ENHANCED CBM/CMM RECOVERY

1.0 Overview/Description of the Technology

The coalification process in coal seams generates coal, water, carbon dioxide (CO_2), and methane. The byproducts are stored in both the fracture space (generated by the shrinkage of the source plant material) and is adsorbed on the surface of the coal. Methane is preferentially stored on the coal surface and is held there hydrostatically until the pressure drops and the methane molecule “pops” off. There are three main methods which can induce methane release from coal:

- Reduce the overall pressure, usually by dewatering the formation either through pumping or mining

- Reduce the partial pressure of the methane by injecting another inert gas into the formation

- Replace the methane on the surface with another compound, such as CO_2.

This report describes enhanced CBM/CMM (ECBM) recovery techniques, representing the latter two methods, which involve reducing the partial pressure of methane and/or replacing the methane on the coal surface. Both reservoir simulations and early pilot projects indicate that ECBM can accelerate and increase methane production from unmineable coal seams, and also in mineable coal seams in advance of mining. The process is implemented by injecting inert gas at one location and recovering methane gas at another (Figure 1).

Deep unmineable coal formations provide an opportunity to both sequester CO_2 into coal seams (from anthropogenic sources) and increase the production of methane where the adsorption of CO_2 causes the desorption of methane. This process has the potential to sequester large volumes of CO_2 (reducing its impacts on possible global warming), while improving the efficiency and potential profitability of natural gas recovery. Lab studies indicate that coal adsorbs nearly twice as much volume of CO_2 as methane.

There are some concerns, however, that injection of CO_2 into mineable coals presents a safety hazard, as the mines are required to have a limit of 3% CO_2 by volume in the mine air. One potential method for reducing CO_2 levels in the mine air is to use a mixture of CO_2 and other gases, such as nitrogen. Studies indicate that for each volume of nitrogen that is injected, two volumes of methane are produced. There is growing interest in mixed nitrogen/CO_2 injection for two reasons: there may be a synergy of production mechanisms, and its use would result in the lowering of CO_2 levels in the mine air.

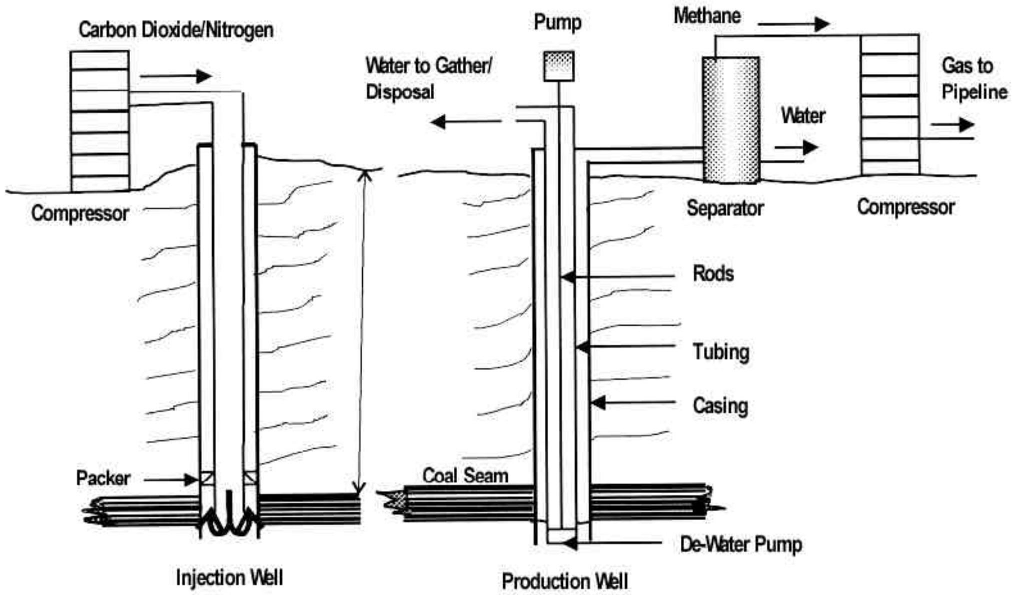

Figure 1. Gas is injected in one well and methane is recovered in another well. (After O.H. Barzandji, K-H.A.A. Wolf, J. Bruining, *Combination Of Laboratory Experiments And Field Simulations On The Improvement Of Coalbed Methane Production By Carbon Dioxide Injection*, Delft University of Technology Second International Methane Mitigation Conference, Novosibirsk, Russia, June 18-23, 2000).

Injection of nitrogen, usually generated by manufactured gas plants, reduces the partial pressure and therefore the concentration of methane in the coals in the fracture system. Even though the partial pressure is reduced, the total pressure is generally constant (depending on whether or not the seam is being dewatered) and the fluids maintain head that drives liquids to the production wells. It is theorized that nitrogen injection affects methane production from the coal seam via inert gas stripping and sorption displacement. Coals can replace between 25% to 50% of their methane storage capacity with nitrogen.

The gas sorption capacity (GSC) is generally assumed to decrease with increasing temperature, increasing ash content, and increasing moisture content; GSC increases with increasing coal rank, and with increasing pressure (Figure 2).

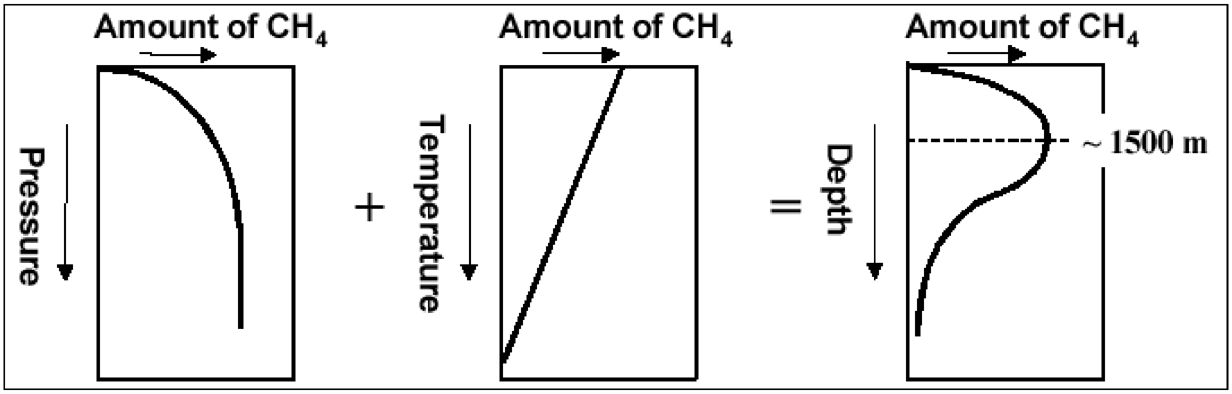

Figure 2. Schematic of sorption capacity with geologic parameters. (After F. van Bergen and H.J.M. Pagnier)

2.0 Current Status and Research Projects

The applicability of ECBM approaches for enhancing CMM/CBM production is currently being tested at four pilot demonstration sites in North America.

- The Allison CO_2 sequestration pilot by Burlington Resources has been underway in the San Juan Basin since 1995. To date, 4.7 Bcf of CO_2 has been injected, with only limited CO_2 breakthrough. Since primary production was declining through dewatering, lowered reservoir pressures and well re-stimulations, reservoir simulation was used to predict potential pilot performance. It is estimated that injection reported to date will yield 1.6 Bcf of incremental natural gas reserves.

- A pilot demonstration in Alberta, Canada is testing a process of injecting CO_2 into one of Alberta's deep unmineable coal beds. Preliminary computer modeling suggests that selected techniques for fracturing the coals around wells could be improved with a substantial increase in methane recovery. The initial field activity consists of a single well test, designed to measure reservoir properties, to increase primary production by an effective fracturing technique, and to evaluate CO_2 -enhanced methane recovery.

- From 1992 to 1994, an Amoco pilot project in the San Juan Basin, the Tiffany Project, injected nitrogen into a coalseam. Gas production before the pilot was 100 to 200 thousand cubic feet per day (Mcfd). During the nitrogen injection, methane production rates increased to 1,000 Mcfd with a constant water production rate. There was nitrogen breakthrough at the production wells, therefore necessitating no extra processing. At the end of the injection period, the methane production dropped back to a declining 400 Mcfd with nitrogen still in the stream.

- Consol Energy (operator of the largest underground mining operation in North America) will drill a five-well pilot on a 200-acre undeveloped block in northern West Virginia in the Appalachian Basin. The project will include one mineable seam and one unmineable seam. Consol Energy will produce methane without CO_2 injection for nine months using deviated slant wells with multi-laterals from the surface. The company then will inject CO_2 into the unmineable seam only and monitor enhanced recovery for 2 years. The project is expected to continue for 5 – 7 years.

3.0 Potential Impact on U.S. CMM Emissions

EPA has estimated that methane emissions from coal mining in the U.S. amounted to 3.7 to 6.5 terragrams (185-325 billion cubic feet (Bcf)) in 2000, which constitutes a significant source of greenhouse gas emissions; amounting to one trillion cubic feet (Tcf) of gas released to the atmosphere every 3 to 5 years. If ECBM technology is 50% effective, methane emissions from mineable coal seams are cut in half, and total U.S. emissions of methane could be reduced. The total emission equation is clouded somewhat by the fact that the injected CO_2 will be eventually emitted when the coal is mined. However, since the global warming potential of methane is over 20 times that of CO_2, a net gain in effective greenhouse gas emissions is realized. Moreover, safety in the mine is improved by the removal of an explosive gas.

The role of ECBM technology in reducing CMM emissions could be significant, as it could increase the recovery percentage of methane from vertical wells and in-mine horizontal wells. This is because when the mine face advances to the degasified area, there will be less methane in the coal. Recovery percentages for CMM/CBM projects typically range from between 30% and 60%. Based on pilot and simulation exercises, ECBM may be able to boost these recovery rates by an additional 20% to 30%.

If the process is applied to the unmineable coal, methane emissions are not reduced, but CO_2 is sequestered, and more methane is added to the world's energy supply. In unmineable coal seams, the greatest greenhouse gas reduction benefit results from sequestering CO_2, where an estimated 8.8 gigatons (Gt) of CO_2 could be sequestered in unmineable coal seams in the U.S., with an additional 55 Tcf of methane recovery potential, over twice the current estimated technically recoverable potential (Table 1).

Table 1
CBM Reserves and Potential ECBM Impact in the Unmineable Coal Seams in the United States

Basin	(A) Cum. Production EOY 2000 (Tcf)	(B) Reserves BOY 2001 (Tcf)	(A+B) Total Current Recovery Potential (Tcf)	ECBM Recovery Potential (Tcf)	Estimated CO_2 Sequestration Potential (G t)
San Juan	7.8	8.6	16.4	17	2.8
Uinta	0.2	1.6	1.8	5	0.7
Raton	0.1	1.1	1.2	4	0.6
Powder River	0.3	1.6	1.9	10	1.6
Other	1.5	2.6	4.1	19	3.1
Total	**9.9**	**15.5**	**25.4**	**55**	**8.8**

Source: Advanced Resources International, Inc., 2002.

Coal mine methane targets, on the other hand, are generally shallower than most conventional coalbed methane operations in unmineable coal seams, and may have more or less methane available, depending upon depth, hydrostatic pressure, and other factors. However, assuming that ECBM techniques are utilized in the 18 gassiest coal mines in the United States (those emitting more than 5 Mmcf per day), and that these mines recover about 30% of the emitted methane with current approaches, and another 20% could be recovered using enhanced recovery methods, U.S. methane emissions from coal mines could be reduced by 12.8 Bcf/year (35 MMcf/day) through the application of ECBM techniques.

For the next set of gassy mines (those currently emitting between 0.1 and 5.0 MMcf per day), reduced ECBM costs (particularly associated with CO_2 or nitrogen supplies) or financial incentives (e.g., to encourage the sequestration of CO_2 into coal seams) could improve the economic viability of ECBM techniques. If the new, more cost effective techniques are developed and demonstrated, and 20% to 30% of the mines emitting between 0.1 and 5.0 MMcf per day utilize ECBM approaches for coal seam declassification, from 4.7 to 7.0 Bcf per year of methane emissions to the atmosphere could be avoided.

4.0 Representative Project Economics

CO_2/nitrogen injection into coal seams can be economic if the value of the produced gas exceeds the cost of producing the gas, plus the cost of transporting the gas minus the cost of taxes or CO_2 credits. For a conceptual, but representative, CO_2-ECBM project, at a wellhead gas price of $2.00 per Mcf and assuming that the cost of the production wells and infrastructure is already sunk, the potential positive (undiscounted) cash flow is $1.36 - $1.16 per Mcf. If it is a new project, where new production wells must be drilled and production lines laid, the potential profit drops by $0.13 - $0.20 per Mcf, which leaves the operator with a profit of $0.96 to $1.23 per Mcf (Table 2). Of course, actual project economics will depend on site-specific considerations, operational characteristics, and numerous other factors. The economics for a specific situation could differ considerably from that shown here for illustrative purposes.

Table 2
Estimated Capital and Operating Costs for a Conceptual CO_2-ECBM Project
(100-Well Project)

Item	Unit Cost	Number Per Project	Total Cost ($MM)	Incremental Cost[1] ($/Mcf CH_4)
CO_2 Injection Wells (new; M$)	300	50	15.0	$0.08
CO_2 Inj. Wells (recompletion; M$)	100	50	5.0	$0.03
Hot Tap Connection (M$)	150	1	0.15	$0.00
CO_2 Lateral Line (M$/mile; 6-in)	120	10	1.2	$0.01
CO_2 Distribution Lines (M$/mile)[2]	80	50	4.0	$0.02
Total Capital Costs			**25.4**	**$0.13**
CO_2 Injectant Costs			100-140	$0.50-0.70
Incr. O&M Costs (M$/month)	10	240	2.4	$0.01
Total Costs (undiscounted)				**$0.64 - 0.84**
Total Costs (discounted @10%)				**$0.84 – 1.04**

[1] Assuming 40% improvement in recovery in a typical 5-Bcf well, for a total 200 Bcf of ECBM, and a 2:1 net CO_2/CH_4 ratio. [2] Assuming 320-acre injection well spacing.

From "CO_2 Injection for Enhanced Coalbed Methane Recovery: Project Screening and Design," Scott H. Stevens, Advanced Resources International, Inc., Lanny Schoeling, Shell CO_2 Company, Ltd., and Larry Pekot, Advanced Resources International, Inc., International Coalbed Methane Symposium, University of Alabama, Tuscaloosa, May 3-7, 1999

5.0 Limitations/ Barriers to Implementation

The potential barriers or limitations to ECBM fall into the three broad categories: geologic, economic, and policy. The geologic limitations are fixed in the absence of advances in technology; if the gas is not present in commercial quantities or if the gas cannot be produced, the project would not support an ECBM project, especially given the additional costs.

Assuming favorable geologic characteristics, the operator must then examine the economics of the project. A wide variety of factors can influence project economics, and thus, the likely application of ECBM processes in mineable coal seams. Finally, regulatory requirements and/or potential financial incentives can tip the balance for or against marginal projects.

Important factors to consider within each of these categories include:

<u>Geological</u>

- Homogeneity
- Simple structure
- Permeability >1 md
- Depth 300-1,500 meters
- Concentrated coal geometry
- Production rates

- Development timing
- Water disposal
- Amount of available gas

<u>Economic</u>

- Cost of CO_2
- Cost of N_2
- Availability of injectant gas
- Value of methane
- Cost of processing
- Cost of implementation
- Transportation

Policy/Legislation

- Tax or CO_2 Credits
- Mine safety regulations

6.0 Where the Technology Is Heading/Potential Future Advances

According to the U.S. Department of Energy, there are a number of areas that require further study and R&D to better develop and demonstrate ECBM technology. Areas where further research is recommended include the following:

- Physical and chemical properties of coal
  - Adsorption/desorption of CO_2
  - Interaction with SO_x and NO_x
  - Absolute and relative permeability
  - Swelling behavior from CO_2 adsorption.

- Modeling tools for simultaneous fluid flow, gas adsorption-desorption, deformation and gas-flow dynamics in coal-bed reservoir intervals.

- Cost and performance data from a full-scale integrated demonstration of methane production, power generation, and CO_2 sequestration.

- Reservoir screening criteria for assessment purposes, matching CO_2 generators to potential sequestration sites using screening criteria.

- Pilot test of flue gas injection to evaluate ability of CO_2 to adsorb to the coal surface, displacing the methane, while the nitrogen sweeps the methane.

- Technologies and methods for injection and production in low-permeability and deep formations.

- Injection engineering and design techniques for optimizing CO_2 sequestration and methane production in coal beds.

- CO_2, methane, coal interactions in water-saturated intervals to evaluate whether dewatering is needed prior to CO_2 injection.

- Methods for monitoring migration of CO_2 and its byproducts using a combination of hydrologic, seismic, tracer, and mechanical methods.

- Assessments of the impact of microbial activity on the long-term fate of CO_2 in coal formations.

References

CO_2-Enhanced Coalbed Methane Recovery in the Allison Unit, San Juan Basin, Lanny Schoeling, Kinder Morgan CO_2 Company, LP. and Mike McGovern, Burlington Resources Inc.

Economics of Flue Gas Injection and CO_2 Sequestration in Coalbed Methane Reservoirs, S. Wong, W.D. Gunter, D. Law, Alberta Research Council, and M.J. Major, Tesseract Corp., in Greenhouse Gas Control Technologies.

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