentration in excess of 1,800 mg/l is considered unfit even for industrial use. The is discharged directly into the Odra River, without any treatment.

5.3 ČSM CONCESSION CASE STUDY

5.3.1 PRESENT CONDITIONS

The ČSM concession, the only mining concession independent of OKD, is still a state-controlled enterprise, although it is preparing for privatization. ČSM is located in the northeastern part of the OKR, adjacent to the Polish border south of the city of Karviná. There are two mines operating within the ČSM concession, ČSM North and ČSM South. Mining operations commenced in 1968 and the average mining depth is 770 m.

The coal rank is primarily high volatile bituminous A and the average mined seam thickness is 1.77 m. The total exploited area in the concession is 22 square km and 10 coal seams are currently being mined. Mining methods used are longwall and subsidence mining. Coal production has decreased from 2.68 million tons in 1989 to 1.91 million tons in 1990. Eighty-five percent of coal produced is coking coal, which is sold to coking plants and iron works in both the Czech and Slovak Republics. About 10 percent of the coal is exported.

ČSM emitted 43 million cubic meters of methane to the atmosphere in 1990. Thirty-one percent of the methane liberated by this mine was recovered by in-mine drainage systems, and all the drained methane (nearly 20 million cubic meters in 1990) was used by the heating plant at the mine concession. This is not enough fuel to meet fuel requirements of the heating plant. In the summer, additional coalbed methane is purchased from the Darkov mining concession, which is sold at a reduced price because it would otherwise be vented to the atmosphere. In the winter, 6 million cubic meters of natural gas is purchased from the CIS.

The current mineable balance coal reserves for the ČSM concession are 214.4 million tons, and total documented coal resources are 532 million tons (Table 6). The estimated methane reserves associated with the mineable balance coal reserves are 7.0 billion cubic meters, and 17.4 billion cubic meters are associated with the total coal resource. About 33 cubic meters of methane are liberated per ton of coal mined at ČSM.

There are currently no electric power plants at the ČSM concession.

5.3.2 PROJECT TYPES

The applicability of vertical mine pre-drainage (Stage I) should be investigated, as should improved underground drainage methods (Stage II). If methane recovery can be expanded, gas would not have to be purchased. Expansion of an existing gas storage field such as Žukov (Figure 15) could also help solve the problem of seasonal supply variations. Currently, gob production (Stage III) is not efficient due to leaking barriers, which are built to isolate the gob areas from the active workings. Improvements could be made to increase the quality of gob gas by better sealing these barriers, to prevent the inflow of mine air into the gob area. Again, this would offset the need to purchase gas from other mines or from the CIS.

Monitoring of the volume and composition of mine waste waters should be considered in order to prepare for any water that may be co-produced with surface coalbed methane wells (Appendix C). The volume of water currently discharged from mining operations averages 1.1 cubic meters of water for every ton of coal mined. The amount of total dissolved salts in this water averages 12,341 mg/l. The water is discharged directly from the mine into local streams, and is detrimental to water quality.

5.4 DARKOV CONCESSION CASE STUDY

5.4.1 PRESENT CONDITIONS

The Darkov concession is located directly between the ČSA and ČSM concessions (Figure 9). There are currently three operating mines; the Barbara mine which commenced operations in 1890 and has an average mine depth of 780 m, the Gabriela mine which commenced operations in 1852 and has an average mine depth of 720 m, and the Darkov mine which commenced operations in 1982 and has an average mine depth of 550 m.

The Darkov concession covers approximately 15 square km. Coal rank within the concession is high volatile bituminous B and C with average seam thicknesses ranging from 2 to 6 m at the Barbara Mine, 2 to 3 m at the Gabriela Mine, and 1.5 to 3 m at the Darkov Mine. The Darkov concession produces more hard coal than any other concession in Czechoslovakia. Production was 3.0 million tons in 1990, down from 4.6 million tons in 1989.

In 1990, about 40 percent of the methane liberated by the Darkov mine was drained, and nearly 97 percent of the drained methane was utilized. More than 36.2 million cubic meters of methane were emitted to the atmosphere, however (Table 10). Of the total methane utilized, some was used at the Darkov concession, but most of it was used by the ČSM concession and other consumers. The Darkov concession is now utilizing more methane in its new coal-slurry drying room. It also plans to continue providing methane to ČSM. Methane is not drained from two of the Darkov concession mines, Barbara and Gabriela, because their coal tends to spontaneously combust and thus mine engineers prefer to keep the methane concentration high. For fire prevention, nitrogen supplied by pipeline from Nova Hut' is pumped into gob areas, and the resulting mixture of nitrogen and methane is ultimately released to the atmosphere via the ventilation system. Mine engineers are skeptical of introducing surface drainage in advance of mining or degasifying gob areas, as they believe these methods would not reduce the methane content to less than combustible concentrations. A history of fatal mine fires has made safety a top concern at these mines.

The current mineable balance coal reserves are 324 million tons, and the total documented coal resource is 583 million tons (Table 6). The estimated methane reserves associated with the mineable balance coal reserves are 6.4 billion cubic meters, and 11.5 billion cubic meters of methane are estimated in the total coal resource. About 20 million cubic meters of methane are liberated per ton of coal mined from the Darkov concession.

There are currently no electric power plants located at the Darkov Concession. Their power needs are supplied by four sources within the OKR.

5.4.2 PROJECT TYPES

Despite the reluctance of mine engineers, it may be worthwhile to evaluate the potential for degasification of workings that are presently considered to be a safety hazard due to spontaneous combustion, as long as safety remains the utmost priority. Sealing of gob or abandoned areas in the Gabriela and Barbara mines could eliminate or control heating in mined seams, thus reducing the potential for spontaneous combustion. In addition, detection systems to monitor heating should be installed, and the adequacy of the ventilation systems should be assessed and possibly reorganized to reduce pressure leaks (Feng et al, 1973). These adjustments might eliminate the need to keep methane concentrations high, which can be a safety hazard in itself. Surface drainage in advance of mining (Stage I), drainage during mining (Stage II), and gob drainage (Stage III) could then be undertaken in the Gabriela and Barbara mines. In addition, implementation of Stage I methane recovery at the Darkov mine, as well as improved Stage II and III recovery, would further reduce emissions.

Presently, 400 million Kcs (13 million US) are spent annually by the Darkov concession for power. Any amount of recovered methane that could be used to generate power, either from a small IC engine or a gas turbine, would help the economics of these mines. The status of the inactive gas turbine located at the concession should be investigated, to decide if it would be technically and economically feasible to operate this turbine using coalbed methane.

As with the other concessions, the potential for co-production of water along with methane from surface wells should be considered (Appendix C). The mine produces 0.25 m^3 of water per ton of coal. It has a total dissolved salt content of 18,980 mg/l, and is discharged directly to streams, adversely affecting water quality.

5.5 STAŘÍČ CONCESSION CASE STUDY

5.5.1 PRESENT CONDITIONS

The Stařfč concession is located in the southern part of the OKR near the town of Frýdek-Místek. There are currently three mines operating within the concession, Stařfč I, Stařfč II, and Stařfč III. Operations at the concession began in 1970, and the mines have an average depth of 750 m.

The Stařfč concession covers approximately 40 square km, and an extension of another 30 square km has been proposed. The coal rank is high volatile bituminous A and is used almost exclusively for coking. Coal production is below average due to the complex geology of the region (steeply dipping beds up to 40°) and thin seams (averaging 88 cm but as thin as 55 cm). Production has decreased from 1.45 million tons in 1988 to 1.29 million tons in 1990.

Mines of the Stařič concession emit nearly 31 million cubic meters of methane to the atmosphere annually (1990). Methane is drained via in-mine (Stage II) and gob (Stage III) recovery techniques. Each year, about 30 million cubic meters of methane are drained from the mine, and of this, 28 million cubic meters are utilized, partly by the mine and partly by outside consumers. In the winter, the mine does not produce enough gas to meet the needs of its own boiler rooms, while in the summer, it does not need all of the gas it drains, and thus vents the remainder to the atmosphere.

The current mineable balance reserves are 226 million tons, and the total documented coal resource is 353 million tons (Table 6). The estimated methane reserves associated with the mineable balance coal reserves are 10.4 billion cubic meters, and 16.2 billion cubic meters of methane are associated with the total coal resource. Thirty-one million cubic meters of methane are liberated per ton of coal mined from the Štařič concession.

5.5.2 PROJECT TYPES

Mine officials are considering selling the summer surplus of coalbed methane to the nearby Biocel wood products plant, or to the Nova Hut' steel mill. The potential to increase methane recovery using pre-mine (Stage I) and improved in-mine and gob drainage methods (Stages II and III) should be investigated. As demand increases from these consumers and other consumers within the region, increased coalbed methane production may be economical. Sale of the gas could begin immediately because the mines are already linked to the pipeline distribution system.

Development of a nearby facility for storing surplus summer gas has also been proposed in the depleted Staříč gas field (Figure 15). Further investigations into increasing the potential for gas storage capacities with the OKR should be considered.

The potential for co-production of water along with methane from surface wells should be considered (Appendix C). According to 1990 data supplied by the OKD Department of Ecology, the Staříč mines pumped an average of 0.25 cubic meters of water for every ton of coal mined. The amount of total dissolved salts in this water averaged 7,922 mg/l. The water is initially pumped into storage ponds located near the mine, but is eventually discharged into the nearest stream. The discharge of these waters is detrimental to the water quality of the streams. Alternative disposal methods are discussed in Appendix C.

5.6 EXPLORATION AND DEVELOPMENT OPPORTUNITIES

Opportunities for coalbed methane exploration and development in Czechoslovakia appear promising. For exploration companies and investors wishing to pursue opportunities in the Czech Republic, a general procedural outline follows, based on potential investor experience. Further information can be found in Mining Act No. 44/1988, issued by the Czech National Council, and in Sack (1991).

A foreign company wishing to explore for coalbed methane should contact the Department of Raw Mineral Policy at the Ministry for Economic Policy and Development of the Czech Republic, in Prague. The company must present an exploration and development proposal, and have sufficient resources to finance the proposal. If such plan is approved by the Department of Raw Mineral Policy, the foreign company must then form a joint venture with a Czech company operating in the locality to be explored. After a joint venture agreement is reached, an exploration license is granted to the joint venture company.

CHAPTER 6

RECOMMENDATIONS FOR FURTHER ACTION

Agencies such as the Federal Ministry of Economy, the Ministry for Economic Policy and Development of the Czech Republic (MEPDCR), and the Czech Ministry of Environment, as well as the state mining enterprise OKD and its daughter companies, have recently indicated a keen interest in the potential for coalbed methane development and utilization in Czechoslovakia. Based on the results of this study, it is clear that development and utilization of coalbed methane in Czechoslovakia should be further investigated. All possible mechanisms for encouraging or facilitating coalbed methane usage should be evaluated, appropriate policies and incentives should be developed, and coalbed methane development and utilization should be a priority in Czechoslovakia's energy restructuring program.

Foreign governments and international agencies, as well as foreign companies, can assist Czechoslovakia with this process by providing technical and financial assistance for coalbed methane projects. Follow-up efforts should be designed to inform, educate, and train Czechoslovakian technical experts, as well as appropriate government personnel, regarding the potential role coalbed methane could play in the country's energy economy. Subsequent studies should also evaluate the feasibility of coalbed methane development and utilization at specific sites, ultimately leading to the implementation of demonstration projects.

6.1 FOLLOW-UP TECHNICAL ASSISTANCE ACTIVITIES

6.1.1 COALBED METHANE CLEARINGHOUSE

A coalbed methane clearinghouse funded by the U.S. EPA has been established in Katowice, Poland to address information needs of Poland (Pilcher et al, 1991). This clearinghouse, which was modeled after the Gas Research Institute's successful coalbed methane clearinghouses in the U.S., could be expanded to include not only Poland, but Czechoslovakia and other countries in central and eastern Europe that have coalbed methane potential. If this clearinghouse is successful, identical facilities could then be set up in each of the countries.

6.1.2 TRAINING

Training programs will be necessary to educate both mining industry technical personnel and government representatives. For the technical personnel, training should include methane recovery and use (emphasizing pre-mine drainage from the surface) and resource assessment. Programs for government representatives could include developing appropriate environmental and other regulatory frameworks to ensure safe implementation of methane recovery projects, legal and economic training, training in project feasibility assessment, and training related to project approval processes. These training programs would be developed in conjunction with the development of the clearinghouse and other follow-up studies. Agencies interested in providing training should work closely with appropriate Czechoslovakian representatives to identify needs and design efficient programs.

6.1.3 METHANE RECOVERY TECHNICAL ASSESSMENT

The applicability of several methane recovery approaches should be assessed at OKR mines, including methane pre-drainage using vertical wells, intensified in-mine drainage, and post-mining drainage using in-mine and vertical gob wells. In assessing alternative technical approaches, the opportunity to both increase gas quantities and improve gas quality (concentration) should be evaluated.

In the initial phase, the program would include detailed evaluation of current and possible methane drainage practices at selected OKR mines. Methane drainage consultants, working closely with OKD and mine officials, would review geologic and other data, mining plans, methane drainage designs, and methane production information. This team would identify new methane recovery approaches that should be tested. The final output of the team would be an experimental program of methane recovery that would be undertaken in the pilot phase at one or more mines.

6.1.4 STUDY OF POTENTIAL FOR METHANE USE IN POWER GENERATION

Methane utilization consultants, working closely with Czechoslovakian power generation experts, should assess the potential for methane use at thermal and electrical power generation facilities in the Ostrava-Karviná region. Where warranted, recommendations should be made as to modifications to existing power plants, and/or development of new power facilities. Options to consider include cofiring coal and methane, converting boilers to intermittent use of methane, use of methane in fluidized bed combustion, methane use in internal combustion engines, and use of methane in gas turbines.

Even with expanded mine methane recovery, much of the methane liberated will be in ventilation air, at concentrations of less than 1 percent. Therefore, in assessing the potential for methane use in power generation, use of ventilation air as combustion air in nearby boilers should be considered in terms of economic and technical feasibility. At U.S. gas prices of about $50/thousand cubic meters, these techniques are not currently economically viable. At higher gas prices, however, these technologies may be justified. For example, in Czechoslovakia imported gas prices are currently over $100/thousand cubic meters. In other cases, mines may also release gas recovered by drainage systems because it does not meet minimum quality requirements of about 35 percent.

6.1.5 GAS ENRICHMENT

As discussed in Section 3.2.4, two types of gas enrichment technologies may be well suited to enriching low-methane gas recovered by mine methane drainage systems. These technologies, namely pressure-swing adsorption and membrane gas separation, have proven feasible for feed gas streams containing 70 to 80 percent methane. However, the feasibility of enriching low-methane gas (30 to 50 percent methane) has not been tested.

The economic viability of enriching this low-methane gas to pipeline quality may be enhanced by the following factors:

- The fact that gas prices in Czechoslovakia are relatively high (compared to the U.S.);
- The recently enacted Czech Hydrocarbon Law imposes significant costs on methane emissions, further encouraging the use of gas recovered from mines; and
- The cost of the feed gas is effectively zero, since it would otherwise be vented to the atmosphere.

In preparing a pilot project, the technical and economic feasibility of using these gas enrichment methods on low methane gas should be assessed. Then, the most promising technologies should be selected and demonstration projects implemented.

6.1.6 STUDY OF POTENTIAL FOR INCREASING UNDERGROUND GAS STORAGE

It may also be desirable to evaluate the potential for increasing the underground gas storage capacity of the OKR region, as the ability to store coalbed methane to allow for seasonal fluctuations in demand could make it more economical to use. Options for increasing gas storage include enlarging existing underground storage facilities, developing new facilities in depleted natural gas reservoirs, and developing new facilities in abandoned mines. Gas storage consultants, working closely with Czechoslovakian gas storage experts, should identify potential gas storage projects in the OKR.

The technical and economic feasibility of a proposed gas storage project would need to be assessed. One aspect of such an assessment would be a comparison of the cost of importing natural gas from the CIS, or of using other fuels such as coal, versus the potential benefits of expanding underground storage for coalbed methane.

6.2 <u>FOLLOW-UP POLICY AND GOVERNMENT INITIATIVES</u>

In addition to technical assistance activities, establishing appropriate policies and initiatives pertaining to several related areas would further encourage methane recovery. Activities important in establishing these policies and initiatives include:

6.2.1 IMPACTS ASSESSMENT

As part of the effort to further assess coalbed methane development in the OKR, it is essential that the potential impacts be fully examined. This assessment should consider the impacts of both expanded methane recovery at active coal mines, and coalbed methane production using vertical wells in non-mining areas. Thus, it will provide information that is useful in managing the development of the types of methane recovery activities that are encouraged through this project and also those that may proceed commercially. Among the items that should be considered are

- Environmental Impacts air, water, and soil quality, and natural habitats
- Socioeconomic Impacts - changes in land use, employment, and economics
- Infrastructure Impacts - transportation services, including pipelines

This assessment should be prepared by a team of consultants working closely with local personnel from the Czech Ministry of Environment, OKD, mine officials, and local planning groups. The assessment should be undertaken in a manner that transfers to in-country personnel the experience of preparing such impact statements.

6.2.2 REGULATORY ASSESSMENT

The adequacy of existing regulations, fees, and fines affecting coalbed methane development should be evaluated. The assessment would include an examination of the structure and suitability of coalbed methane pricing, ownership, and leasing laws. It should also include an examination of project approval processes and permitting requirements. Environmental regulations to be evaluated include those regarding water disposal, siting, and land rehabilitation.

Based on this assessment, appropriate recommendations for modifications to existing regulations, as well as implementation of new regulations, could be made.

6.2.3 MARKET AND INVESTMENT ASSESSMENT

A market and investment assessment should be widely disseminated among government agencies and the private sector, as part of a general effort to promote mutual communication between government, mining officials, and potential investors in coalbed methane projects. Increased awareness of opportunities could help facilitate joint ventures between coal mines and gas production companies.

Potential markets for methane produced by active coal mines, as wells as methane produced by coal reserves, should be assessed, and the investments required to bring this gas to market identified. With respect to the gas recovered by active coal mines, the evaluation should include assessment of utilization options for low grade (less than 30 percent methane), medium grade (30 - 90 percent methane) and high grade (greater than 90 percent methane) gases. Potential users should be identified and investments for gas transmission facilities and/or conversion of possible customers from coal to gas described. The investment requirements for gas production should also be identified.

This assessment should also include a financial analysis to establish the economic feasibility of coalbed methane development relative to other options. For this analysis, the costs of the necessary production, transmission, and utilization facilities should be determined, as well as the value of the produced gas. This analysis should be conducted with respect to both gas recovered in active mining operations and gas produced from coal seams in non-mining areas.

As with the impact assessment, a team of consultants should work closely with OKD and other mining experts, the Czech Ministry of Environment, and local planning agencies. In addition to making the necessary assessments, the assessment methodology should be transferred to the in-country personnel.

Based on the results of the market and investment assessment, appropriate incentives for facilitating coalbed methane development should be considered. Among the types of tax credits which could be considered are those encouraging the production and sale of coalbed methane, as well as credits rewarding mines for not venting coalbed methane.

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APPENDIX A - USE OF THE KRIGING METHOD FOR GRIDDING AND CONTOURING DATA

The Kriging method was used to grid and contour the data presented in Figure 10. Kriging is a geostatistical method that the mining industry uses to estimate the variability of an ore body and predict the quality of the ore as it is mined. This method takes into account that geologic data is not randomly collected and therefore a certain amount of variance in the values of the sample population is due to its geographic location.

Geologic data is not random because samples taken for testing or evaluation are often selected due to ease of retrieval, or simply because most boreholes or mines are located with the anticipation of encountering an "ore body" or "pay zone".

Ore bodies, or pay zones, are economically recoverable reserves, and are by definition anomalous. They often comprise concentrations of the desired element many times the background values of those contained in the surrounding rock. So a method for statistical analysis of a data set that has been preselected because of its anomalous values was developed by a South African mining engineer named Krige.

Implementing the concept of regionalized variables (i.e., the variance of values due to their location in space), Krige developed methods of taking irregularly spaced data from the field and estimating values at points that would be encountered during future mining or exploratory drilling. In other words, Krige gridded an area of interest and estimated the values at each grid point, which incorporated variance due to location of the sample in space (Krige and Rendu, 1975).

Sometimes, maps of data that have been gridded and contoured using the Kriging method will contain several data points that fall outside what would, in a conventionally contoured map, be the appropriate contour interval; for example, the number "20" could appear between the "30 to 40" contour interval. This is because the contours are drawn on grid points that were calculated mathematically by the Kriging process. Figure 10 was created by "Kriging" with respect to all points, and consequently the contours reflect the contouring program's mathematical fit of the predicted values at each grid point, not necessarily the position of individual data points. Therefore, the appearance of a number outside the "appropriate" contour interval does not reflect an error in the gridding or contouring process.

Kriging is a good means of determining spatial trends in specific emissions. These trends also tend to correlate with lithological and structural trends. For example, in the Upper Silesian Coal Basin, areas of high specific emissions correlate with areas where the Carboniferous formations are overlain by a thick sequence of Miocene strata that has not been penetrated by faults. This suggests that the Miocene layer may help to trap the methane in the coal and surrounding porous rocks.

APPENDIX B - COMPARISON OF RESOURCE ESTIMATION METHODOLOGIES

Table B-1 shows the variability caused by using various methodologies to estimate resources of coalbed methane in Carboniferous basins of the United States, Poland and Czechoslovakia. In Part I of the table, it can be seen that in general, US resource estimates by Byrer et al (1987) and ICF (1990) are higher than estimates made by Brown et al (1991) of the Potential Gas Committee. The estimates of Byrer and ICF are potential resource estimates, without overly strict limits dictated by technological restraints. Estimates developed by the Potential Gas Committee are more conservative, reflecting the limits of presently available technology and present-day economics. Obviously both estimates are useful. The reader should note that the Central Appalachian Basin contains coal resources comparable to those found in the Upper Silesian Coal Basin (USCB), and that the magnitude of the coalbed methane resource is also comparable. Comparison of the amount of methane liberated per ton of coal mined in these two basins suggests that the coals of the Central Appalachian Basin are even gassier than those of the USCB.

Part II of the table allows comparison of the variables shown for the USA in Part I with the USCB in Poland and Czechoslovakia. It also shows the results of estimates of the coalbed methane resource using:

- methane contents based on desorption data from Poland
- specific emissions (methane liberated per ton of coal mined),
- specific emissions, adjusted for factors that limit the amount of gas contributed to the volume emitted into the coal mine by coal seams.

Part III of the table allows the reader to compare the resulting resource densities for the Polish part of the USCB with those calculated by Kotas et al (1992). Kotas' calculations estimate methane resources contained in a "standard kilometer of area" in unmined resource areas that will be let as coalbed methane concessions. His estimate is based on thousands of desorption data values from more than 1000 boreholes, unadjusted for lost gas. Note that the maximum resource density is reasonably close for all three methods. None of the methods compared in this part of the table include limits posed by economics or technology.

TABLE B-1. COMPARISON OF RESOURCE ESTIMATES FOR SELECTED CARBONIFEROUS COAL BASINS

PART I. UNITED STATES COAL BASINS

BASIN	AREA OF HIGHEST METHANE POTENTIAL (km)²	COAL RESOURCE (BILLION TONS) (BYRER ET AL, 1987) MIN.	MAX.	(ICF, 1990)	METHANE CONTENT (m³/T)¹ (BYRER ET AL, 1987) MIN.	MAX.	(ICF, 1990) MIN.	MAX.	SPECIFIC EMISSIONS (m³ / T) (DEPASQUALE, 1992) MIN.	MAX.	ESTIMATED TOTAL GAS-IN-PLACE (BILLION m³) (BYRER ET AL, 1987) MIN.	MAX.	(ICF, 1990)	(BROWN ET AL, 1991) MIN.	MAX.
NORTHERN APPALACHIAN	11,600	N/A	367.2	319.3	2.5	13.9	0.09	13.8	22.4	42.0	N/A	1726	1726	58	624
CENTRAL APPALACHIAN	10,400	73.0	109.0	13.6	3.9	12.5	1.1	21.2	44.2	81.9	283	1358	142	50	119
ILLINOIS	11,140	N/A	18.4	331.1	0.9	4.7	1.0	21.7	7.0	10.2	38	597	597	34	156
BLACK WARRIOR	17,600	N/A	33.5	56.2	0.2	18.6	1.6	16.8	85.3	166.0	N/A	566	566	85	269

PART II. THE UPPER SILESIAN COAL BASIN (POLAND AND CZECHOSLOVAKIA)

BASIN	AREA OF HIGHEST METHANE POTENTIAL (km)²	COAL RESOURCE² (BILLION TONS) (MEPNRF, 1989 AND MEPDCR, 1991) MIN.	MAX.	METHANE CONTENT¹ (m³/T) MIN.	MAX.	SPECIFIC EMISSIONS (m³/T) MIN.	MAX.	WEIGHTED AVERAGE	ESTIMATED GAS-IN-PLACE (BILLION m³) CALCULATED BY:³ SPECIFIC EMISSIONS UN-ADJUSTED	10% OF SPECIFIC EMISSIONS	65% OF SPECIFIC EMISSIONS	ASSUMED GAS CONTENT 4.4 m³/T	23.0 m³/T
UPPER SILESIAN (POLAND)	5,300	30.0	123.7	4.4	23	0.01	46.03	12.3	1522	152	989	544	2845
UPPER SILESIAN (OKR)	1,200	3.0	16.1	4.4	23	8.21	86.80	31.7	511	51	332	71	371
UPPER SILESIAN (ENTIRE)	6,500	33.0	139.8	4.4	23				2033	203	1321	615	3216

PART III. COALBED METHANE RESOURCE DENSITY IN THE POLISH PORTION OF THE UPPER SILESIAN COAL BASIN

BASIN	RESOURCE DENSITY (MILLION m³ / km²) BASED ON: SPECIFIC EMISSIONS UN-ADJUSTED	10% OF SPECIFIC EMISSIONS	65% OF SPECIFIC EMISSIONS	ASSUMED GAS CONTENT 4.4 m³/T	23 m³/T	ACCORDING TO KOTAS ET AL (1992) MIN.	MAX.
UPPER SILESIAN (POLAND)	287	29	187	103	537	188	240

¹ As measured by desorption tests. Note that values for Poland represent actual desorption measurements. No desorption measurements from the OKR were available,so it was assumed that values would be similar to those measured in Polish coals.

² As reported in Pilcher et al, 1991, and the present report. Note that the maximum coal and coalbed methane resources of the Polish part of the basin are slightly larger here than in Pilcher et al, 1991; due to a translation error, non-balance coals and associated methane resources were inadvertently omitted from Pilcher et al, 1991.

³ See discussion in Section 2.3

APPENDIX C - WATER DISPOSAL CONSIDERATIONS

Disposal of water produced by OKR mines poses a serious environmental problem. About 20 million cubic meters of water, containing more than 200 thousand tons of dissolved salts, are produced by OKR mines each year, nearly all of which is discharged to the Odra drainage. Table B-1 shows the quantity and quality of water produced by these mines. The Czechoslovakian government is seeking solutions to the mine water disposal problem, and is considering implementation of environmentally sound water management methods. There are many options, some of which are already in use in the Polish part of the Upper Silesian Coal Basin.

The coal layers themselves are generally considered to be dry; the primary source of water is the Miocene Detrit layer, a sandstone and conglomerate aquifer overlying the Carboniferous. Water enters the mines via fractures which are in communication with the Detrit layer.

When considering a coalbed methane drilling program in any region of the world, it must be recognized that production of the gas often results in coproduction of water present in the coal seams. The volume of water produced depends on the hydrogeologic characteristics of the coal-bearing formations, and it is difficult to predict this volume when planning exploration in a new area. It is possible that coalbed methane production in the OKR will also entail water production, but given the structural complexity of the region, the volume of water produced could very widely in different parts of the district. It is also difficult to predict the salinity of the water which may be produced, but it is likely that it will resemble that produced by nearby coal mines.

It is therefore difficult to predict how much, if any, water would be produced from coalbed methane wells in the OKR or other parts of Czechoslovakia, but the potential for water production and the need for environmentally sound disposal is an important consideration. Fortunately, there are many economically and environmentally successful water treatment and/or disposal methods that could be applicable to both mine water and coalbed methane water disposal. These methods include injection of saline water into wells (shallow or deep, depending on the circumstances); treatment of saline water by reverse osmosis, desalination, or electrodialysis; or a combination of these methods. These and other saline water management techniques are discussed in Wacinski et al (1992).

Historically, saline water produced from coal mines in the Upper Silesian Coal Basin has discharged to rivers, with little or no treatment. Because this practice has had severe environmental and economic consequences, programs aimed at improving management of saline mine water are being formulated. If saline water is co-produced with coalbed methane, it would be advantageous to jointly dispose of water produced by mines and coalbed methane wells. Some saline water treatment systems, such as desalination plants, could be fueled by coalbed methane.

TABLE C-1. QUANTITY AND QUALITY OF WATER PRODUCED FROM OKR MINE CONCESSIONS, AND VOLUME PRODUCED RELATIVE TO COAL PRODUCTION (1990 DATA)

MINE CONCESSION	WATER DISCHARGED (THOUSAND CUBIC METERS)	COAL PRODUCTION (kT)	TOTAL DISSOLVED SALTS (TONS)	WATER PRODUCED PER TON OF COAL MINED (m^3/TON)	TOTAL DISSOLVED SALTS (mg/l)
ODRA*	3,002.6	852.3	16,019	3.52	5,335.0
SVERMA*	1,697.4	606.2	8,324	2.80	4,904.0
HERMANICE*	1,241.6	496.0	10,849	2.50	8,737.9
OSTRAVA*	2,092.0	957.8	10,602	2.18	5,067.9
FUCIK*	2,187.9	1,281.1	34,055	1.71	15,565.2
CSM	2,054.4	1,911.9	25,354	1.07	12,341.3
CSA	1,602.0	1,761.5	32,587	0.91	20,341.4
DOUBRAVA	931.4	1,293.4	36,339	0.72	39,015.5
FRANTISEK	324.1	715.3	1,803	0.45	5,563.1
9 KVETEN	428.3	1,137.4	1,996	0.38	4,660.3
DUKLA	568.4	1,769.3	21,828	0.32	38,402.5
PASKOV	218.2	720.1	1,585	0.30	7,264.0
DARKOV	732.5	2,945.9	13,903	0.25	18,980.2
STARIC	319.1	1,288.5	2,527	0.25	7,919.1
LAZY	161.9	1,998.2	657	0.08	4,058.1

* CONCESSIONS WHOSE MINES ARE IN THE PROCESS OF BEING CLOSED OR ARE LIKELY TO BE CLOSED BY 1995 (SVERMA MINE CLOSED JANUARY 1992)

SOURCE: OKD DEPARTMENT OF ECOLOGY, OSTRAVA