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WORLD COALBED METHANE PROJECTS

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A b s t r a c t . Worldwide coalbed methane resources, once considered as a new "unconventional" natural gas resources, are now being recognised as a potential source of methane in many countries with extensive coal basins. Coal deposits occur abundantly in many locations throughout the world. Unfortunately, for most of the countries (and especially European countries) the geological conditions are not as simple as in the American basins (complex structure of the basins, very low coal permeability) and unmodified use of the US coalbed methane technology could lead to disappointing results.

Good gas productivity in coalbed methane projects will probably only be achieved through the adaptation and development of existing technologies in the exploration, drilling and production fields. Using strictly classical oil and gas technologies does not seem to be capable of producing adequate results. Exploitation of CBM resources will be a challenge for the next century. Success depends on our ability to change our way of thinking and to find solutions for the real difficulties of CBM exploitation.

In the United States, the existing natural gas pipeline system has provided a ready means for distributing and marketing the extracted CBM. However, establishing natural gas markets outside of the USA will be more challenging. In locations such as eastern Australia, China or southern Africa there are no existing pipeline facilities for the distribution and sale of the gas. The construction of hundreds of miles of pipeline may be required to connect the CBM production sites to the Consumers' market.

In the paper is presented information about the most interesting CBM projects in the world.

K e y w o r d s : coalbed methane reserves, coalbed methane projects, coalbed methane technology.

INTRODUCTION

Given the widespread distribution of coal-bearing strata around the world, it is reasonable to assume that high-quality basins with commercial possibilities for coalbed gas production exist. Thick, gas-filled coal seams are present on all populated continents as shown by coal production statistics and numerous methane-related mining disasters. In some countries, such as China, the potential gas resources contained in the coal seams may exceed the conventional gas resource base. However, it is still too early to know how efficiently and quickly this enormous international gas resource can be utilized as an economic gas reserve.

Since the early 1990s, there have been significant developments in coal mine methane recovery, particularly in the number of active recovery and use projects, and the volume of methane sold (Kuuskraa *et al*., 1992; Coal industry..., 1993; Kuuskraa, Boyer, 1993; Levine, 1994; Bellus, 1995). Today, there are at least 17 mines with active methane recovery and use projects in the US, recovering almost 50 bn ft^3 (1.4 bn m^3) of methane annually, or about 134 m ft^3/day (3.8 m m^3/day). Mines inject most of this methane into commercial gas pipelines, but a small amount is used for power generation or heating.

In the past twenty years, annual coalbed methane (CBM) production in the US has grown from negligible amounts to more than 28.3 bn m^3 from more than 6,000 wells, accounting for 5 per cent of annual domestic gas production. Latest estimates by the Energy Information Administration (US Department of Energy) place US proved CBM reserves at 300 bn m^3 (10.6 Tcf).

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COAL AND COALBED METHANE RESERVES AND RESOURCES

Stated simply, the coal resource base worldwide is large. The proven reserves of coal are generally accepted to be those quantities which geological and engineering information indicate with reasonable certainty that they can be recovered in the future from known deposits under existing economic and operating conditions. Known reserves logged at the end of 1994 exceeded 29,365 EJ, about 1×10^{12} tonnes (1,718.9 EJ in Africa, 8,870.4 EJ in Central and Eastern Europe, 5.6 EJ in Middle East, 7,044.6 EJ in North America, 287.0 EJ in South America, 2,675.5 EJ in Western Europe, and 8,763.5 EJ in Western Pacific and Asia). The largest coal reserves are located in Central and Eastern Europe (30%), West Pacific and Asia (30%), and North America (24%). In 1994, the largest amounts of coal were produced in the same three regions. However, these proven reserves are only a portion of the total coal resource, which may be as much as 25 times greater. Four countries: Russia, China, the United States, and Canada account for nearly 90% of the total. In view of this very large amount of coal, it is reasonable to infer the existence of a large world coalbed gas resource (Stefanov, 1939; Nieć, 1989; Murray, 1994; Wyman, Kuuskraa, 1995; Energy information..., 1997; Seminar and roundtable..., 1998; G. Stiegel, US Energy Dep. — oral inf.).

Worldwide CBM resources may range from 84 trillion m^3 to more than 350 trillion m^3 (3000 to 12.600 Tcf) (Table 1).

Table 1

Coal and coal seam gas resources in selected countries (after Kuuskraa *et al.*, 1992)

Country	Coal [bn tonnes]	Coal seam gas [trillion m^3]
Russia	6,500	17–113
China	4,000	30–79
United States	3,970	7.8–18.4
Canada	7,000	8.5–12.0
Australia	1,700	8.5–14.2
Germany	320	2.83
United Kingdom	190	1.70
Kazakhstan	170	1.13
Poland	160	2.83
India	160	0.85
Southern Africa*	150	1.13
Ukraine	140	1.70
Total	24,460	84–358

* includes Republic of South Africa, Zimbabwe and Botswana

TECHNICAL PROCESSES FOR COALBED METHANE RECOVERY

Unlike typical natural gas reservoirs, methane in coalbeds is mainly in the adsorbed form. Coal, as a rock medium, varies considerably. Typical beds usually have a laminar structure and a low permeability in the order of a few md. Therefore, the main problem in efficient methane recovery from coalbeds lies in initiating the process of methane release from coal (gas desorption is associated with a "swelling" of the body of coal), stimulation of the coal medium, and maintenance of proper production conditions.

The ways of removing methane from coalbeds include:

— horizontal holes drilled in the face of the coal seam being mixed,

— vertical holes drilled into the coal seam for ventilation,

— holes drilled from the surface to coalbeds, similarly to typical gas reservoirs exploitation holes,

— extraction of methane with ventilation air from the working areas of coal mines,

— extraction of methane through gob wells drilled from the surface to a depth above the mined coal seam.

As was mentioned earlier, methane has to desorb from the coal before it can flow to the well. Gas desorption increases as the coalbed brine is removed from the coal. Disposal of these brines by injection into disposal wells, by surface disposal, or by treatment to recover usable water supplies, is an integral part of methane recovery from coal.

When methane extraction via vertical wells drilled from the surface takes place from beds which are not and will not be mined for coal, methane desorption is increased by hydraulic, gas/nitrogen or CO_2 fracturing or cavitation. When applying these processes, it should be realized that Young's Modulus for coal is small; therefore, high fracturing pressures and backfilling having a suitable granular structure (sand filling) and porosity (gravel filling) have to be applied.

In hydraulic fracturing, a fracture zone or system of fractures is formed in coalbeds. As already mentioned, the coal matrix has a very low permeability, and the fracture systems are the main channels of gas flow (Way *et al.*, 1986; Siemek *et al.*, 1994; Weil *et al.*, 1996). To achieve reasonable drainage of the methane resource, wells have to be closely spaced. Low-cost techniques for drilling and completion of wells are essential for economic recovery.

Most of the current projects fall into one of the following two categories:

— natural gas projects that produce coalbed gas from unmined coal, mine seams or basins,

— mining-related projects with a primary aim to improve mine safety and productivity by draining methane from the coal and mine by vertical, horizontal, and gob (caved area) wells.

The mining projects also have environmental incentives. By recovering gas and utilizing it as a clean burning fuel, methane (a potent greenhouse gas) emissions to the atmosphere are reduced.

COALBED METHANE PROJECTS

Methane in coal mine gas emitted into the atmosphere due to coal mining is not only a problem for mine safety, but also has an undesirable effect on global warming (Marshall *et al.*, 1998; Mostad, 1999). Therefore, some countries prioritise CBM projects. These projects will contribute to the prevention of global warming and coal mine safety and establish an effective use of energy resources.

United States

Coalbed methane is a gas formed by the decomposition of the organic matter in coal and is found throughout the United States. Coalbed methane is recovered in some states (for example, Alabama, New Mexico, Colorado, Virginia, and Wyoming) and added to the supply of natural gas, which is composed chiefly of methane. Proved reserves of coalbed methane total 311 x 10^9 m^3, located mostly in the San Juan and Raton Basins of Colorado and New Mexico. The recoverable resource base for coalbed methane currently comprises an estimated 2.55 x 10^{12} m^3 in the lower 48 states and 1.6 x 10^{12} m^3 in Alaska. The production of coalbed methane in 1997 was 31 x 10^9 m^3 or about 6% of the United States dry gas production (Table 2).

Table 2

United States coalbed methane proved reserves and production [in 10^9 m^3] (after Energy Information Report, 1997)

State	1994		1997	
	Reserves	Production	Reserves	Production
Alabama	28	3	31	3
Colorado	82	5	110	9
New Mexico	117	15	123	17
Other*	48	1	61	2
Total	275	24	325	31

* includes Oklahoma, Pennsylvania, Utah, Virginia, West Virginia, and Wyoming

These 1994 data include only the C_1 emissions in the ventilation air. Measurement of other emissions was not reported prior to 1997 (Marshall *et al.*, 1998; Murray, Schwochow, 1998; T. Grindley, US Energy Dep. — oral inf.).

U.S. methane emissions from coal mining were nearly 4x10^6 tonnes in 1995, more than 14% below 1990 levels, primarily because of decreased emissions from the ventilation and degasification systems of the nation's gassiest coal mines and growing methane recovery from coal mines. Emissions from degasification are estimated to be on the order of 300,000 tonnes lower than previously believed. Meanwhile, methane recovery has grown more rapidly than previously reported, largely due to significant growth in Virginia. Virginia production is now >2.8 x 10^6 m^3 x 365 = 1.02 x 10^9 m^3/a. This recovery was started by Island Creek with a 1.1 x 10^6 m^3/a CBM/CMM production when CONSOL, Inc. acquired Island Creek. In 1993, CONSOL acquired Island Creek Coal and the gassy Pocahontas VP No. 3, VP No. 5, and VP No. 6, which included the methane recovery system installed by Island on these mines. CONSOL combined the methane recovery from their Buchanan No. 1 mine and has continued to increase total system recovery to more than half of the "Other" production. In December 1995, CONSOL sold the gas rights from these mines to MCNIC Oil and Gas. The methane recovered from these mines is responsible for more than 0.5 x 10^6 tonnes of the increase in methane recovery. Both the Energy Policy Act of 1992 and legislation enacted in West Virginia during 1994 contained similar language aimed at bolstering coalbed methane development.

Australia

A project of 5 years duration started in 1996 with CSIRO on Mine Gas Control within a framework of collaborative coal mine safety research. The objectives of the project are to control gas emission in an underground coal mine and to make an optimum evaluation of the technology of gas drainage (G. Stiegel, US Energy Dep. — oral inf.).

In the years 1997–1998, the following two tasks were undertaken:

— creation of drainage holes in a disused mine to develop, test, and demonstrate effective gob drainage methods for abandoned mine workings,

— gas flow estimation and measurement in the gob to predict the gas flow patterns which will allow the development of drainage techniques and ventilation to manage gas emission during and after mining, while controlling spontaneous combustion in the gob.

Belgium

Belgium, like other European countries, has a long history of producing CBM in association with coal mining operations (Mostad, 1999). During the fifties, Europe was able to produce up to 1.8 x 10^6 m^3/d, of which Belgium contributed up to 0.3 x 10^6 m^3/d. The particularly high yields of methane at this time were due mainly to the beneficial effect of the mining operations on the permeability of the strata and overlaying coal. Methane was produced from wells drilled ahead of the future gob area (de-stressed and fissured area created above the mining front).

Based on the important experience gained during these years and the new development of the Coal Bed Methane (CBM) industry in the United States, the potential of areas away from previous mining works are presently re-evaluated. A description of the coal basin structure is given with the delineation of potential areas for CBM production. Two targeted areas (≈75 km^2) with coal resources at depths estimated between 700 and 1250 meters have the potential for a plateau of production of approximately one million m^3 of gas per day.

China

China is the world's largest producer of coal, producing 1.4×10^9 tonnes in 1997. China is also the world's largest consumer of coal, which covers about 75% of the country's total energy needs. CBM emissions are closely associated with mining activity. The methane gas discharged into the atmosphere as by-product of coal mining is said to have a 20 to 60 times larger greenhouse effect than carbon dioxide on a molecular basis. In China, the methane content of coal is particularly high because most of the coal production is from underground mines at deep levels containing far more methane gas than open-cast mines. Annually, the total CBM emitted is estimated at 19×10^6 m^3 by the United Nations Development Program (UNDP), about 5×10^6 m^3 by U.S. EPA and 7.7×10^6 m^3 by the Ministry of Coal Industry (MOCI). This quantity seems set to rise in the future because coal output is increasing and mines are getting deeper. In 1996, the total CBM recovered was 618.6×10^6 m^3, roughly 8% of total emissions (G. Stiegel, US Energy Dep. — oral inf.).

In spite of the fact that methane gas is a clean and useful energy source, most of the gas removed to increase mine safety in China has been discharged into the atmosphere without being used. If the coal mine gas exhausted from mines was recovered and used effectively, the emission of methane gas, at present having a significant greenhouse effect, could not only be controlled, but could be effectively utilized as a source of energy. In view of the situation in China, CBM projects were initiated with a view to reducing global warming, improving mine safety, and utilizing the CBM as an energy source by efficient recovery and effective use.

Underground removal and utilization of CBM started in the Chinese coal mining industry in the 1950s. Within the last 10 years, considerable progress has been made in exploration from the surface and in the development of CBM extraction in virgin coal seams with the powerful support of the Chinese government and the active participation of international communities and foreign investors. The experience and results gained in both underground drainage and surface drilling confirm that the exploitation and utilization of China's CBM resources will be promising and profitable.

A state-owned company, China United Coalbed Methane Corporation Ltd. (CUCBM) is empowered to undertake exploration, development, and production of CBM in cooperation with foreign companies. The development of CBM from surface boreholes has great potential. CUCBM has set targets for CBM production in China from surface boreholes of 1×10^9 m^3 annually by the year 2000 and 10×10^9 m^3 annually by 2010.

The large CBM resource in China provides a reliable and substantial basis for the exploitation of CBM. It is characterized by a relatively concentrated regional distribution. Geographically, about 62% of the total CBM resources lie in North China; 66% of the total is in coal seams at depths between 1,000 and 2,000 meters. The total resource is $30–35 \times 10^{12}$ m^3 at depths down to 2,000 m.

The course of development of China's CBM industry may be divided into three stages:

— underground venting and drainage of coal gas,
— surface drilling and extraction of CBM,
— establishment and development of a CBM industry.

In 1993, the number of coal mines where a coal gas venting system was in place reached 115, which produced an annual total of 534×10^6 m^3 of gas.

Potential barriers to CBM development are:

— lack of technology,
— focus on CBM removal for mine safety as the principal concern, rather than CBM use,
— lack of infrastructure,
— lack of awareness of environmental issues,
— lack of funds for investment in CBM.

The following projects, among others, are at a development stage:

1. CBM Development in Panzhuang Mine.
2. APEC Coal Mine Gas.
3. CBM Exploration and Development in the Yangquan Coal Area.
4. Texaco Huaibei CBM Development.
5. Arco and Philips.
6. UN-GEF Development of CBM Resources.
7. UN Deep CBM Exploration.

Czech Republic

In the Czech Republic, CBM resources are estimated to be $51–371 \times 10^9$ m^3, of which $12–88 \times 10^9$ m^3 are verified. The most interesting is the Ostrava–Karvina Coal Basin, 1600 km^2 in area, which accounts for 99.8% of methane emissions from mines. There are coal seams with an average coal thickness of 150 m. The methane content of the coal is from 4.4 to 20 m^3/t. Annually, gas extraction plants produce about 120×10^6 m^3 of methane. CBM is being recovered from both abandoned coal mines and virgin coal seams.

OKD, DPB PASKOV Inc. took part in a pilot project of the exploration of CBM in 1994–1997. Prospecting took place in the carboniferous virgin coal seams of the Czech Part of the Upper Silesian Coal Basin. The present annual coal production is about 13×10^6 tonnes. The company owns concessions in 10 prospecting areas with a total area of 196 km^2. These areas are situated outside the present mining areas. CBM reserves at prospecting areas of OKD, DPB PASKOV Inc. were estimated at $10–20 \times 10^9$ m^3. Three surface boreholes (VA-1, TR-2, and DP-1) were sunk in different parts of the basin to provide basic information on the gas content of the coal seams. Three hydraulic fractures were induced in two of these wells. On the basis of these results, and along with the results of the earlier measurements of gas content, the basic favourable and unfavourable geological parameters were determined for the needs of CBM exploitation (International Conference ...., 1998).

France

The output of the Lorraine Coal Field in the East of France is 4.5×10^6 tonnes annually of clean coal. The volume of methane is $184{,}106 \times 10^6$ m^3 annually (56% CH_4), drawn from 3 operational collieries and from disused workings. Extraction is achieved from old workings and the active longwall-face workings by means of drill holes and confined chambers. The underground methane network is equipped with gas sensors (CH_4, O_2, CO), temperature probes, and pneumatic sluices, permitting remote gas content control and adjustment from the surface (*op. cit.*).

Germany

The coal basin in the Saar is the second largest coal mining district in Germany. The coal-bearing stratum stretches from the open surface to a depth of over 5,000 m. Active mining today takes place at depths between 600 and 1500 m. The individual seam thickness of seams ranges from 0.5 to over 5 meters. The gas content of the coal is 4 to 10 m^3/t (*op. cit.*).

To date, several deep boreholes have been sunk in three exploratory phases for the extraction of CBM. Following the American example, among others, initial stimulations with fracture technology were tested at the beginning of the 1990's. In borehole Aspenliubel l, which produced a continuous gas output from 1996–1997, the borehole completion (deep well pumps) had to be replaced when extraction began because of complicated extraction condition (mixtures of gas and water). The results obtained from the Saar CBM project substantiate the technical feasibility of extracting gas from coal seams. Within the scope of a demonstration project sponsored by the EU, the project was scheduled to be continued in 1998 with a further borehole in Saarland.

India

India is the world's third largest coal producer. More than half of India's energy requirements are covered by domestic coal. Of that, coal represents approximately 70% of the fuel used for power generation. Annual coal production in 1997 was 299 x 10^6 tonnes and coal consumption about 311 x 10^6 tonnes (G. Stiegel, US Energy Dep. — oral inf.).

Given the large coal resources in India, CBM could play a substantial role in future activities. CBM could cut India's energy deficit and the surging demand for imported natural gas. The estimated resource base is between 850 x 10^9 m^3 and 4,075 x 10^9 m^3, ranging in the Damodar Valley from 283 x 10^9 m^3 to more than 3,226 x 10^9 m^3, and in the Cambay Basin about 311 x 10^9 m^3 for coal seams between 610 and 1524 meters deep.

In 1993, the first CBM drilling program started in India in Northern Gujarat. Under the program, three wells were drilled. Two of the wells, LBM No. 1 and LBM No. 2, are about 10 km apart. Both wells were completed and stimulated. The third well, LBM No. 3, was drilled as an offset to LBM No. 1 as part of a planned five-well pilot project. Based on data from these three CBM wells and several dozen well logs from the surrounding area, it could be shown that the three main coal seams are consistently thick and laterally persistent throughout the Mehsana CBM project area. In addition, the gas content values are in the range of 5 to 7 m^3/t, surprisingly high given the low rank of the coal.

In 1994, Amoco India Petroleum Co. was awarded a government concession for CBM evaluation in virgin coal at the Ranganj, Jharia, East Bokaro, and North Karanpura coalfields. Based on rank, thickness, and limited sorption isotherm data, Amoco India estimated CBM resources to be 283 to 680 x 10^9 m^3 and recoverable gas in the order of 40 x 10^9 m^3 in the unmined coals of these fields.

In September 1996, Amoco India suspended the project because it was unable to secure a commitment from the government to fund or build a gas pipeline into the remote Damodar fields. Furthermore, a mutually satisfactory production agreement for gas sales could not be concluded.

Japan

Ishikari coalfield is the most gassy coalfield in Japan. Until 1995, there were many coal mines in this coalfield. Due to the great depth and large gas emission, all coal mines were closed and there are no coal mines in this coalfield nowadays. The maximum working depth was 1,200 m below surface, average gas content was 9.5 m^3/t and average specific gas emission was 45.1 m^3/t. The gas is still emitted from abandoned goaf through shafts (Hirosawa, 1999; Ohga, Shimada, 1999).

In order to evaluate the possibility of gas production from surface boreholes and of gas recovery from the abandoned goaf, re-evaluation of coal and gas reserves and simulation of gas production from the surface wells were carried out.

There are some obstacles for development and utilisation of CBM. One is lack of a pipeline network system for natural gas in Hokkaido. Therefore, utilisation of CBM is limited. And the selling price of electricity is very low. As a result, gas is used for fuel of small scale power generation and generated electricity is used for private use. Another constraint is that drilling cost is very expensive. The drilling cost of 500 m length well is about from 0.5 to 1.0 million dollars. This is the biggest problem for development and utilisation of CBM project.

Kazakhstan

The Government of Kazakhstan and the joint stock company Ispat–Karmet (an Indian–Kazakhstan joint venture), are interested in developing feasibility studies and subsequent investment for coalbed methane capture and utilization in the Karaganda coal mining basin (International conference..., 1998).

Methane has long been ventilated from the Karaganda coal-mining basin in an effort to protect worker safety and reduce the incidence of explosion. Interest in reduction of greenhouse gas effects, in air quality, and in the energy potential of the methane has caused the Government to begin investigating the possibility of extraction of the coalbed methane and its utilisation. Studies have verified that there is gas in commercial volumes available and that there is a substantial regional market for the gas as a fuel. Indeed, some experts believe that this is the best methane extraction project opportunity in the former Soviet Union.

The project site would be the mines of the Karaganda coal-mining basin in Northern Kazakhstan. The mines are owned by a joint stock company, Ispat–Karmet, and by the Government of Kazakhstan.

Poland

In 1994, the total energy consumption in Poland was about 4.18 PJ: 76% coal, 15% oil, 8% natural gas, and 1% hydroelectric. Coal is not only the dominant fuel in Poland's economy, but it is also the main source of foreign exchange earnings for the country. In 1995, over 98% of oil and almost 80% of natural gas was imported.

Poland is fourth in the world in the production of hard coal with total reserves of 102 to 150 x 10^9 tonnes and 40 x 10^9 tonnes recoverable; hence, CBM could become an integral part of the energy economy. CBM could help offset some of the debt incurred by the coal industry and could help balance the trade deficit by reducing the need to import natural gas (Karwasiecka, Kwarciński, 1994; Rychlicki, Twardowski, 1995; Rychlicki *et al*., 1995; Twardowski, Rychlicki, 1995; Twardowski *et al*., 1997).

Poland has the potential to be the second largest CBM producer in the world, on the basis of the reserves in two of the three major coal basins. Resource estimates for the Upper Silesian Coal Basin range from 351 to 1,300 x 10^9 m^3 and in the Lower Silesian and Lublin Basin from 76 to 150 x 10^9 m^3.

Methane extraction from coal seams and surrounding rocks in Polish mines encounters considerable difficulties arising first of all from the low porosity of the rocks, being restricted in general to between 2 and 12%. Thus, methane removal prior to extraction operations is characterized by low effectiveness both in relation to the quantities of recovered methane and its concentration in methane drainage pipelines. Because of this, in many cases methane is released to the atmosphere from the methane drainage pipeline. In addition to the methane removed from mine workings by ventilation systems in the Upper Silesian mines, an annual additional 650 x 10^6 m^3 of CH_4 are released to the atmosphere. The efficiency of classic methane extraction does not exceed 40%. In the majority of cases the methane is recovered from post-longwall gobs.

An increase of methane-removal efficiency to as much as 80% can be expected after broader implementation of an overlying methane extraction method. However, favourable conditions for the application of this method do not always occur, even in multi-seam conditions. It seems that there are considerable chances to increase the methane drainage effectiveness by using directed fracture techniques. Considering the technological ease of use, the methodology may be widely applied to achieve initial methane removal from the deposits. Similarly, it has frequently been used to reduce the rockburst hazard.

Studies on CBM projects in Poland continue, principally in the Upper Silesian Coal Basin. Potential barriers to CBM development are:

— lack of technology; there is a need to enlarge gas storage facilities and to improve methane drainage systems (Szpunar *et al*., 1992);

— taxes; more favourable tax conditions could help to stimulate CBM utilization;

— adaptation to a market economy; the inefficient hard coal industry is struggling to compete in the market economy; government-controlled coal prices and "social employment" remain as serious barriers.

In Poland, the following projects have been undertaken:

1. Amoco Poland Ltd. project in Upper Silesia.
2. Electrogaz Ventures Ltd. Project in Upper Silesia.
3. PolTex Methane-Texaco Inc. Project in Upper Silesia.
4. Metanel S.A. Project in Upper Silesia.
5. McCormick Energy Project in Upper Silesia.

Russia

Russia is the world's fourth largest coal producer. In 1997, the coal mines produced 261 x 10^6 tonnes of coal. Russia is also one of the world's largest producers of CBM. CBM constitutes 15% of the total national anthropogenic methane emissions.

CBM recovery and utilization projects are expected to encourage local economic development by potentially offsetting the number of jobs lost during restructuring and by enhancing the financial viability of coal mines. CBM projects may improve the profitability of mines by increasing revenues or by decreasing costs. A project with as few as 10 of the mines in the Kuznetsk Coal Basin, could achieve annual reductions of 4.6 x 10^6 tonnes of CO_2 equivalent (International Conference..., 1998; G. Stiegel, US Energy Dep. — oral inf.).

To improve the situation for utilization of CBM in the coal mining regions of the Russian Federation, the Skochinsky Institute of Mining, PechorNIIproekt and the mine associations "Vorkutaugol", "Leninskugol", and "Belovougol", carried out investigations and mine observations in order to determine efficient technologies and conditions of recovery by degassing mines of coalbed methane suitable for utilization. Among others, the methods of adjacent seam and gob degassing through wells drilled from the mine workings and the surface, as well as different schemes of degassing the seams being mined with underground wells, were studied. The results obtained in the Kuznetsk coal basin are interesting and the studies are continuing. To be successful, projects need input and cooperation from several main ministries, local authorities, and other institutions in Russia. The Technical Working Group (TWG) will promote cooperation.

Potential barriers to CBM development are:

— lack of experience in using CBM as fuel,

— political instability,

— lack of capital,

— lack of information available to outside investors.

The most important CBM project is connected with the utilization of CBM in a boiler house at the Pervomayskaya Mine. The mine releases 14,000 tonnes annually of methane. Presently, none of it is being used. The project will involve the conversion of boilers to burn 6.50 tonnes annually of CBM with coal, which will serve as a model for expanding CBM use in the Kuznetsk Coal Basin. Estimated CBM resources associated with the coal reserves of the Kuzbass mines range from 194 to 342 x 10^9 m^3. The project has three main components:

1. Enhanced drilling.
2. Creation of centralized systems of collection and separation.
3. Reconstruction of a boiler house to co-fire coal and methane. The fuel mixture will have an average methane concentration of 40% or greater, and a potential energy equivalent of 38 GJ/h. The gas input may vary from less than 10% to up to 100% of total fuel supply, depending on the furnace design and the needs of the boiler operator.

CBM will be used to produce electricity and for heating. The project has special importance, in that it will help to solve the problem of safety at the workplace. There have been a few accidents in the region, which have killed several people in recent months through methane exposure. The Administration of the Kuzbas region and the Ministry of Fuel and Energy have provided support for this project.

South Africa

South Africa is the fifth largest producer of coal in the world, with annual production in 1997 at 220 x 10^6 tonnes, and consumption at 154 x 10^6 tonnes. South Africa contains the seventh largest coal reserves in the world (54 x 10^9 tonnes). Because of these large reserves, CBM could become a viable and profitable energy source for South Africa. CBM could obviate the future need to import natural gas. Several areas have been identified as having potential for CBM development. More mines are expected to open in which CBM technologies could be incorporated. If these mines are not approved by government officials in response to environmental activism, Sasol (South Africa's third largest coal producer) will have to explore other ways to further expand production at its existing room-and-pillar mines.

Potential barriers to CBM development are (G. Stiegel, US Energy Dep. — oral inf.):

— allocation of ownership rights has not yet been determined (except in the Springbok Flats Project),

— current government subsidies are deterring foreign investment,

— treatment of development costs precludes the write-off of development costs against other income,

— there is potential for preferential tax treatment,

— political changes within the country have created a situation where dramatic improvements are needed in the country's infrastructure in order to enable it to meet the needs of its people,

— there could be a transition from energy self-sufficient policies to new energy policies.

In November 1995, a pre-feasibility study was undertaken at Springbok Flats, Northeast Transvaal the rural areas of Lebowa, Venda, and Gazankula. The pre-feasibility study analysis indicated a potential methane production of 0.71 x 10^6 m^3, which could be absorbed by markets in the immediate vicinity. In December 1996, Phase I of the feasibility study was started. The Phase I study included drilling of four core holes to measure gas content, geophysical logs of the holes, and reservoir simulation. The success of Phase I would determine if Phase II would be made. Phase II would consist of drilling larger holes for permeability testing, another round of reservoir simulation, a detailed inventory of possible natural gas markets and applicable gas pricing, and a detailed economic analysis of all aspects of the project. The study is to include an environmental impact assessment that will encompass an evaluation of the benefit of natural gas substitution for coal and firewood heat energy. The Phase I drilling was completed in November 1998. The wells drilled in the Lebowa Region yielded no natural gas. This ended the project with no funding given for Phase II activities.

Turkey

Only preliminary investigations to assess Turkey's coalbed methane capture and utilization potential have been conducted. Turkey does not currently have any economically significant CBM production. The Black Sea Coast area of Turkey has substantial hard coal and coal-related resources; substantial amounts of methane are continuously emitted from the coal mines. Recovery and use of this methane could be beneficial because of reduced future methane-related hazards to miners and improvement to the local and global environment (T. Grindley, G. Stiegel, US Energy Dep. — oral inf.).

Turkey has a growing demand for energy. The Turkish nation is now dependent upon imported energy for a substantial portion of its energy needs. In particular, natural gas demand is increasing faster than the supply. The demand for natural gas used for power generation is increasing even more rapidly than overall demand. Gas will be a key factor in Turkey's future economic performance and strategic stability. Turkey needs reliable gas supply sources and would benefit by reduced imports.

CBM from the Zonguldak hard coal region could be a very significant factor in Turkey's energy economy. Development of the methane gas resources would alleviate some of the current and future shortages of energy in Turkey. The resources identified could fuel gas-fired power plants and supply raw material to a newly created petrochemical complex. Electric power could be distributed to the power grid and targeted to existing and new industries. The CBM in-place resources in two districts of the Zonguldak hard coal region are presently estimated to be at least 3 x 10^{12} m^3 (TCM). Assessment of CBM resources in the third largest district is continuing.

No policies specifically impeding CBM development have been identified. Potential barriers are the requirements for and the logistics of importing equipment. Training of Turkish personnel is needed. Infrastructure for operations and equipment mobility must be developed, as must maintenance facilities and machine shops. Power plant development will generate demand for turbines, electrical equipment, transformers, transmission lines, electronic equipment, and computerized systems.

A joint venture engaged the services of Raven Ridge Resources, Incorporated, to survey and estimate the CBM resources of the Zonguldak hard coal region, Districts 1 and 2, during 1997. District 1 covers 1,870 square kilometres and District 2,2605 square kilometres. Raven Ridge Resources have estimated that the CBM resources in Districts 1 and 2 in the Westphalian coal and sandstone reservoirs exceed 2.56 x 10^{12} m^3, most of which is thought to lie in sandstone reservoirs.

The aggregate thickness of the Westphalian coal-bearing strata exceeds 1,000 meters. Raven Ridge Resources have not estimated the resources of the Namurian coal-bearing interval that underlies the Westphalian Kozlu coal measures. Numerous prospective coals and sandstones occur in the Namurian sediments in which significant coalbed methane gas resources may occur. Westphalian coal samples collected from actively mined areas were analysed to determine source rock characteristics. The testing suggests that these coal samples can be classified as humic, are mature to late-mature Type II and Type III kerogen coals, and are a likely source of gas condensate and minor quantities of oil.

CBM's legal status in Turkey is now clarified. Many relevant Turkish laws and regulations are not officially translated into English. CBM evaluations may differ from natural gas.

Ukraine

Ukraine is one of the most inefficient users of energy. Collections of payments for gas and electric power are poor, and much of that is in barter rather than cash. Therefore, CBM could forestall the future need to import natural gas (T. Grindley, G. Stiegel, US Energy Dep. — oral inf.; International Conference..., 1998).

EuroGas, Inc., through its 100% owned subsidiary EuroGas Ukraine, controls substantial coal-bed methane reserves in Western Ukraine and Donetsk–Donbas area.

EuroGas created a joint venture Company, named EuroDonGas, with Makievka Mining Company. This joint venture prepared a work program to drill three wells in 1999 to confirm reserves estimated at 6 Tcf of gas, according to Ukrainian and foreign specialists. The gas will be produced from sandstones overlying coal seams from depths of between 600 to 1,200 m.

EuroGas formed another joint venture with Alternative Fuel Corporation to develop vast resources of methane for the Gorskaya Mine in the Donbas area. Three wells and two gob wells are planned for this area. This program will be conducted with probable cooperation with Global Environmental Fund of World Bank. Again, the estimated resources are in the range of 5 to 7 Tcf of gas.

The last area of coalbed methane development in Ukraine is the area of Western Ukraine in the Lublin Coal Basin. EuroGas formed a joint venture with ZahidUkrGeologyia (Ukrainian Company base in Lviv). Resources are estimated at 2 Tcf.

Also under development in Ukraine are the GEF Coalbed Methane Recovery Project at Gorskaya Mine, Lugansk Oblast, and the CBM project in Lviv–Volyn Coal Basin.

The GEF Coalbed Methane Recovery Project consists of drilling wells from the surface, gas production tests and, if warranted, connection to a gas pipeline for high-quality gas and on-site electricity for low-quality gas. In the case of CBM in the Lviv–Volyn Coal Basin, three CBM gas wells were drilled to depths of 400–500 m. Zahidukrgeologia estimates the geological reserves at this site at approximately 10×10^9 m^3.

Potential barriers to CBM development are:

— lack of experience in licensing and technology,

— inadequate framework for private sector development,

— legislative and legal framework for investments not complete,

— high taxes,

— no cash payments for energy supplied.

CONCLUSION

Many of the techniques for producing CBM have been adapted from conventional oilfield drilling, completion, stimulation and production operations. However, coal's unusual behaviour and nature as both a source rock and reservoir rock for natural gas (and occasionally oil) demand new technologies and ideas from many disciplines.

Innovative production technologies for CBM will continue to evolve as we gain new technical understanding and insight into the nature and behaviour of coal seam gas reservoirs. All coal basins are different, however, and no one suite of technologies can be prescribed in a given area without careful geological and engineering evaluations. Even then, modifications will be necessary for successful exploitation. Not all technologies are applicable in all areas, and the gas in some coal deposits is beyond the reach of even the most advanced technologies and the strongest desires.

The availability of technology, the environment, and the optimistic outlook and growing demand for natural gas are, and will be, the main motivations for CBM development efforts around the world, as we have seen already in Australia, China, India, Poland, Russia and Ukraine. Interest is growing in other European, Asian and South American countries as well. Whether we consider the oilfield environment or the mine environment, the outlook is most encouraging.

Worldwide coalbed methane resources, once considered as a new "unconventional" natural gas resource, are now being recognized as a potential source of methane in many countries with extensive coal basins. To date, industrial production of CBM has been demonstrated only in the U.S. This is because, in that country, the geological and economic conditions are particularly favourable. As a result of this situation, new technologies (open hole cavity, multi seam frac, etc.) have been developed by American specialists.

Coal deposits occur abundantly in many locations throughout the world. Unfortunately, for most of the countries, and especially European countries, the geological conditions are not as simple as in the American basins, having complex basin structures and very low coal permeability. Unmodified use of U.S. coalbed methane technology could lead to disappointing results. Good gas productivity in coalbed methane projects will probably only be achieved through the adaptation and development of existing technologies in exploration, drilling, and production fields. Applying strictly classical oil and gas technologies does not seem to be capable of producing adequate results. Exploitation of European CBM resources will be a challenge for the next century. Success depends on our ability to change our way of thinking and to find solutions for the real difficulties of CBM exploitation.

In the United States, the existing natural gas pipeline system has provided a ready means for distributing and marketing the extracted CBM. However, establishing natural gas markets outside of the U.S. will be more challenging. In locations such as Eastern Australia, China, or Southern Africa, there are no existing pipeline facilities for the distribution and sale of the gas. The construction of hundreds of miles of pipeline may be required to connect the CBM production sites to the consumers' market.

In addition to the lack of distribution facilities for the gas, a market to use the gas may also need to be established. This may require a long-term procedure to convert urban and industrial centres to natural gas use, the installation of gas-fired electric power plants, especially cogeneration facilities, and the construction of new chemical plants for fertilizer or methanol production. The use of the gas as a fuel for vehicles, such as CNG or LNG, may also provide alternative markets for extracted CBM.

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