CO_2 STORAGE IN DEEP COAL SEAMS/ COAL BED METHANE RECOVERY: DOE/FE'S TECHNOLOGY DESIGN AND IMPLEMENTATION PLAN:

SURVEY QUESTIONNAIRE FOR INTERVIEWS WITH SCIENTISTS

Prepared for:
Fourth International Forum on Geologic Sequestration of CO2 in Deep, Unmineable Coalseams "Coal-Seq IV"

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BACKGROUND

Deep, unmineable coal seams have been posed as potential storage sites for industrial CO_2 emissions.

To understand this potential, a number of significant technology issues need to be further examined:

- CO_2 storage capacity of deep coals,
- Geologically favorable settings for injecting/storing CO_2 in coals, and
- Long-term interactions between CO_2 and coals.

In addition, it will be important to better integrate the two mutually beneficial activities of CO_2 storage and ECBM.

To examine and address the issues of CO_2 storage in coals in the new DOE/FE Carbon Sequestration Roadmap, a survey questionnaire was prepared and forwarded to a series of key individuals.

CO_2 STORAGE IN COAL, U.S. FIELD TESTS

Location	Lead Organizations	CO2 Injection	Coal Properties	Experiment Description
San Juan Basin	Advanced Resources International Burlington Resources	370,000 tons of CO_2 over 6 yrs	3,100 ft 100 mDarcy Bituminous HVA 43 ft. thick (avg.)	Recovered one volume of incremental methane per four volumes of CO_2 injected.
Appalachian Basin	CONSOL Energy	26,000 tons of CO_2 over 1 yr	1,400 ft 1-10 mDarcy Bituminous HVB	Test horizontal wells for CO_2 injection into coal.
Mid-Continent Basin	Kansas Geological Survey	Pre-pilot	400-1,100 ft <10 mDarcy Bituminous HVB 2-4 ft. thick	Investigate injection of landfill gas and kiln gas into coal.

CO_2 STORAGE IN COALS, U.S. FIELD TEST (ALLISON UNIT)

The longest ECBM field project is in the Allison Unit of the San Juan Basin, operated by Burlington Resources and evaluated by Advanced Resources International.

Approximately 370,000 tons of CO_2 were injected into the deep (3,000+ feet) Fruitland coal seam between 1995 and 2001.

The project produced 1.6 Bcf of additional coalbed methane, injected 370,000 tons (6.4 Bcf of CO_2) and stored a net 300,000 tons (5.2 Bcf) of CO_2. The 70,000 tons (1.2 Bcf) of produced CO_2 were reinjected.

Notable was the decline in the injectivity of CO_2 from an initial 6 MMcfd (350 tons per day) to approximately 3 MMcfd (175 tons per day), in four injection wells. This was likely due to coal swelling and possibly other injectivity reducing mechanisms. CO_2 injectivity was improving (to 4 MMcfd) during latter years.

Alternative well completion strategies, such as hydraulic stimulation and use of horizontal wells, were not used at the project site.

CO_2 STORAGE IN COALS, OTHER FIELD TESTS

Location	Lead Organizations	Injection Scale	Coal	Experiment Description
Poland, Upper Silesian Basin	RECOPOL	100 tons of CO_2 over several months	3,700 ft < 1 mDarcy Bitumnous HVA 4-11 ft. thick	Initial injection rates (1.1–1.4 tons per day at 210 bar) much lower than expected. Recently fractured the injection well leading to higher injection rates.
Canada, Alberta Fenn-Big Valley	Alberta Research Council	220 tons of CO_2 in 13 slugs; 220 tons flue gas (13% CO_2) over ten days	4,300 ft 2-4 mDarcy Bituminous HVB 10-16 ft thick	Huff and Puff CO_2 injection tests. Realized unexpectedly high CO_2 injectivity (13.6 m^3/D-kPa) possibly due to natural or induced fracturing.
China, Quinshi Basin	China United Coal Bed Methane Company Alberta Research Council	220 tons of CO_2 over 22 days	1,600 ft < 1 mDarcy Anthracite 15-20 ft. thick	Huff and Puff CO_2 injection test. Technology transfer effort between Canada and China.
Japan, Hokkaido Ishikari Coal Field	Kansai Environmental Engineering Center (KANSO) METI	36 tons of CO_2 over 15 days (11/04)	2,900 ft 1.0 mDarcy Bituminous HVA 18 ft. thick	Multi-well test. Injection rate much lower than expected, 2 tons per day. Well being “treated” to improve injectivity. Multi-well test planned for this summer.

CO_2 STORAGE IN COALS, PLANNED FIELD TESTS

Location	Lead Organizations	Injection Scale	Coal	Experiment Description
Canada, Edmonton	Suncor	20,000 tons CO_2 over 1 yr	1,600 ft 10 mDarcy 10-16 ft. thick	1 CO_2 injector and 2 CBM producers. Plan to inject for a year a max rate of 100 tons/day. Project now underway.
U.S., Varied	Phase II Regional Partnerships	5 proposed projects. Propose to inject 100 and 75,000 tons CO_2 . Range of coals depths, permeabilities and geologic settings.		

CO_2 STORAGE IN COALS, OTHER FIELD TESTS

A number of CO_2 "huff and puff" tests have been conducted, and one smaller-scale field test is being implemented by Suncor near Edmonton, Canada.

The U.S. DOE's recently announced Phase II Regional Sequestration Partnerships will include five field tests of CO_2 storage in coals.

Still, the level of private sector interest in CO_2 ECBM is lower than desirable, and the technical knowledge base and field experience with injecting CO_2 into coal seams, as part of ECBM or as stand alone, is limited.

SURVEY POPULATION

The Survey was sent to twelve individuals. Ten completed Survey responses were received, as follows:

1	Sally Benson	LBNL
2	Grant Bromhal	NETL
3	Charlie Byrer	NETL
4	Peter Cook	CO2 CRC
5	John Gale	IEA GHG Programme
6	Bill Gunter	Alberta Research Council
7	Henk Pagnier	TNO, Recopol
8	Jack Pashin	Alabama Geological Survey
9	Scott Reeves	Advanced Resources International
10	Shinji Yamaguchi	Akita University, Japan

Survey Question #1

A. In your opinion, what are the four to five highest priority knowledge gaps or technology barriers that affect the prospects for efficiently storing CO_2 in deep coals? What specific technology challenges are posed by the simultaneous recovery of coal bed methane? If these gaps or barriers are specific to a particular rank of coal or a particular geographic or geologic setting, please identify.

1. **Coal Swelling and Loss of Permeability/Injectivity Due to CO_2 or Other Injectants.**
   - **Cited by majority of respondents**
   - **Special issue for lower permeability coals and lower coal ranks**
   - **Major differences observed between lab results and field experience**
   - **Need to understand effects of confining pressure and presence of water**

2. **Technologies for Overcoming Loss of Permeability/Injectivity.**
   - **Cited by majority of respondents**
   - **Examine applicability of horizontal injection wells**
   - **Feasibility of stimulating injection wells without damaging reservoir caprock**
   - **Understanding changes in injectivity with time (due to release of methane, other effects)**
   - **Need for small scale field tests/field experience**

Survey Question #1 *(Cont'd)*

A. In your opinion, what are the four to five highest priority knowledge gaps or technology barriers that affect the prospects for efficiently storing CO_2 in deep coals? What specific technology challenges are posed by the simultaneous recovery of coal bed methane? If these gaps or barriers are specific to a particular rank of coal or a particular geographic or geologic setting, please identify. (Cont'd)

3. Ability to Find and Characterize Geologically Favorable Settings

- **Limited data on deep coals**
- **Difficulties in establishing permeability from cores**
- **Concerns over coal continuity**
- **Realistic estimates and methodologies for storage capacity**

4. Relationship of ECBM and CO_2 Storage in Coals

- **Leakage of displaced methane**
- **Rapid buildup in pressure when storing CO_2 in coals**
- **Essential linkage between storage and ECBM**

5. Monitoring of CO_2 Flow and Retention

- **Seismic technology**
- **Other methods**

6. Other Cited Topics/Concerns

- **Effect of CO_2 (gas, supercritical, liquid) and oxygen on coal properties and behavior.**
- **Role of coals as "seal" or leakage absorber**
- **Rank, temperature and sorption relationships**
- **Physics of coal swelling/shrinkage and CO_2/CH_4 exchange in models.**

Survey Question #2

B. In your opinion, what are the three to four highest priority economic and environmental barriers to the storage of CO_2 in coals for the joint purposes of greenhouse gas mitigation and enhanced coal bed methane recovery? Please note the comment in Question #1 related to coal rank or setting.

1. Economic Barriers

a.) Need to Drill Large Number of Wells

- **Low injectivity**
- **Need both injection and production wells**
- **Coal continuity and maximum pressure**
- **How much will ECBM revenues reduce costs?**

b.) High Cost of CO_2 Capture from Industrial Sources

- **Need lower cost capture technologies**
- **Competition with natural CO_2**
- **Do we need to separate CO_2 from flue gas?**

c.) Uncertainty and Risks

- **Value of storing CO_2 (credits)**
- **Breakthrough of CO_2 in production wells**
- **Cost/performance of stimulation and horizontal wells**
- **How do we identify favorable/unfavorable areas?**

Survey Question #2 *(Cont'd)*

B. In your opinion, what are the three to four highest priority economic and environmental barriers to the storage of CO_2 in coals for the joint purposes of greenhouse gas mitigation and enhanced coal bed methane recovery? Please note the comment in Question #1 related to coal rank or setting. (Cont'd)

2. Environmental Barriers

a.) Establishing "Permanence" and Avoiding Leakage

- **Migration of CO_2 and methane**
- **Long term storage integrity, particularly near population areas**
- **Loss of pressure due to tectonic, hydrodynamic effects**
- **Is a caprock and a structure essential?**

b.) Interaction With Potable Water and Disposing Produced Water

- **Effects on groundwater**
- **Production of fresh water**
- **Disposal of saline water**
- **Which of the new technologies will be lowest in cost?**

3. Other Barriers

a.) Definition of Unmineable Coals

- **Deep and thin coals**
- **Communication among seams**
- **Future mining depth limits**
- **Could coals play a role as "temporary" CO_2 storage?**

Survey Question #3

C. Please identify the set of research and development activities that would help address the identified barriers in Questions #1 and #2. Please note if the proposed activities are coal rank or setting specific.

1. **Increased Number of Field Pilots**
   - **Single well injectivity tests**
   - **Long term CO_2 storage and breakthrough tests**
   - **Full scale economic demos**
   - **Optimizing injectivity tests**
   - **How many tests are required to remove uncertainty and risk?**

2. **Improved and Validated Predictive Models**
   - **Rigorous modeling of changes in permeability due to CO_2 storage and methane release**
   - **Methodology for calculating storage capacity**
   - **Better understanding of the linkage of CO_2 storage and ECBM**
   - **How rigorously do models need to replicate the exact science?**

Survey Question #3 *(Cont'd)*

C. Please identify the set of research and development activities that would help address the identified barriers in Questions #1 and #2. Please note if the proposed activities are coal rank or setting specific.

3. **Increased Data on Coal Settings and Properties**
   - **Define unminable coals**
   - **Measure coal properties at pressure**
   - **Data base on permeability, particularly for deep coals**
   - **Caprock integrity**

4. **Develop and Test Advanced Monitoring Systems**
   - **Well to well seismic**
   - **Tiltmeters**
   - **Change in conductivity**

5. **Examine Alternative Water Disposal Methods**
   - **Potable water**
   - **Brakish water**

Survey Question #4

D. Is there a clear priority that comes from the identified work areas or a natural sequencing of work? If so, please describe the basis for priority/sequencing and apply it to the identified activities.

1. **Parallel Program of Lab Research and Field Activities.** Concentrate lab activities on geotechnical, sorption and swelling properties. Field projects should use depleted CBM reservoirs with infrastructure in place.
2. **Need for an Integrated Program.** Individual projects conducted by various PI's will not be as cost-effective as an integrated program.
3. **Concentration on CO_2 Monitoring Technology.** No established methods for monitoring the flow and storage of CO_2 currently exist.
4. **Undertake Significant Size Field Test.** Key topics to be addressed are establishing injectivity and realistic storage capacity.

Survey Question #4 *(Cont'd)*

D. Is there a clear priority that comes from the identified work areas or a natural sequencing of work? If so, please describe the basis for priority/sequencing and apply it to the identified activities. (Cont'd)

5. **Emphasize R&D on Basic Coal Reservoir Properties.** Essential for improving predictive models and designing field tests.
6. **Need to Address Numerous Issues:**
   a) Unmineable coals
   b) Favorable settings for ECBM
   c) Water studies and disposal
   d) Alternative well completion and stimulation
7. **Undertake Reasonable Scale Multi-Well Pilot.** Include a strong program of lab verified modeling and monitoring.
8. **Solve Uncertainty Around Coal Swelling.** Conduct work on coal swelling in presence of water and under pressure.
9. **Address Unmineable Coals and Improve Predictive Models.**
10. **Examine CO_2/CH_4 Exchange and Production Enhancement Options.**

SUMMARY

I would be interested in your comments and perceptions on the responses to the Survey Questionnaire!

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