Global methane and the coal industry

A two-part report on methane emissions from the coal industry and coalbed methane recovery and use
INTERNATIONAL ENERGY AGENCY
2, RUE ANDRÉ-PASCAL, 75775 PARIS CEDEX 16, FRANCE

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ii) An information system on the international oil market as well as consultation with oil companies;

iii) Co-operation with oil producing and other oil consuming countries with a view to developing a stable international energy trade as well as the rational management and use of world energy resources in the interests of all countries;

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FOREWORD

The IEA in recent years has focused increased attention on evaluating techniques for the reduction, control, use and disposal of greenhouse gases derived from fossil fuels. The IEA’s Coal Industry Advisory Board (CIAB) has made a valuable and authoritative contribution to this challenging work in this two-part report pertaining to global methane emissions from the coal industry and coalbed methane recovery and use.

Part I of the report entitled Global Methane Emissions from the Coal Industry takes the important early step of preparing an inventory of coalbed methane emissions arising from coal production. The study was first circulated in 1993 and is re-issued here in combination with the recently completed Part II.

Part II, entitled Global Coalbed Methane Recovery and Use: Current Practices and Prospects for Expansion, follows logically from the earlier study cited above. It first examines the current status of technology and practices for coalbed methane recovery in conjunction with coal mining operations and describes the methods by which coalbed methane is recovered in countries where coalbed methane utilisation is well established. The study then considers the potential for increased recovery and utilisation of coalbed methane emitted in conjunction with mining operations taking into account economic, technical and regulatory factors that affect decisions on the handling of recovery. It draws on the expertise and firsthand experience of coal industry operators who are routinely engaged in coalbed methane recovery and utilisation.

The CIAB report is intended to help clarify the issues surrounding coalbed methane recovery and to assist IEA Member Governments in evaluating the potential benefits of policies aimed at increasing such recovery in countries where these practices are relatively unknown. By identifying the mining conditions that are best suited for methane recovery and assessing the geology of the coal reserves in major coal producing countries, Global Coalbed Methane Recovery and Use: Current Practices and Prospects for Expansion offers valuable perspectives on the countries where the prospects for increased methane recovery and economic utilisation are greatest.

The study suggests that for this potential to be realised, appropriate technological know-how must be available, institutional and regulatory conditions must be favourable and the economic environment needs to be conducive to the commercial viability of recovery and utilisation. The IEA has been increasingly active in the areas of facilitating the flow of technology information, identifying institutional barriers that influence the diffusion of technology and know-how into the marketplace, assessing policy options for the removal of such barriers and advocating reliance on market principles as the most cost-effective way to assure diversity and reliability of fuel supplies at the same time as improving environmental quality. This CIAB report is extremely helpful to the contribution to these activities.

Holger Stoeg
Executive Director
GLOBAL METHANE AND THE COAL INDUSTRY: 
A Two-Part Report on Methane Emissions from the Coal Industry 
and Coalbed Methane Recovery and Use

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PART 1

GLOBAL METHANE EMISSIONS
FROM THE COAL INDUSTRY

COAL INDUSTRY ADVISORY BOARD
GLOBAL CLIMATE COMMITTEE

OCTOBER, 1992
ABSTRACT

Total methane emissions from worldwide mining, preparation, transport and storage of coal are estimated to be approximately 25 million tonnes/year. Slightly more than one million tonnes of methane are utilized by the industry. Thus, the net annual discharge to the atmosphere is 24 million tonnes. Methane emissions data were available for the U.S., the U.K., former U.S.S.R., Australia, China, Germany, Poland and Czechoslovakia. Methane emissions for India and S. Africa were estimated from a linear correlation between the average depth of mining and specific methane emissions derived from the available data for the eight countries. These ten largest coal producing countries represented nearly 90% of world coal production in 1990. Total methane emissions for the world coal industry were calculated by prorating the methane emissions from these ten countries in proportion to coal production. Global methane emissions from all sources, natural and man-made, are estimated at 425.675 million tonnes/yr. Therefore, the coal industry worldwide contributes 4 to 6 percent of global methane emissions.
INTRODUCTION

At its October, 1991 Board meeting, the Coal Industry Advisory Board (CIAB) requested that the Global Climate Committee (GCC) develop an estimate of global methane emissions from the coal industry. This report endeavors to develop such an estimate based on individual estimates for the ten largest coal producing countries, which represented nearly 90% of world coal production in 1990. Eight of these countries (the U.S., the U.K., Australia, the former U.S.S.R., Germany, Poland, China and Czechoslovakia) provide reasonably good estimates of methane emissions from their coal mines. Reliable methane emissions data for the two remaining countries, India and South Africa, are not available at this time. Therefore, it was necessary to develop estimates for these two countries based on the limited information that is available. (See Methodology section.)

Methane emissions from coal in the ten largest coal producing countries totaled approximately 22 million tonnes\(^1\) in 1990 (Table 1), the latest year for which information is available\(^2\). Total methane emissions from the world coal industry are estimated to be approximately 25 million tonnes/yr. Slightly more than one million tonnes of methane are utilized by industry. Thus, the net annual discharge to the atmosphere is about 24 million tonnes.

Virtually all (95%) methane emissions from coal are produced by underground mines, even though deep mines represent only 54% of world coal production. The relatively low methane emissions from surface production are due to the shallow depths of surface mineable reserves which are inherently low in methane content. Additionally, much of the world’s surface mined coals are low in rank, namely lignite, sub-bituminous and low rank bituminous coal, which do not contain much gas.

Figure 1 illustrates the relationship of gas content to coal reservoir pressure for various U.S. coal seams. The coal reservoir pressure generally increases with the depth of the coal seam; however, this relationship may vary significantly from one region to another. The mining process creates entries in mines that are nearly at atmospheric pressure and also breaks down coal into small pieces releasing methane and other occluded gases. Hence, most of the gas produced from underground mines is released

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1. One million tonnes of methane at 15°C and an atmospheric pressure of 760 mm of mercury = 1471 million cubic meters
2. 1990 coal production data with underground and surface production breakdowns were provided by the National Coal Association, U.S.A.
during the mining process. In some highly gassy coal seams, it is necessary to drill the coal seams prior to mining and drain methane. The process is known as “coal seam degasification”. A small portion of the methane is released after mining during the preparation, storage and transportation of the coal.

The net total methane emissions from the world coal industry of 24 million tonnes/yr represent 4-6% of total global methane emissions, including natural sources. Most of the global methane emissions accrue directly from natural sources, such as swamps and bogs, decay of vegetation, termites that flourish in dead plants, and the digestive tracts of animals. Man-made sources of methane include rice paddies, landfills, oil and natural gas production and transmission, and coal mining. Methane emissions worldwide are currently estimated to be in the range of 425-675 million tonnes, of which natural sources represent nearly 60% (1).

China and the former U.S.S.R. are estimated to produce 58% of the methane liberated from world coal production. By contrast, these two countries represented less than 42% of world coal production in 1990. China’s relatively high rate of methane liberation is due to the disproportionate share of its production from underground mines, 62%, versus an average of 42 percent for other major coal producing countries. The relatively high rate of methane liberation for the former U.S.S.R. is due to the greater depths of its underground mines. The average depth of underground mines in the former U.S.S.R. is approximately 600 meters versus an average of 300 meters for the other major coal producing countries.
METHANE CONTENT OF COAL

Coal seams were formed over millions of years by the biochemical decay and metamorphic transformation of the original vegetable matter. This process, known as “coalification,” produces large quantities of by-product gases. The volume of by-product gases increases with the rank of coal, and is the highest for anthracite, where the formation of every tonne of coal produces approximately 765 cubic meters of methane (2). Most of these gases escape to the atmosphere during the coalification process, but a small fraction has been retained in the coal. The amount of gas retained depends on the rank of coal and a number of environmental conditions, such as the depth of burial, immediate roof and floor, geological anomalies, tectonic forces, and the temperature involved during the coalification process.

In general, the higher the rank of coal and the greater the depth of the coal seam, the higher is its gas content. Actual gas contents of various coal seams indicate a range of 0 to 22 cubic meters per tonne. Figure 1 shows the variation of gas content for certain U.S. coal seams. The quality of gas contained in coal also varies from region to region. In general, 90 to 95% of the gas produced from coal seams is methane (and other hydrocarbons) and the rest are mostly inert (e.g. nitrogen, carbon dioxide, argon) and other minor constituents (e.g. helium, hydrogen, etc).

Notable exceptions to the above generalizations do occur. For example, some Australian coal seams have a high CO₂ content while some Polish and Czechoslovakian coal seams show a high proportion of nitrogen. Similarly, gas contents appear to increase with depth, but at different rates (3). While strong correlations can be made between gas content and, the rank and depth of the coal seam, the best method for determining the gas content is to take a core of the coal seam in question and measure its gas content using well-known techniques (4).

COAL MINING AND METHANE EMISSIONS

Coal is generally mined by two methods: surface mining and underground mining. Surface mining (also known as strip mining, open cut or open-cast mining) involves complete removal of overburden and exposure of the economically minable coal seams. The latter is then extracted using well-known mining techniques, such as drilling, blasting, loading and hauling in trucks. Of necessity, these coal seams are
shallow in depth and do not contain significant amounts of gas. Additionally, most of the surface mined coals around the world are of low rank, namely lignite and sub-bituminous coals, which do not contain much gas. Methane emissions from surface mined coal are therefore very small.

Figure 1
Variation of Gas Content with Rank and Reservoir Pressure of Coal for U.S. Coal Seams

Underground coal mining involves accessing of the coal seam through slopes or shafts. The coal is mined using mechanized cutting, or driviting and blasting, loading, and transporting out of the mine. Most methane liberation is due to deep mining. Underground mining can be divided into two phases of mining: (a) development and (b) pillar extraction. Development work involves drivage of a network of tunnels into the coal seam to create a large number of pillars to be mined later. This is usually done with a machine known as a “continuous miner”. The machine cuts and loads coal into a shuttle car which in turn hauls and dumps the coal onto a moving belt or rail car. The coal travels out of the mine on a series of belts or rail cars and is finally brought out via a slope or a shaft.
All methane produced during the development phase of underground mining is from the coal seam being mined and hence relatively easier to measure. The gas is emitted at the working face as well as in previously mined areas. The mined coal also keeps desorbing gas during its travel in the mine and continues to do so until it is ultimately consumed. All emitted methane is mixed with mine air, diluted to safe levels and discharged on the surface. If these development headings experience a high rate of methane emissions, the coal seam is degassed using hydraulically stimulated vertical wells or long horizontal boreholes in advance of mining (5) (6).

The second phase of underground mining involves complete or partial extraction of the coal pillars. Smaller pillars are extracted by continuous miners by splitting them into even smaller pillars, but large blocks of coal (150m x 1500m to 275m x 4000m) are extracted by a technique called “longwall mining”. In either case the mined coal produces methane, but in addition, the extraction of these pillars causes the overlying strata to subside and the underlying strata to heave. The vented mine workings constitute a natural pressure sink, into which methane flows from the entire disturbed area (known as the “gob” or “goaf” area). Several authors have studied methane emission rates in the gob areas (7) (8) (9).

The gob methane emissions rate depends on the rate of longwall face advance, the geology, size of the longwall panel, and the gas content and thickness of coal seams in the gas emission space. In view of this, predicting the rate of methane emissions from these gobs involves great mathematical complexity. Most of the gas emitted is carried by ventilation air, but in some cases, vertical boreholes (mostly in the U.S.) or cross-measure boreholes (mostly in Europe and Asia) are drilled to capture methane and drain it to the surface. The drained gas tends to be of variable quality (30 to 100% methane) and may be used for specific applications or vented into the atmosphere.

**METHODOLOGY**

Although it is possible to forecast methane emissions from a given mine if the reservoir properties, such as gas content, reservoir pressure, permeability and porosity of coal seams, and the mining methods are well known, it is extremely difficult to do so for an entire country containing various coal fields with hundreds of coal seams. The difficulty of the task becomes even more obvious when a global estimation of methane emission is attempted. Several authors (10) (11) have attempted to forecast global methane emissions from coal mines based on extrapolation from very limited data. However, the only reliable technique for this task is to prepare a realistic inventory of methane emissions on a country-by-country basis.

In 1990, 60 countries produced 4.7 billion tonnes of coal (12). The top ten countries, (China, the U.S., the former U.S.S.R., Germany, Poland, Australia, India, South Africa, Czechoslovakia and the U.K.) produced nearly 90% of the total. For expediency, it was decided to concentrate on these 10 countries for accurate estimation of their methane emissions. The total methane emissions from these ten countries were then prorated to arrive at a rough estimate of global methane emissions from coal.
REFERENCES


14. Personal communication with Mr. Michael Trevits of the U.S. Bureau of Mines Research Center, Pittsburgh, PA, USA.

APPENDIX

METHANE EMISSIONS CALCULATIONS
FOR THE TEN LARGEST
COAL PRODUCING COUNTRIES
CHINA

China is the world’s largest coal producer. Proven reserves are approximately 900 billion tonnes, of which about 70% are bituminous, 16% are anthracite and 14% are lignite. Nearly 75% of China’s energy demand is met by coal. Figure 1 shows the coal deposits of China. About 80% of its resources are concentrated in north-central China and Inner Mongolia. Coal production by rank for 1990 is as follows:

<table>
<thead>
<tr>
<th>Type</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous Coal</td>
<td>967 Million Tonnes</td>
</tr>
<tr>
<td>Lignite</td>
<td>80 Million Tonnes</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,053 Million Tonnes</strong></td>
</tr>
</tbody>
</table>

Over 90% of the total production is mined underground and the rest is produced from surface mines. China’s coal seams differ widely from region to region, but they are easy to mine. Seams mined average 2.7 meters in thickness. Most seams are flat to slightly dipping. About 20% dip from 10-25 degrees and 8% of all coal seams are steeply inclined.

The average depth of all mines is estimated to be 330 meters. However, some mines attain depths of 1000 meters. Most of underground mining in the state-owned mines is done with longwall faces, although the degree of mechanization is not as high as in some developed countries. There are, at present, 618 state-owned coal mines in China, which produce 44% of total production. These mines operate about 2500 longwall faces but the rate of advance appears to be slow because overall longwall productivity is quite low. There are about 1800 locally run collective mines, which accounted for about 20% of coal production. The remaining 36% of coal is mined from more than 79,000 smaller mines. Mining in non-state-owned mines is totally unmechanized. Their production ranges from 5000 to 100,000 tonnes per year. Most of these mines are non-gassy and their methane emissions are likely to be similar to post-mining emissions; i.e., methane emissions are estimated to be 0.9 cubic meters/tonne. Most of the methane is produced from state-owned mines and is estimated at 10 billion cubic meters/yr (1). About 100 state-owned mines practice some kind of methane drainage and the total methane drained is about 1 billion cubic meters/yr.

METHANE EMISSIONS ESTIMATE

A. Mine Ventilation Air Methane Emissions
   (i) State owned mines = 9000 million cubic meters
   (ii) Other underground mines = .9 x .48 x 1053 = 455 million cubic meters

B. Coal Seam Degasification Methane Emissions = 1000 million cubic meters

C. Post Mining Methane Emissions = .9 x 967 = 870 million cubic meters

D. Surface-mined Coal Methane Emissions = 0.05 x 86 = 4 million cubic meters

| Total Methane Emissions/Yr = 11.329 million cubic meters = 7.70 million tonnes |
| Total Methane Utilized/Yr = 205 million cubic meters = 0.14 million tonnes |
| Net Methane Emissions/Yr = 11,124 million cubic meters = 7.56 million tonnes |
| Specific Methane Emissions from Underground Mines = 10.8 cubic meters/tonne |

* Underground production from non-state owned mines is estimated to be approximately 48% of total production.
THE FORMER U.S.S.R.

Coal deposits occur in many regions of the former U.S.S.R., but they are distributed irregularly over the country. All ranks of coal are found in the U.S.S.R., ranging from lignite to anthracite. The coal reserves are vast amounting to nearly five trillion tons or 47% of the total world reserve. Figure 2 shows their main coal deposits. The thickness of coal seams being mined underground ranges from 0.5 to 25 meters. Nearly 25% of all coal is produced from mines working at a depth greater than 100 meters. Seam dip ranges from flat to 80 degrees. Average depth of underground mines in various coalfields appears to be 600 meters. In 1990, the former U.S.S.R. produced 361 million tons of coal from underground mines and 342 million tonnes from surface mines. Coal production by rank is as follows:

<table>
<thead>
<tr>
<th>Coal Type</th>
<th>Million Tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous</td>
<td>545</td>
</tr>
<tr>
<td>Lignite</td>
<td>158</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>703</strong></td>
</tr>
</tbody>
</table>

Methane emissions data for former U.S.S.R. mines are as shown below.

METHANE EMISSIONS ESTIMATE

A & R Mine Ventilation Air and Coal Seam Degasification Methane Emissions = 7.005 million cubic meters

C. Post Mining Methane Emissions = 0.9 x 361 = 325 million cubic meters

D. Surface-mined Coal Methane Emissions
   (i) Bituminous/Sub bituminous Coal = 0.24 x 184 = 44 million cubic meters
   (ii) Lignite/Brown Coal = 0.05 x 158 = 7.9 million cubic meters

<table>
<thead>
<tr>
<th>Table Row</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Methane Emissions/Yr =</td>
<td>7,382 million cubic meters = 5.02 million tonnes</td>
<td></td>
</tr>
<tr>
<td>Total Methane Utilized/Yr =</td>
<td>(280) million cubic meters = (0.19) million tonnes</td>
<td></td>
</tr>
<tr>
<td>Net Methane Emissions/Yr =</td>
<td>7,102 million cubic meters = 4.83 million tonnes</td>
<td></td>
</tr>
<tr>
<td>Specific Methane Emissions from Underground Mines =</td>
<td>19.4 cubic meters/tonne</td>
<td></td>
</tr>
</tbody>
</table>

UNITED STATES

Figure 3 shows the coal deposits of the U.S. Coal is widespread throughout the U.S.A. and is the most abundant fossil fuel, accounting for 90% of all the country’s energy resources. Total resources of coal are estimated to be 2.3 trillion tonnes (about 25% of the world’s total resources) of which 1.1 trillion tonnes are hard coal and 1.2 trillion tonnes are lignite. Coal production in 1990 was 931 million tonnes of which 384 million tonnes were produced from underground mines. The rest of the production was surface mined. The production breakdown by rank was as follows:

- Bituminous Coal: 629 Million Tonnes
- Sub-bituminous Coal: 222 Million Tonnes
- Lignite: 80 Million Tonnes
- Total: 931 Million Tonnes
Over 90% of all underground coal mined in the U.S. is produced at depths of less than 300 meters. A
dozens of mines are deeper and reach depths of 700 meters. Generally, the coal seams are flat or slightly
dipping (from 2 to 8 degrees). It is unlikely that mining depths will change significantly over the next
20 years.

METHANE EMISSIONS ESTIMATE

A. Mine Ventilation Air Methane Emissions:
The U.S. Bureau of Mines has kept excellent records of methane emitted by mine ventilation air\(^1\). In
1988, 487 underground mines emitted 309 million cubic meters of methane. Total underground coal
production was 347 million tonnes giving a specific (ventilation air) methane emission of 8.79 cubic
meters per tonne. Hence, 1990 methane emissions are estimated as follows:

\[ 8.79 \times 384 = 3375 \text{ million cubic meters} \]

B. Coal Seam Degasification Methane Emissions:
Hydraulically stimulated vertical wells and underground horizontal drilling are used in gassy mines
to degasify the virgin coal. Vertical gob wells are used in thirty-five mines to drain the gob gas.
Total methane drained (figures obtained via personal contacts) is approximately 1471 million cubic
meters/yr.

C. Post Mining Methane Emissions:

\[ 0.9 \times 384 = 346 \text{ million cubic meters} \]

D. Surface-Mined Coal Methane Emissions:

(i) Bituminous/Sub-bituminous Coal = \(0.24 \times 467 = 112\) million cubic meters

(ii) Lignite/Brown Coal = \(0.03 \times 80 = 4\) million cubic meters

\[
\begin{array}{lcl}
\text{Total Methane Emissions/Yr} &=& 5,308 \text{ million cubic meters} = 5.61 \text{ million tonnes} \\
\text{Total Methane Utilized/Yr} &=& (459) \text{ million cubic meters} = (0.31) \text{ million tonnes} \\
\text{Net Methane Emissions/Yr} &=& 4,849 \text{ million cubic meters} = 3.30 \text{ million tonnes} \\
\text{Specific Methane Emissions from Underground Mines} &=& 12.6 \text{ cubic meters/tonne}
\end{array}
\]

GERMANY

Total coal reserves of Germany (excluding the eastern part of Germany) is in excess of 300 billion tonnes. All ranks of coal are mined in four different basins. Figure 4 shows the coal deposits for western Germany. Only 15% of coal is mined in underground mines; the rest is surface-mined. Production breakdown for 1990 by rank is as follows:

- Bituminous Coal: 78 Million Tonnes
- Lignite: 256 Million Tonnes
- Total: 434 Million Tonnes

The Ruhr and Saar basins are the most important coal and methane producing regions. In the Ruhr coalfield, 30 to 40 minable coal seams are present in a total sequence of 3000 meters of coal measures. The coalfield outcrops south of the line through Duisburg, Essen, Bochum and Dortmund, and the depth of the seam increases to the north. Average depth of mining within the coalfield is 800 meters.

In the Saar coalfield, mining is carried out in Schwelbach and Wablschier coal seams at depths ranging from 600 to 1200 m. Longwall mining is the predominant method of underground mining.
METHANE EMISSIONS ESTIMATE

A mine by mine survey of methane emissions yields the following estimates:

A. Mine Ventilation Air Methane Emissions = 1,204 million cubic meters
B. Coal Seam Degasification Methane Emissions = 520 million cubic meters
C. Post Mining Methane Emissions = 0.9 x 78 = 70 million cubic meters
D. Surface-Mined Coal Methane Emissions = Lignite/Brown Coal = 0.015 x 356 = 5.3 million cubic meters

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Methane Emissions/yr</td>
<td>1,799 million cubic meters</td>
<td>1.22 million tonnes</td>
</tr>
<tr>
<td>Total Methane Utilized/yr</td>
<td>(371) million cubic meters</td>
<td>(0.25) million tonnes</td>
</tr>
<tr>
<td>Net Methane Emissions/yr</td>
<td>1,428 million cubic meters</td>
<td>.97 million tonnes</td>
</tr>
<tr>
<td>Specific Methane Emissions from Underground Mines</td>
<td>22.4 cubic meters/tonne</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4
Coal Fields of Germany

1. Personal Communications with Professor Dr. Gunter Zimmermeyer of Deutschen Steinkohlenbergbaus, Glückaufhaus, 45128 Essen.
POLAND

Poland’s hard coal deposits are found in three major basins; the Upper Silesia Basin, the Lower Silesia Basin, and the Lublin Basin (see Figure 5). The Upper Silesia Basin, which straddles the Polish-Czechoslovakian border in the south, is the most important coal-producing region in Poland. There are nearly 70 deep mines in the country that mine 148 million tonnes of coal per year. Surface mines produce 68 million tonnes annually. Production by rank is as follows:

<table>
<thead>
<tr>
<th>Coal Type</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous Coal</td>
<td>148 Million Tonnes</td>
</tr>
<tr>
<td>Lignite</td>
<td>68 Million Tonnes</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>216 Million Tonnes</strong></td>
</tr>
</tbody>
</table>

*Figure 5*

Coal Fields of Poland
The average depth of mines in the Upper Silesia is 670 meters while Lower Silesia mines have an average depth of 840 meters. Most underground mining is done with longwalls.

**METHANE EMISSIONS ESTIMATE**


C. Post-mining Methane Emissions = 0.9 \times 148 = 133 million cubic meters

D. Surface-mined Coal Methane Emissions = Lignite/Brown Coal = 0.05 \times 68 = 3.4 million cubic meters

| Total Methane Emissions/Yr = | 1,980 million cubic meters = 1.35 million tonnes |
| Total Methane Utilized/Yr = | (201) million cubic meters = (0.14) million tonnes |
| Net Methane Emissions/Yr = | 1,779 million cubic meters = 1.21 million tonnes |
| Specific Methane Emissions from Underground Mines (weighted average) = | 12.5 cubic meters/tonne |

---

**THE UNITED KINGDOM**

Extensive deposits of carboniferous hard coal are found throughout the United Kingdom (see Figure 6). Total coal resources are estimated at 190 billion tonnes. Coal was mined in 12 areas with an annual production of 95 million tonnes in 1990, of which 79 million tonnes were from underground mines. (It should be noted that British underground coal production in 1991 declined to 71 million tonnes and that total methane emissions should have declined proportionately.)

The thickness of the coal seams is in the range of 1.5 to 2 meters. The dip of the coal seams is generally less than 20 degrees. The average depth of mining is approximately 500 meters. The maximum depth of mining is about 1200 meters. Underground mining is done with mechanized equipment and predominantly with retreat longwall methods. Production by rank in 1990 was as follows:

- Anthracite/Bituminous Coal: 95 Million Tonnes
- Total: 95 Million Tonnes

---

Australia possesses coal ranging in rank from anthracite to lignite. The predominant reserves of hard coal are of bituminous rank. In New South Wales, the coal seams being mined are generally flat and occur at relatively shallow depth. Median depth of all underground mines is about 300 meters. Only about 7% of coal is mined from depths of 500 meters or more. In Queensland the coal seams being mined are even shallower. Median depth is around 150 meters. About 90% of the state’s total production is from surface mines. A recent study gives a fair estimate of methane emissions from Australia’s mines. Based on the concurrent coal production, the specific methane was deduced to be 11.2 cubic meters/tonne.

METHANE EMISSIONS ESTIMATE

A & B. Mine Ventilation Air and Coal Seam Degasification Methane Emissions = 11.2 x 53 = 594 million cubic meters
C. Post Mining Methane Emissions = 0.9 x 53 = 48 million cubic meters
D. Surface-Mined Coal Methane Emissions =
   (i) Bituminous/Sub-bituminous Coal = 0.24 x 74 = 18 million cubic meters
   (ii) Lignite/Brown Coal = 0.05 x 36 = 1.8 million cubic meters

<table>
<thead>
<tr>
<th>Methane Emissions/Year</th>
<th>Total Methane Emissions</th>
<th>Total Methane Utilized/Year</th>
<th>Net Methane Emissions/Year</th>
<th>Specific Methane Emissions from Underground Mines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>662 million cubic meters</td>
<td>(177) million cubic meters</td>
<td>540 million cubic meters</td>
<td>11.2 cubic meters/tonne</td>
</tr>
<tr>
<td></td>
<td>0.45 million tonnes</td>
<td>(0.09) million tonnes</td>
<td>.37 million tonnes</td>
<td></td>
</tr>
</tbody>
</table>

SOUTH AFRICA

The coal industry of the Republic of South Africa is highly concentrated with eight mining companies accounting for over 90% of production. There are 16 individual coal fields in the country of which six are of major importance. Total coal production in 1990 was 206 million tonnes, of which 124 million tonnes (60%) were from underground mines. Production by rank was as follows:

<table>
<thead>
<tr>
<th>Coal Type</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous Coal</td>
<td>206 Million Tonnes</td>
</tr>
<tr>
<td>Total</td>
<td>206 Million Tonnes</td>
</tr>
</tbody>
</table>

Figure 8 shows the major coal deposits of South Africa. The majority of coal seams in South Africa is flat and occurs at an average depth of less than 200 meters. Most of the coal seams have an average thickness of 2 to 3 meters. Conventionally mechanized room and pillar mining is the predominant method of underground mining, but many mines have introduced continuous miners in the past 15 years.

METHANE EMISSIONS ESTIMATE

No direct information on methane emissions from South African coal mines is available. Assuming an average depth of 200 meters for all underground coal mines, the specific methane emissions for South Africa works out to be 9 cubic meters/tonne.

A & B. Mine Ventilation Air and Coal Seam Degasification Methane Emissions = $9 \times 124 = 1116$ million cubic meters

C. Post Mining Methane Emissions = $0.9 \times 124 = 112$ million cubic meters

D. Surface-Mined Coal Methane Emissions = $0.24 \times 82 = 20$ million cubic meters

<table>
<thead>
<tr>
<th>Total Methane Emissions/Yr</th>
<th>1,248 million cubic meters</th>
<th>0.85 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Methane Utilized/Yr</td>
<td>(0) million cubic meters</td>
<td>(0.00) million tonnes</td>
</tr>
<tr>
<td>Net Methane Emissions/Yr</td>
<td>1,248 million cubic meters</td>
<td>.85 million tonnes</td>
</tr>
<tr>
<td>Specific Methane Emissions from Underground Mines</td>
<td>9 cubic meters/tonne</td>
<td></td>
</tr>
</tbody>
</table>

Figure 8
Coal Fields of South Africa
INDIA

Coal India Limited, a public holding company, is responsible for all productions of coal in India. Coal deposits of India range in geological age from the Permian to the Eocene. There are four large hard coal deposits in the country: Raniganj in W. Bengal, Jharia and Bokaro in Bihar, and Singrauli in Madhya Pradesh. There are seven lignite deposits of which the largest and the most important is Neyveli in the Southern part of India. Figure 9 shows major coal deposits in India. Total coal reserves are estimated at approximately 85 billion tonnes.

Of the total production of 212 million tonnes, only 64 million tonnes (30%) are mined from underground mines. Nearly 70% of the total hard coal reserves of India are contained in seams thicker than 3 meters. Production of coal by rank is as follows:

<table>
<thead>
<tr>
<th>Coal Type</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous Coal</td>
<td>199 Million</td>
</tr>
<tr>
<td>Lignite</td>
<td>13 Million</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>212 Million</strong></td>
</tr>
</tbody>
</table>

_Figure 9_

Coal Fields of India

[CMap of major coalfields in India with major fields labeled and a key to abbreviations included]
The depth of India’s underground mines generally varies from 100-400 meters and averages about 200 meters. The deepest mines are nearly 700 meters deep and lie in the state of West Bengal.

Room and pillar mining is the predominant underground mining method. Pre-cutting and blasting have replaced traditional hand mining, although the underground mining of coal is still quite labor intensive with little mechanization. Face mechanization is being attempted and longwall mining has been introduced in several mines.

METHANE EMISSIONS ESTIMATE

Most of the coal seams of India are not gassy. Even the deeper coal seams do not have as high a gas content as similarly deep coal seams in the U.S. or Europe. No coal seam degasification is done. Considering the average depth of 200 meters and using the equation in the text, a specific methane emission of 9 cubic meters/tonne was estimated for all underground mine coal.

A & B. Mine Ventilation Air and Coal Seam Degasification Methane Emissions = 9 x 64 = 576 million cubic meters

C. Post Mining Methane Emissions = 0.9 x 64 = 58 million cubic meters

D. Surface-mined Coal Methane Emissions =
   (i) Bituminous/Sub-bituminous Coal = 0.24 x 139 = 33 million cubic meters
   (ii) Lignite/Brown Coal = 0.05 x 9 = 0.5 million cubic meters

| Total Methane Emissions/Yr = | 668 million cubic meters = | 0.45 million tonnes |
| Total Methane Utilized/Yr = | (0) million cubic meters = | (0.0) million tonnes |
| Net Methane Emissions/Yr = | 668 million cubic meters = | 0.45 million tonnes |

FORMER CZECHOSLOVAKIA

The coal fields of Czechoslovakia are shown in Figure 10. Hard coal is produced from the Ostrava-Karvina district of the Upper Silesian Basin, the Central Bohemian Coal Basin, Lower Silesian Coal Basin and Ceske Budejovice Basin near the Austrian border. In 1989, total coal production was 119 million tonnes, of which only 25 million tonnes were from underground mines. Ostrava-Karvina district is the major producer of underground coal. Nearly 20 million tons of coal are produced from 14 mines. These mines also produce most of their coalbed methane emissions. Total methane emissions from these mines are reported to be 525 million cubic meters for a coal production of about 20 million tonnes, yielding a specific methane emission of 26 cubic meters/tonne. Average mining depth is approximately 740 meters.

METHANE EMISSIONS ESTIMATE

A & B. Ventilation Air and Coal Seam Degasification Methane Emissions = 525 million cubic meters

C. Post Mining Methane Emissions = 0.9 x 25 = 23 million cubic meters

D. Surface-mined Coal Methane Emissions =
   (i) Sub-bituminous Coal = 0.24 x 85 = 20 million cubic meters
   (ii) Lignite/Brown Coal = 0.05 x 9 = 0.5 million cubic meters

<table>
<thead>
<tr>
<th>Total Methane Emissions/yr</th>
<th>569 million cubic meters</th>
<th>0.39 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Methane Utilized/yr</td>
<td>(126) million cubic meters</td>
<td>(0.09) million tonnes</td>
</tr>
<tr>
<td>Net Methane Emissions/yr</td>
<td>443 million cubic meters</td>
<td>.30 million tonnes</td>
</tr>
<tr>
<td>Specific Methane Emissions from Underground Mines</td>
<td>26.0 cubic meters/tonne</td>
<td></td>
</tr>
</tbody>
</table>
PART 2

GLOBAL COALBED METHANE RECOVERY AND USE:
CURRENT PRACTICES AND
PROSPECTS FOR EXPANSION

COAL INDUSTRY ADVISORY BOARD
GLOBAL CLIMATE COMMITTEE

OCTOBER 1993
ABSTRACT

The 1992 CIAB study entitled *Global Methane Emissions from the Coal Industry* estimated that global methane emissions from the world coal industry were about 25 million tonnes\(^1\) (Mt) per year (1). Coalbed methane recovery in conjunction with coal mining operations is practiced at some level in most, if not all, of the world’s coal-producing countries. However, of the 25 Mt of methane emitted by the coal mining industry worldwide, only about 7% is recovered and utilized. Although a higher percentage is recovered, utilization is not always practical, therefore some of the recovered gas is released. The purpose of this report is to examine the potential for increased recovery and utilization of coalbed methane emitted *in conjunction with mining operations*, given the economic, technical and regulatory constraints facing the world coal industry.

Under ideal conditions (i.e. deep gassy seams where longwall mining methods are utilized, institutional barriers are minimized, and state-of-the-art technology and knowledge are available) as much as 60 to 70% of the coalbed methane emissions at a specific mine can be recovered and utilized. Under less favorable conditions (i.e. intermediate depth seams containing less gas) only 30% to 40% of the coalbed methane can be recovered. Shallow underground mines and surface minable seams offer little potential for commercially viable projects to recover coalbed methane.

A review of the coalbed methane recovery practices in the major coal producing nations and an assessment of the geology of their coal reserves indicates that the theoretical or technical potential exists, in certain countries, to recover as much as 45% of the coalbed methane currently being released into the atmosphere. For this (HIGH POTENTIAL) group, conditions conducive to coalbed methane recovery are fairly consistent in one or more of a country’s major coal basins. Realizing the full potential is contingent on access to state-of-the-art technology and drilling techniques, as well as an economic environment conducive to the commercial viability of coalbed methane recovery and utilization projects. For the second (MEDIUM POTENTIAL) group of countries, the overall recovery and utilization potential is slightly lower, i.e. the opportunities for commercially viable projects are somewhat more diffuse than in the first group. In the third (LOW POTENTIAL) group of countries, the opportunities for commercially viable coalbed methane recovery projects are very limited.

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\(^1\) One million tonnes of methane at 15°C and an atmospheric pressure of 760 mm of mercury – 1.411 million cubic meters
The following table compares the theoretical or technological potential for coalbed methane recovery with the actual level of utilization in 1990 for the world’s ten leading coal producing countries:

### Coalbed Methane Recovery Industry Practices and Potential
#### 1990 Estimates

<table>
<thead>
<tr>
<th>Technological Recovery Potential (%)</th>
<th>Coal Production (Mt)</th>
<th>CBM Emitted (Mt)</th>
<th>CBM Recovered (%)</th>
<th>CBM Utilized (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HIGH (35 - 45%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>1,053</td>
<td>7.7</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>C.I.S.</td>
<td>703</td>
<td>5.0</td>
<td>19</td>
<td>4</td>
</tr>
<tr>
<td>Czechoslovakia</td>
<td>119</td>
<td>0.3</td>
<td>27</td>
<td>24</td>
</tr>
<tr>
<td>Germany</td>
<td>434</td>
<td>1.2</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Poland</td>
<td>216</td>
<td>1.4</td>
<td>27</td>
<td>19</td>
</tr>
<tr>
<td>U.K.</td>
<td>95</td>
<td>0.9</td>
<td>35</td>
<td>11</td>
</tr>
<tr>
<td><strong>MEDIUM (30 - 40%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S.A.</td>
<td>931</td>
<td>3.6</td>
<td>41</td>
<td>15*</td>
</tr>
<tr>
<td>Australia</td>
<td>163</td>
<td>0.4</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td><strong>LOW (25 - 35%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>212</td>
<td>0.3</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>South Africa</td>
<td>206</td>
<td>0.8</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

* Based on 1992 Data

These limits reflect the theoretical or technological potential for coalbed methane recovery, and therefore represent the upper limit to utilization. In order to achieve these levels, state-of-the-art technology and knowledge must be universally available and applied. In other words, the gap that exists between the most advanced recovery practices and the more rudimentary practices prevalent in countries such as China and the old Eastern Bloc countries must be eliminated. Moreover, the many institutional obstacles to coalbed methane recovery and utilization must be eliminated.

Less than full access to state-of-the-art technology and knowledge combined with the existence of numerous institutional and economic barriers limit the realizable potential for coalbed methane utilization worldwide, to the 15 to 25% range — two to four times the actual 1990 level. This estimate is based on existing technology and gas prices that are consistent with current IEA forecasts for world energy prices.

The state of the coalbed methane recovery industry varies across the high, medium and low potential groups, as well as within individual groups. The practice of coalbed methane recovery has leveled-off in Germany and the United Kingdom, where coal production has stabilized or is declining. In the U.S., the industry continues to expand as deeper and gassier coal seams are being mined. Although there are numerous sites in the U.S. which could support a coalbed methane recovery project, their commercial viability is questionable. In China, the development of the industry is fast-paced, although limited somewhat by the rate of technology and knowledge transfer from the countries where coalbed methane recovery is more established. Australia has substantial potential, and the transfer of knowledge and technology should ultimately lead to more complete realization of the country’s full potential.
At present, the primary motivation for coalbed methane recovery is mine safety. The ancillary benefit of higher machine availability, i.e. in terms of improvements in productivity are also considered. The economic conditions that support commercial coalbed methane recovery and utilization in conjunction with coal mining are rare. In terms of gas content, permeability and release rates, there are profound differences between the limited number of mines which currently employ sophisticated, comprehensive coalbed methane recovery and utilization technologies and the typical mine in any particular coal basin which does not.

The obstacles to expanding the practice of recovering and utilizing coalbed methane vary from country to country. In general, however, they relate to one or more of the following:

- Mineability of the Coal Seam and Economic Viability of the Mine
- Gas Ownership Issues
- Inconsistent Tax Policies
- Industry Financial Condition
- Availability of Technology

In Germany and the U.K., for example, further increases in coalbed methane recovery and utilization depend primarily on the development of technology to exploit gas with low methane concentration (i.e. less than 1%). Gains relating to extensive surface drilling prior to mining are limited by environmental concerns as well as public resistance to expanding surface operations. Nonetheless, increases in coalbed methane recovery are achievable through increased use of state-of-the-art technology and drilling techniques, if current concerns about mining and safety issues can be resolved. In China, CIS, Eastern Europe and Australia, there is substantial potential for the introduction and extensive use of both in-seam and surface drilling techniques. In the U.S., obstacles to further development of commercial ventures include conflicting government policies and ownership issues.

A policy to expand coalbed methane utilization could contain both passive and aggressive elements. The passive elements include primarily the facilitation of knowledge and technology transfer between nations and the resolution through legislation of ownership issues where they exist. A more aggressive approach would include the availability of financial incentives for coalbed methane utilization. Although the CIAB does not support the use of subsidies to promote coalbed methane utilization, the past availability of tax credits has been a significant factor leading to increased utilization in the U.S.
INTRODUCTION

This study is an extension of the October, 1992 CIAB study entitled *Global Methane Emissions From The Coal Industry* which reported that methane emissions from coal mining worldwide amounted to about 25 Mt per year. At present, less than 7% of the methane released from coal mining is actually recovered and utilized. Recent studies suggest that substantial increases in the amount of coalbed methane recovered and utilized may be possible.

Whereas the earlier CIAB study contained country-by-country estimates of methane emissions from the coal industry, the focus of this study is to identify the potential for expanding the recovery and utilization of coalbed methane in conjunction with mining operations. The study does not address issues relating to coalbed methane extraction that is not associated with coal mining.

The extent of coalbed methane recovery and utilization is very low worldwide because the geologic, geographic and economic conditions necessary to support large-scale commercial coalbed methane projects are rare and access to state-of-the-art technology and recovery techniques is limited. This report attempts to provide an understanding of the technological and institutional limitations to commercial recovery and utilization of coalbed methane, and how these limitations might be overcome.
ORIGIN AND RELEASE OF COALBED METHANE

The process of coal formation, i.e. the biochemical decay and metamorphic transformation of vegetable matter, generates large quantities of gases — as much as 1,300 cubic meters per tonne of coal formed (2). The amount of gas generated from the coalification process increases with rank. The ability of the coal to retain the gas, i.e. its adsorptive capacity, also increases with rank. Although the coalification process yields large amounts of gas, a large fraction “escapes” during the burial and metamorphosis of the decaying material. The gas retained in coal ranges from negligible quantities to as much as 25 cubic meters per tonne (m³/t), normally increasing with rank and depth (3).

Methane is the major component of the gas in coal, accounting for 80 to 95% of the volume. The balance is made up of ethane, propane, butane, carbon dioxide, hydrogen, oxygen, nitrogen and helium. The heating value of coalbed methane drained from virgin coal is generally higher than 33.5 Megajoules per cubic meter (MJ/m³). Thus, undiluted coalbed methane is very similar to natural gas in composition and calorific value, and as such can be used interchangeably with natural gas in most applications.

Almost all (95%) of the methane emissions from coal are associated with underground mines. Most of the gas (about 90%) emanates from coal seams deeper than 300 meters and is recoverable with existing technology and techniques. A substantial amount of the methane (as much as 75%) released during mining is from strata above and below the active coal seam.

Coal recovery factors differ among mining processes, e.g. between longwall mining and room and pillar mining, and these differences are manifested in differences in initial methane release. Over time, however, as pillars fail, the caving effect associated with room and pillar mining tends to approach the more extensive caving associated with longwall mining. As the caving proceeds the gas is released. Therefore, while the initial difference in gas release may be as much as 20% (lower for room and pillar mining), over time the amount of gas released tends to converge.

In shallow underground coal mines, where the gas content of coal seams is generally less than 6 m³/t, no methane recovery is warranted. The mine ventilation air removes all methane from the mine safely. In the deepest mines with the highest gas content in the coal and surrounding strata, 30 to 60% of the methane must be removed by degasification. The balance of the coalbed methane released by mining is mixed with ventilation air (at a rate of between 5 and 30 tonnes of air for each tonne of coal extracted) and discharged into the atmosphere. Generally, the maximum allowable methane concentration in mine air is 1% in mine entries used by personnel. In areas less frequented by mine personnel, methane levels cannot exceed 2%.
The largest fraction of recovered methane is produced from gob areas, where methane concentrations in the gas can be as high as 100%. However, methane concentrations typically decline to the 30 to 50% level over time. A relatively small amount of methane is drained from solid coal in a nearly pure state, prior to mining.

Since the coalbed methane reservoir properties, e.g. gas content and permeability, vary from seam to seam, the technologies for methane recovery vary considerably within countries and even between mines. Therefore, generalizations about the economic viability of coalbed methane projects are tenuous at best.

**COALBED METHANE RECOVERY**

The safety of the work force and the productivity of the mining operations entails a thorough and efficient removal of methane from gassy coal mines. The statutory requirement in most mines, worldwide, is to limit ambient concentrations of methane gas to 1%. Mine operators are basically limited to two methods for maintaining the statutory limit of 1%: ventilation and degasification. And in most mines, it is easily achieved with ventilation alone.

**VENTILATION**

Mine ventilation is the oldest and most common method of removing methane from underground mines. Large fans are used to circulate 5 to 30 tonnes of air for every tonne of coal mined in order to dilute the coalbed methane and coal dust with outside air and to transport the mixture to the surface for discharge. Methane concentrations in air are explosive in the range of 5 to 15%. Although ventilation and degasification are supplementary and complementary activities, historically, ventilation has been the primary method for methane control in most mines.

**COAL SEAM DEGASIFICATION**

When coal seams are deep and very gassy, the ventilation air requirements become excessive and it is often impossible to dilute all methane to safe levels. Under these circumstances a mine operator must commit substantial resources to degas the coal seam and associated strata prior to and during mining. Therefore, the overall cost of methane removal and recovery under these conditions is minimized by optimizing the ratio of methane removed by degasification to that removed by ventilation.

Methane control through degasification involves removing the gas from the coal seam and surrounding strata prior to the mining of the coal, using vertical fracturing or frac wells and/or horizontal boreholes, and gob wells. Initiated well in advance of mining, a comprehensive degasification program, including pre- and post-mining well drilling, can remove 60 to 70% of the coalbed methane. Nonetheless, ventilation is always necessary, although degasification can reduce ventilation air requirements significantly. The techniques currently used to recover methane from coal mines are summarized below:
Frac Wells

Since the industry began using vertical wells drilled from the surface to degas coal seams (20 years ago in the U.S.), the drilling, completion, and gas production techniques have undergone considerable changes. Vertical wells drilled into the coal seam seldom produce significant amounts of gas without stimulation. Therefore, these wells are stimulated (fractured) hydraulically, much in the same way that conventional gas wells would be stimulated. Early efforts to modify the technique for application in coal seams were largely unsuccessful. The pressure of fracturing often exceeded the strength of the roof and floor material, creating cracks and fissures which compromised roof and floor integrity, while failing to improve gas flow.

The current practice of hydraulic stimulation of coal seams minimizes roof damage while achieving extensive fracturing. The technique has yielded gas flows up to 7,000 m³/day from a well in certain coal seams (4). Increasingly, these wells are drilled in advance of mining, and are later converted to gob degas wells. Under ideal conditions, 60 to 70% of the methane contained in the coal seam can be removed using vertical degasification wells drilled more than 10 years in advance of mining. The use of these techniques is not always compatible with local operating conditions (roof conditions may preclude stimulation or the gas content of the overlying strata is low).

Vertical wells typically intersect the coal seam vertically. Although they can be drilled without interfering with mining operations, they generally produce gas at lower rates than horizontal boreholes drilled into the coal seam, which tend to be longer than the fractures created by fracturing from a vertical well. Thus, directional boreholes drilled from the surface and gradually deflected to intersect the coal seam horizontally would incorporate both advantages. The industry has been frustrated in its attempts to complete and produce gas from such boreholes, due to the high cost of drilling and the difficulty of dewatering. Therefore, further research seems appropriate.

Horizontal Boreholes

Horizontal boreholes generally are drilled in advance of mining from existing mine workings in permeable coal seams. They are typically 300 to 900 meters in length, and initially yield high gas production. However, as mining approaches, production declines sharply. The typical life is one to two years. In the Pittsburgh seam, which is located in the Eastern United States, the cumulative production from a single borehole drilled from mine workings is three to five million cubic meters of gas over a period of one to two years (5). Thus, this technique is less suitable for sustained production and long-term utilization projects. Nonetheless, it is often the most effective and the least expensive way to control methane in the working sections of a permeable coal seam.

Horizontal boreholes also can be drilled 600 to 900 meters into the coal seam from rooms at the base of a shaft. Using this method, four to eight horizontal boreholes can produce 14,000 to 56,000 m³/day depending on the properties of the coal seam. In addition to effectively degassing the coal seam, advocates of this type of program claim that horizontal boreholes can also provide valuable information about the coal seam, e.g. the location of faults, washouts, sand channels, etc. A disadvantage of this approach, however, is the high front-end cost of sinking shafts well ahead of mining in order to conduct horizontal drilling. Moreover, uncertainties regarding the direction and rate of future mine development make substantial investment in shafts that may not be needed for future mining highly speculative.
Gob Wells

Next to the amount of methane carried away by the ventilating air, gob degasification wells produce the largest volume of methane from a mine. The most common technique for capturing this gas is to drill several vertical wells into the strata overlying a longwall panel prior to mining. Vertical frac wells can be converted to gob wells as mining advances. Additional gob wells also can be drilled just prior to mining. Methane is vented by natural convection or aided by suction fans. The rate of gas production depends on numerous factors, e.g. the rate of face advance, the geology and gas content, and the extent of pre-mining degasification.

Cross-Measure Boreholes

An alternative to vertical gob wells is the drilling of cross-measure boreholes from existing entries into the strata overlying developed longwall panels to recover gob gas. This is practiced extensively in Europe. Local conditions usually dictate the choice of gob drainage technique. Cross-measure boreholes seldom exceed 50% gas recovery. Therefore, they are not as efficient as vertical gob wells where nearly 70% recovery can be achieved.

Sealed Areas

In order to limit the flow of gas into active mine workings or to prevent flooding, development headings are occasionally sealed. The sealed area often becomes a rich methane reservoir. Mined-out areas, areas of low quality coal, or entire mines are also sealed for economic or safety reasons. Generally, existing gob wells are utilized for gas production from sealed areas. However, in the absence of existing gob wells or one or more vertical wells, usually of large diameter, e.g. 450 to 500 mm, are drilled over the area to vent the methane in order to prevent leakage from the sealed areas into the mine. The primary difficulty with gas production from sealed areas is the inability to estimate the rate of production or the rate of production decline. The benefit, on the other hand, is an improvement in the quality of the gas produced, as well as a decrease in the ventilation requirements, because the active mining area has been reduced.

COALBED METHANE UTILIZATION

An earlier CIA/B study indicates that methane release from coal mining, worldwide, is about 25 Mt per year. With existing practices, this gas is released in essentially three forms, as shown in the following table:

<table>
<thead>
<tr>
<th>Coalbed Methane Gas Type</th>
<th>Origin</th>
<th>CH₄ Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Quality</td>
<td>Ventilation Air</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>Medium Quality</td>
<td>Gob Wells (Unsealed)</td>
<td>30 to 95%</td>
</tr>
<tr>
<td>High Quality</td>
<td>Vertical Wells, Horizontal Wells &amp; Sealed Gob Wells</td>
<td>&gt; 95%</td>
</tr>
</tbody>
</table>
VENTILATION AIR (LOW QUALITY)

Ventilation air, due to its low methane concentration, has limited application with existing technology. Due to its low gas content, it is not likely to serve as the principal source of fuel in a combustor, and the economic justification for transporting the gas is tenuous. Currently, the only application contemplated for ventilation air is as combustion air, i.e. as the principal source of oxygen in a combustor.

The main problem with ventilation air is its extremely low heating value. The methane content of ventilation air rarely reaches the statutory limit of 1%. Fans ventilating active longwall panels generally produce concentrations less than 0.5% methane. Moreover, as mining advances, and other bleeder shafts take over, the methane content of ventilation air from older air shafts diminishes considerably. Due to the very low gas content and the high variability of gas volumes contained in it, the cost of compressing and transporting ventilation air cannot be justified with today’s technology. Indeed, the energy required to compress and transport the ventilation air is often higher than its inherent thermal energy.

UNSEALED GOB WELLS (MEDIUM QUALITY GAS)

Applications for unsealed gob wells, although limited, do exist. Because of its higher methane concentration, transporting the gas to a central point for processing or use can be justified when conditions are favorable. Potential uses include fuel for coal dryers or other types of industrial furnaces or kilns, fuel for a gas turbine for power generation, and possibly as a feedstock.

The methane in ventilation air and from degas wells could also be a key component in a fully integrated utilization program. The hallmark of such a program would be the full and complete utilization of most if not all usable coal mine wastes and byproducts, including preparation plant reject, ventilation air, and gas from degas wells. A small fluidized bed combustor could burn the fines from the preparation plant or other combustible wastes, co-fired with gas from degas wells and ventilation air. The system could recycle water from the preparation plant reject, raise steam to generate electricity, and use the hot gases for heating air to dry clean coal. The economics of such a plan could be supported by the reduction in costs of handling preparation plant reject and power cost savings. Ancillary benefits include power sales.

The investment for on-site utilization of medium quality gas consist of the wells and gathering system, in addition to the utilization plant (e.g. combustor). On-site utilization normally does not require purification, i.e. separation of oxygen, carbon dioxide and water.

VERTICAL WELLS/SEALED GOB WELLS/HORIZONTAL BOREHOLES (HIGH QUALITY GAS)

The highest value outlet for high quality gas is pipeline sales. Of course, off-site utilization entails meeting the needs of pipeline owners for quality and quantity. Generally, pipeline quality gas in the U.S. must have methane concentrations of at least 96 percent and contain no more than 4 percent non-combustible gases (e.g. carbon dioxide, nitrogen, and helium). Furthermore, the gas must not contain any water or hydrogen.
Quantity considerations relate to the capacity of pipelines serving the area as well as their preference for steady, uninterrupted supply. Without an economic means for storage, pipeline operators’ low tolerance for fluctuations in gas flow may limit the volume of coalbed methane a coal producer can commit to. This, in turn, may force the coal producer to vent volumes exceeding his commitment, or force him to accept a much lower price for these incremental volumes.

The recovery and utilization strategies for coalbed methane are summarized in Exhibit 1, which is adapted from material prepared by the U.S./Japan Working Group on Methane (6). As the table indicates, on-site utilization of coal seam gas involves firing the gas in a combustor for direct heat applications, such as drying coal, generating electricity or raising steam for industrial or residential use. Other methods of utilizing coalbed methane as chemical feedstocks have been proposed, including the production of ammonia, methanol or other organic chemicals. However, the economic viability of these applications remains to be established. Typically, factors limiting on-site utilization include the distances between wells or fans and the overall gas volume and quality requirements for the application. There is also considerable uncertainty as to the amount of gas that will eventually be recovered.

ECONOMICS OF COALBED METHANE UTILIZATION

There are obvious linkages between the decision to recover coalbed methane and the decision to utilize coalbed methane. Recovery is a necessary condition for utilization. It is not, however, a sufficient condition for utilization. The decision to recover coalbed methane, e.g. through degasification, is based on an evaluation of the costs of alternative methods of methane control. The mine can be ventilated; gas release rates can be altered by adjusting production rates or by modifying mining techniques; or the gas can be removed via degasification (recovery). In other words, the economics of coalbed methane recovery derive from minimizing the cost of methane control necessary to maintain safe working conditions.

The financial attractiveness of coalbed methane utilization, on the other hand, requires an evaluation of the quantity and quality of the gas, the cost of gas gathering and processing, and the physical accessibility of markets. The sale of coalbed methane as a substitute for natural gas can involve substantial investment in pipelines, compression and treatment facilities. In the U.S., the volatile nature of gas prices can make the financing of such capital intensive projects expensive, if not impossible, to secure. These projects typically require mining operations with high volumes of high quality gas, where degasification is necessary for the safe operation of the mine. Thus, coal production costs associated with coalbed methane recovery through degasification can be considered sunk and the economics for utilization can be evaluated on an incremental basis.

One of the largest components of the capital cost for commercial utilization of coalbed methane is the construction of the pipeline connecting the coalbed methane collection and treatment system with a transmission line. In the U.S., this cost can range from $500,000 to $1,000,000 per mile. Depending on the size and distance of the pipeline, the capital charge can be as much as one-third of the required selling price. This cost can be substantially lower in other coal producing countries due to the close proximity of many mining regions and large population centers.

Projects that can utilize the gas on-site to reduce mine operating costs or to cogenerate electricity and industrial/residential thermal energy require less investment and lower volumes and quality of methane.
gas. On-site utilization could involve a direct heat application or power generation. The key distinguishing elements of a program to sell gas to a pipeline versus on-site utilization include:

1) the technology to purify the gas;
2) the pipeline to carry the gas from the gathering system to the transmission line; and
3) the capital cost of the on-site utilization technology, e.g. the gas turbine for power generation.

In the U.S., the principal commercial scale coalbed methane recovery projects associated with active mining operations are located in Central and Southern Appalachia. A 2.5 Mt per year mine in the region can yield up to 165 million cubic meters in a year, including upper and lower strata gas, for the life of the mine. As an example, the investment required to develop a coalbed methane recovery project for such an operation, including capital for wellhead compressors, the main compressors, gas collection piping, enrichment facilities and a 15 km pipeline to the main transmission pipeline would be approximately $65 million (1993 dollars). These figures exclude well costs, which are typically charged to the mine. The gas price required to justify this investment would be approximately $2.50 per thousand cubic feet (MCF) of gas, which is about $0.50 per thousand cubic feet above current market prices for gas in the U.S.

The economics of on-site power generation projects differ somewhat from gas sales projects because enrichment is not necessary, and there is no need to construct a pipeline. The gas turbine, however, at a cost of $800 to $1,200 per kW is a substantial capital burden. Other costs facing a developer of a power project are the costs of the connection to the transmission system, and a wheelage fee.

The 2.5 Mt per year coal mine described above, yielding 165 million cubic meters of methane per year over a project life of 20 years, could also support an on-site utilization project, e.g. cogeneration or industrial direct heat application. The required price for gas would be in the range of $1.50 to $2.00 per thousand cubic feet, assuming approximately $30 million for wellhead compression and the gathering system. In the case of on-site generation of electricity, these rates are achievable only with an extremely high capacity factor as well as easy access to a transmission system for wheeling the power/energy to the purchaser.

THE GLOBAL POTENTIAL FOR COALBED METHANE RECOVERY

The commercial viability of coalbed methane recovery and utilization projects is determined by three basic factors: geology, technology and the economy. Geology and technology determine the efficiency or technological potential for recovery; the extent of utilization is largely determined by the economic environment.

In general, if the gas content of the minable coal seam is less than 6 m/t, recovery of the methane is impractical. Deeper seams (more than 300 meters) of high rank coal (medium to low-volatile bituminous) hold the most promise for coalbed methane recovery. More shallow seams (200 to 300 meters)
of lesser rank coals (high-volatile bituminous) hold less promise, but nonetheless do offer some potential. Shallow deposits of any rank coal, due to low gas content, offer little or no potential for commercially viable coalbed methane recovery projects.

Coalbed methane recovery has been practiced in all of the major coal producing countries over the past 30 to 40 years. Although there are broad differences in gas content, permeability and other reservoir characteristics of different coal seams mined around the world, there are some basic similarities in the techniques used to recover methane from active mining operations that permit estimates of the theoretical recovery potential. The efficiency of methane recovery appears to be correlated with specific methane emissions (volume of methane produced per tonne of underground coal produced). High specific methane emissions normally indicate high recovery efficiency as shown in the following table, which is based on data from coalfields around the world.

<table>
<thead>
<tr>
<th>Depth (Meters)</th>
<th>Specific Methane Emissions (m³/t)</th>
<th>Recovery Potential (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 200</td>
<td>≤ 6</td>
<td>0</td>
</tr>
<tr>
<td>200 - 300</td>
<td>6 - 9</td>
<td>25 - 35</td>
</tr>
<tr>
<td>300 - 500</td>
<td>10 - 13</td>
<td>30 - 40</td>
</tr>
<tr>
<td>≤ 500</td>
<td>13 - 30</td>
<td>35 - 45</td>
</tr>
</tbody>
</table>

Seam depth and gas content are highly correlated (7). Permeability, the other key determinant of gas release, is not necessarily correlated with depth. However, in the gob created by longwall mining, permeability is not an issue. Therefore, the figures in the table represent technological or theoretical limits, which nonetheless provide a means of estimating the overall coalbed methane recovery potential, and therefore the utilization potential, for a particular country or region. In other words, this is a crude technique which is appropriate for resource evaluation. The more refined estimates necessary for individual project evaluation would require on-site determinations of all parameters.

In the table on the following page, the overall coalbed methane recovery potential for the world’s ten leading coal producers is presented. As the figures in the table indicate, the average theoretical recovery potential for these leading coal producing countries is between 35 and 45% or between 6.5 and 8.7 Mt per year. However, experience suggests that only a fraction of the utilization potential is realizable.

In 1990, only seven percent of methane emissions from the coal industry were actually utilized, according to the earlier CIAB study. The key to realizing the potential for coalbed methane recovery is to ensure the commercial viability of coalbed methane recovery and utilization projects. The obstacles and impediments to coalbed methane recovery and utilization are discussed in the following section. As a measure of the degree to which these obstacles have prevented realizing full recovery and utilization, in 1990 the world’s leading coal producers recovered 20% and utilized only 7%, versus the theoretical or technological potential of 35 to 45% established above.

Due to the existence of economic and political barriers and limited access to state-of-the-art technology and expertise, the potential for commercial utilization of coalbed methane is believed to be in the range of 15 to 25%, versus the technological potential for recovery of 40%. A discussion of these obstacles is provided in the next section.
Global Methane emissions and potential recovery

<table>
<thead>
<tr>
<th>Country</th>
<th>1990 Coal Production (Mt)</th>
<th>Total Methane Emissions (Mt)</th>
<th>Technological Recovery potential (%)</th>
<th>Total Methane Recoverable (Mt)</th>
<th>1990 utilization of methane (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Underground</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>1,053</td>
<td>946</td>
<td>1.1</td>
<td>35 - 45</td>
<td>5.1</td>
</tr>
<tr>
<td>C.I.S.</td>
<td>703</td>
<td>361</td>
<td>5.0</td>
<td>35 - 45</td>
<td>2.0</td>
</tr>
<tr>
<td>U.S.A.</td>
<td>931</td>
<td>384</td>
<td>3.6</td>
<td>30 - 40</td>
<td>1.3</td>
</tr>
<tr>
<td>Poland</td>
<td>216</td>
<td>148</td>
<td>1.4</td>
<td>35 - 45</td>
<td>0.6</td>
</tr>
<tr>
<td>Germany</td>
<td>434</td>
<td>78</td>
<td>1.2</td>
<td>35 - 45</td>
<td>0.5</td>
</tr>
<tr>
<td>U.K.</td>
<td>95</td>
<td>79</td>
<td>0.9</td>
<td>35 - 45</td>
<td>0.4</td>
</tr>
<tr>
<td>S. Africa</td>
<td>206</td>
<td>124</td>
<td>0.8</td>
<td>25 - 35</td>
<td>0.2</td>
</tr>
<tr>
<td>India</td>
<td>212</td>
<td>64</td>
<td>0.5</td>
<td>25 - 35</td>
<td>0.2</td>
</tr>
<tr>
<td>Australia</td>
<td>163</td>
<td>53</td>
<td>0.4</td>
<td>30 - 40</td>
<td>0.1</td>
</tr>
<tr>
<td>Czechoslovakia</td>
<td>119</td>
<td>25</td>
<td>0.3</td>
<td>35 - 45</td>
<td>0.1</td>
</tr>
<tr>
<td>Total</td>
<td>4,132</td>
<td>2,292</td>
<td>21.8</td>
<td>8.5</td>
<td>1.3</td>
</tr>
</tbody>
</table>

OBSTACLES TO COALBED METHANE RECOVERY AND UTILIZATION AND POLICY CONSIDERATIONS

The obstacles to expanding coalbed methane recovery and achieving increased utilization include the following: (1) coal mine safety and economic issues; (2) ownership issues; (3) tax incentives; (4) industry financial condition; and (5) technological considerations.

COAL MINE SAFETY ISSUES AND ECONOMIC ISSUES

Mine safety issues and the economic viability of the coal mine are of paramount concern to coal operators and lie at the core of coalbed methane recovery. These concerns oftentimes can be in conflict with the optimization of methane recovery, and therefore utilization. Examples include the following:

Penetration of the coal seam with cased hole production techniques

If placement of wells is not coordinated with an existing or potential mine plan, the economic viability of the mine or gas producing operation can be jeopardized.
Hydraulic fracturing

Although it has been demonstrated that careful fracturing of the overlying strata can result in little or no damage to the roof, the potential still exists of compromising the integrity of the roof through hydraulic fracturing. In order to ensure mine safety and to preserve the economic viability of the mine, fracturing should not be allowed without the full consideration of the impact on existing and future mining operations.

Control of Ventilation

In order to ensure mine safety and compliance with federal and state regulations, coal operators must not be restricted in the venting of methane gas from active mining operations. This policy must extend to the rate of release from vertical wells and gob wells.

Spacing of Gob Wells

With respect to the spacing of gob wells, maximizing the rate of coal production may require closer spacing of gob wells. Closer spacing of the gob well can lead to excessive dilution of methane, which may prevent efficient utilization.

Major Aquifers

In some coalfields, especially those in the UK, the coal seams are overlain by major aquifers, giving rise to concern about the potential for flooding via coalbed methane wells and boreholes.

The potentially divergent goals of coal extraction versus gas utilization make it difficult to devise practical, effective, and sound public policy for fostering the development of coalbed methane as a resource. Any solution must recognize that the gas in a minable seam of coal typically represents only a fraction of the total value of the coal.

GAS OWNERSHIP

Until very recently, ownership issues have obstructed development of the coalbed methane industry in many countries. For example, in the U.S., owners of the surface, the coal, the oil and gas, and other minerals have asserted ownership of the coalbed methane. Typically, these conflicting interests fail to agree on a mechanism for proceeding with a project without actually determining ownership and just compensation. The ownership issue has now been resolved through legislation in several states: Colorado, Montana, New Mexico, Wyoming, Utah, Virginia, Washington, Mississippi, Louisiana and Alabama. In Virginia, the interests are pooled; royalty payments are placed in escrow, and final distribution of the account is made in accordance with established legal entitlement or upon agreement of the parties claiming interests.

The U.S. Energy Policy Act of 1992 addresses ownership of coalbed methane in a manner similar to that used in the state of Virginia. By 1996, the states of West Virginia, Pennsylvania, Kentucky, Ohio, Tennessee, Indiana, and Illinois must adopt a statutory or regulatory procedure promoting the permitting, drilling and production of coalbed methane wells. Failure to do so results in the federal government imposing its program on the state.
TAX INCENTIVES

In the U.S., the tax code provides a credit for coalbed methane gas produced and sold to a third party. However, the credit was not renewed in the 1992 Energy Plan, which was enacted in October of that year. As a result, only coalbed methane produced from wells drilled and completed before December 31, 1992 can generate a tax credit. At today’s gas prices, the tax credit, currently about $0.90 per million Btu, can represent as much as 50% of the cash inflow for a typical project and has been a critical element in determining commercial viability. Therefore, the tax credit has been an important incentive for the commercialization of coalbed methane utilization in the U.S.

Exhibit 1
Methane Recovery and Utilization Strategies

<table>
<thead>
<tr>
<th>Considerations</th>
<th>Enhanced Gas Well Recovery</th>
<th>Pre-Mining Degasification</th>
<th>Ventilation Air Utilization</th>
<th>Integrated Recovery Combined Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery Techniques</td>
<td>➤ In-Mine Boreholes</td>
<td>➤ Vertical Wells</td>
<td>➤ Fans</td>
<td>➤ All Techniques</td>
</tr>
<tr>
<td></td>
<td>➤ Vertical Gob Wells</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support Technologies</td>
<td>➤ In-Mine Drills and/or Basic Surface Rigs</td>
<td>➤ In-Mine Drills and/or Advanced Surface Rigs</td>
<td>➤ Surface Fans and Ducting</td>
<td>➤ All Technologies</td>
</tr>
<tr>
<td></td>
<td>➤ Compressors, Pumps, and other support facilities</td>
<td>➤ Compressors, Pumps, and other support facilities</td>
<td></td>
<td>➤ Ability to Optimize Degasification Using Combined Strategies</td>
</tr>
<tr>
<td>Gas Quality</td>
<td>➤ Medium Quality (11-29,000 K/m³) (300-800 Btu/cf) (approx. 30-80% CH₄)</td>
<td>➤ High Quality (32-37,000 K/m³) (900-1000 Btu/cf) (above 90% CH₄)</td>
<td>➤ Low Quality (1.5% CH₄; usually below 1%)</td>
<td>➤ All Qualities</td>
</tr>
<tr>
<td>Use Options</td>
<td>➤ On-Site Power Generation</td>
<td>➤ Chemical Feedstocks</td>
<td>➤ Continuation Air for On-Site/Nearby Turbines and Boilers</td>
<td>➤ All Uses</td>
</tr>
<tr>
<td></td>
<td>➤ Gas Distribution Systems</td>
<td>➤ In addition to those uses listed for medium quality gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>➤ Industrial Use</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability</td>
<td>➤ Currently Available</td>
<td>➤ Currently Available</td>
<td>➤ Likely to be Demonstrated by 1995</td>
<td>➤ Currently Available</td>
</tr>
<tr>
<td>Capital Requirements</td>
<td>➤ Low</td>
<td>➤ Medium/High</td>
<td>➤ Low</td>
<td>➤ Medium/High</td>
</tr>
<tr>
<td>Technical Complexity</td>
<td>➤ Low</td>
<td>➤ Medium/High</td>
<td>➤ Low</td>
<td>➤ High</td>
</tr>
<tr>
<td>Applicability</td>
<td>➤ Widely Applicable</td>
<td>➤ Technology, Finance, and Site Dependent</td>
<td>➤ Nearby Utilization Site Dependent</td>
<td>➤ Technology, Finance, and Site Dependent</td>
</tr>
</tbody>
</table>

[Adapted from the U.S./Japan Working Group on Methane]
INDUSTRY FINANCIAL CONDITION

Although coal production worldwide is at all time highs, the profitability and future of many companies, even the existence of entire industries within some countries, is in question. Therefore, the focus of industry management is concentrated on more conventional means of achieving productivity improvements and cost reductions. The weak financial underpinnings of the industry also contribute to capital limitations and rationing, resulting in a reluctance to direct investment funds to more speculative ventures, especially those outside the normal scope of coal mining activity. Removing the other obstacles will go the furthest in a program to encourage coal operators to place a higher priority on coalbed methane recovery and utilization.

TECHNOLOGICAL ISSUES

As technological barriers are overcome, the coalbed methane recovery industry is likely to expand. For example, the development of technology to utilize gas in ventilation air and to enrich medium quality gas would ultimately lead to more expanded utilization of these sources, which account for a substantial portion of the methane release from coal-mining. Alternatively, the development of combustors and turbines that readily accept the lower quality gas as the primary fuel could also lead to increased recovery and utilization. Therefore, federal programs to foster improvements in coalbed methane recovery and utilization could prove effective, much in the same way that the U.S. Department of Energy’s Clean Coal Technology program has advanced that industry.

REFERENCES

1. CIAB, Coal Industry Advisory Board, Global Methane Emissions From the Coal Industry, October 1992
APPENDIX

COALBED METHANE RECOVERY PRACTICES
OF THE LEADING COAL PRODUCING COUNTRIES
INTRODUCTION

The coalbed methane recovery practices of the world’s leading coal-producing nations vary significantly, depending upon the gas content and geologic conditions of the coal seams being mined; the availability of technological and financial resources; and the environmental and legal constraints to commercial utilization.

AUSTRALIA

Approximately 10% of Australia’s coalbed gas is utilized at present, fueling gas turbines for mine-site electricity generation. The control of gas emissions into coal mine workings and the prevention of gas outbursts or ignitions have required a small number of the deeper mines in New South Wales and Queensland to undertake coalbed methane drainage. As mining proceeds into deeper seams, the proportion of mines needing to employ coalbed methane drainage is likely to rise. Except for two mines in the Southern Coalfield of New South Wales (Appin and Westluna), gas collected by methane drainage is not used as an energy source. Because of the success of methane drainage operations in the U.S., which are based on surface well technology, several companies are currently evaluating the coalbed gas potential of the coal basins of New South Wales and Queensland.

The coalbed methane drainage industry in Australia is still in its infancy. Considerable uncertainty remains over whether gas drained from coal seams will be able to supply significant quantities of gas at competitive prices. Development of the industry will require successful research and development of the appropriate technologies, long-term investment and commitment from the coal and petroleum industries, the development of markets for coalbed methane and government policies aimed at cultivating the industry.

Recently, the federal government announced a range of incentives aimed at encouraging investment in capital projects. These incentives have included extending the 150% tax rebate on research funding indefinitely, accelerated depreciation and a new form of bond for financing certain types of projects. In addition, reform in the gas and electricity industries potentially facilitates market entry for new producers by granting access to existing infrastructure.

The geology of Australia’s underground reserves, assuming access to appropriate technology and recovery techniques, would likely support technological recovery potential of 30 to 40%.

**CHINA**

Currently, China has over 100 state run mines with methane recovery systems in place. There are over 600 state run mines, half of which are classified as high gas or outburst mines. Over 90% of China’s annual coal production comes from underground mines. Therefore, methane emissions are likely to increase as both coal production and mine depth increase. The mines with coalbed methane recovery systems recovered approximately 1.0 billion cubic meters in 1990. Chinese authorities hope to expand coalbed methane recovery programs to an additional 30 mines by 1995.

A three year United Nations project to devise a national strategy to develop the coalbed methane industry was started in April 1992. The Chinese government aims to expand coalbed methane recovery by the introduction and demonstration of a wide variety of technologies and techniques and by sensitizing policy makers of the local and central government about the economic and environmental significance of rational recovery and use of coalbed methane resources. The effort is intended to improve air quality locally as well as for the international community, to improve mine safety, and to secure the benefits of developing a new clean-burning energy source.

All of the existing recovery systems in Chinese coal mines use in-mine methods. Between 1970 and 1987, seven experimental vertical wells were drilled to recover coalbed methane, but they failed to achieve the anticipated results. Various reasons are offered for the lack of success: inappropriate drilling and completion tools and techniques and the lack of geologic information to properly site the wells in the most favorable areas. Today, methane recovery in advance of mining via in-mine cross-measure boreholes accounts for 55% of total gas recovered. Horizontal boreholes, recovering methane from the target coal seams, account for another 40% of the gas recovered. Gob drainage, limited by the high risk of spontaneous combustion in underground mines extracting lower rank coal in China, accounts for the remaining 5%. The majority of the gas recovered ranges between 35 and 75% purity.

Although China has over 40 years experience in the practice of coalbed methane recovery, officials point to several reasons for low recovery rates: lack of supportive policies, capital shortages, price disincentives, and lack of techniques and equipment for coal seams with low permeability. The United Nations project is designed to partially solve these problems, and to ensure continued progress and sustainability through the following measures: development of demonstration projects, preparation of a detailed assessment and database of China’s coalbed methane resources, and training of key industry personnel.

Based on the geology of China’s vast coal reserves, and the coalbed methane contained therein, it is reasonable to expect that, with the technology available today, 35 to 45% of the coalbed methane produced could be recovered.

COMMONWEALTH OF INDEPENDENT STATES

The coalbed methane resources of the primary coal producing basins is substantial -approximately 17 million cubic meters. Over 300 mines currently practice methane drainage of some sort.\(^1\) The annual gas volume recovered is estimated at 1.4 billion cubic meters. About 7% of this gas is used at the mines in methane-fired boilers. Prospectively, about 15% of coalbed methane is projected to be recovered using special degassing wells, most of them being drilled directly from the mine workings. A total of 35 to 45% could be recovered if safe techniques for handling an explosive mixture of gas and air were available and/or better technology were used to recover methane.

Individual governments of the C.I.S. countries are seeking their own solutions to the problems of expanding the coalbed methane recovery industry. Through workshops designed to promote the exchange of information on recent developments as well as to provide opportunities to extend contacts between experts from different countries, authorities in these countries hope to accelerate the expansion of their coalbed methane recovery programs.

FORMER CZECHOSLOVAKIA

Total coal production in Czechoslovakia amounts to about 120 Mt, 25 million of which is mined from deep underground mines. These operations produce an estimated 525 million cubic meters of methane annually. Currently, about 140 million cubic meters (27%) are recovered. Almost 90% of the recovered

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methylene is utilized. Based on geology and mining conditions, overall recovery in the range of 35 to 45% is feasible. At least one vertical well has been drilled and fractured and a gob well drilled ahead of mining in the Ostava-Karvina region had very good gas production.

GERMANY

Coalbed methane collection systems in Germany recover nearly 30% of the methane released from mining. About 70% of the recovered gas is utilized for heating or electricity generation. The methane released which is not recovered exits the mine mixed with ventilation air.

Government officials suggest that 43% of the methane from coal mines could be extracted by drainage equipment and could be used in a number of applications. However, obstacles to more complete recovery of coalbed methane exist. Safety regulations in Germany prohibit any utilization if the methane content is less than 25%, in order to keep a sufficient gap to the upper explosive limit of methane-air mixtures. Mixtures containing less than 25% of methane must be released to the atmosphere.¹ If recovery practices were adopted which recovered methane in a more concentrated form, a recovery efficiency of between 35 and 45% could be achieved.

INDIA

India is now the fifth largest coal producing country in the world, producing about 222 million tonnes per year, of which about 30% is mined in underground mines. Most of the mines are relatively shallow and do not warrant coalbed methane gas recovery projects. The deeper mines in the north-east, however, do offer opportunities for coalbed methane recovery. Total methane emissions from underground mines are estimated at 556 million cubic meters. No effort has been made heretofore to recover any methane, although the geology of the nation's coal reserves would tend to support average coalbed methane recovery in the range of 25 to 35%.

POLAND

Poland's hard coal deposits are found in three major areas, the Upper Silesia Basin, the Lower Silesia Basin, and the Lublin Basin. The Upper Silesia Basin, which straddles the Polish-Czechoslovakian

¹ Weber, Dr. G. R., Essen Germany, Steinkohlenbereinbau Essen, Personal Communication, April 1993

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border in the south, is the most important coal and gas producing region in Poland. Under the prevailing conditions of the region, i.e. deep and gassy coal seams mined with longwall technology, the potential recovery of coalbed methane is placed in the range of 25 to 45%. At present, about 27% of the total methane emitted is being recovered, almost three-quarters of which is currently being utilized.

**SOUTH AFRICA**

Total coal production in 1990 was 206 million tonnes. Almost all coal produced is of high rank, but from shallow depths. Very little information on methane emissions from South African coal mines is available. Underground horizontal drilling is done in some mines. However, the primary purpose is exploration and not methane recovery. Total emissions are estimated at 1.1 billion cubic meters as reported in the earlier CIAB study. The geology of the nation’s coalfields suggests that recovery efficiencies of 25 to 35% could be supported.

**THE UNITED KINGDOM**

Mine ventilation is the principal method of keeping methane levels in the mine atmosphere within safe limits, especially for control of methane in the seam being mined. Therefore, much of the gas released by mining is contained in the ventilation air at less than 1% concentration.

There is a long history of coalbed methane use, particularly in the more gassy coalfields, such as South Wales, where some collieries have been interconnected on a gas pipeline network. Most of the recovered gas is used by the mine, either as a source of heat or to generate electricity. At Harworth Colliery in Nottinghamshire a 15 MW generator has recently been commissioned to provide electricity for the mine.

Although the coal industry has demonstrated a willingness and capability to use coalbed methane, utilization is currently restricted by the low concentration of much of the gas which is released in the ventilation air. It is widespread practice in the U.K. to control methane released from the upper and lower strata by drilling cross-measure drainage boreholes up and down from the mine workings of a longwall mine. The boreholes are connected to a pipeline with access to the surface. Nearly 35% of total methane emitted is recovered, but only 11% is utilized.

The geology of most coal seams in the U.K. precludes the use of horizontal in-seam boreholes, because the permeability of British coal seams is generally very low and gas pressures are low.1 Rarely are operators able to reach the lengths of horizontal boreholes in the U.S. Furthermore, no surface holes have yet been drilled in the U.K. for degassing in mining areas. The major concerns include: the effect of hydraulic stimulation on British mining conditions, the relatively high cost of drilling in the deeper seams, the potential problems of drifiting into mining areas through the major aquifers that cover most of the

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operating mines, and the environmental objections to multiple surface facilities and pipelines in coalfield areas. If these problems can be overcome, the geology of British coalfields would seem to support technological recovery potential at levels comparable with Germany, i.e. in the range of 25 to 45%.

UNITED STATES

Methane emissions from coal mines in the U.S. are estimated at 3.6 million tonnes (1990).1 Virtually all of the emissions are believed to come from underground mines. The principal underground mining areas in the U.S. are Northern, Central and Southern Appalachia. Therefore, these coal mining regions offer the greatest potential in terms of an overall increase in coalbed methane recovery.

Over 90% of all underground coal mine in the U.S. is produced at depths of less than 300 meters. Fewer than a dozen mines exceed 700 meters in depth. Hydraulically stimulated vertical wells and underground horizontal drilling are in common use in gassy mines to degasify the virgin coal. Vertical gob wells are used in thirty-five mines to drain gob gas.2 The total methane drained is estimated at one million tonnes per year.

The economics of erecting costly gathering and collection systems are driven by the absolute necessity of drilling degas wells prior to and during mining when longwall technology is used in gassy coal seams. However, their commercial viability can be largely attributed to the tax credit generated by producing gas from wells drilled prior to 1993. This credit has been eliminated for wells drilled after 1992, which could lead to an overall reduction in the amount of coalbed methane recovered as production from the pre-1993 wells begins to subside. The coalbed methane characteristics of the primary underground mining regions in the U.S. are presented in the following table.

<table>
<thead>
<tr>
<th>Coalbed Methane Characteristics</th>
<th>Appalachian Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Southern</td>
</tr>
<tr>
<td>Gas Content (m³/tonne)</td>
<td>2 to 18</td>
</tr>
<tr>
<td>Permeability (md)</td>
<td>1 to 30</td>
</tr>
<tr>
<td>Coal Rank</td>
<td>Low &amp; Medium</td>
</tr>
<tr>
<td></td>
<td>Volatile</td>
</tr>
<tr>
<td>Gas in Place (Million Tonnes)</td>
<td>95 to 200</td>
</tr>
<tr>
<td>Target Depth (m)</td>
<td>300 to 650</td>
</tr>
</tbody>
</table>


1. CIAB, Coal Industry Advisory Board, Global Methane Emissions From the Coal Industry, October 1992
2. Ibid.
The overall recovery and utilization of coalbed methane emitted from the coal industry in the U.S. today, are estimated at 30% and 15%, respectively, following the recent addition of two major coalbed methane recovery projects in Central Appalachia. With the completion of these project, the remaining sites which offer any substantive potential are much more diffuse and their commercial viability is tenuous. Therefore, recovery potential is believed to be in the range 30 to 40% for the country as a whole.
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