Sequestration Project Fact Sheet List

Project Title	Primary Contractor	Fact Sheet Listing
Optimal Geological Environments for Carbon Dioxide Disposal in Saline Aquifers	University of Texas at Austin (BEG)	S-3
Advancing the Science of CO_2 Sequestration In Deep, Unmineable Coal Seams	Advanced Resources International	S-7
Enhanced Coalbed Methane Production and Sequestration of CO_2 in Unmineable Coal Seams	Consol	S-11
CO_2 Sequestration Potential of Texas Low-Rank Coals	Texas Engineering Experiment Station	S-15
Experimental Evaluation of Chemical Sequestration of CO_2 in Deep Saline Formations (Storage of CO_2 in the Geologic Formations in the Ohio River Valley Region)	Batelle Columbus Laboratories	S-17
Geological Sequestration of CO_2 : GEO-SEQ	LBNL, LLNL, ORNL	S-21
Strategies for Controlling Coal Permeability in CO_2-Enhanced Coalbed Methane Recovery	Oak Ridge National Laboratory	S-23
Feasibility of Large-Scale CO_2 Ocean Sequestration	Monterey Bay Aquarium Research Institute	S-25
CO_2 Sequestration in Basalt Formations	Pacific Northwest National Laboratory (PNNL)	S-27
International Collaboration on CO_2 Sequestration	MIT	S-29
Laboratory Investigations in Support of Carbon Dioxide-Limestone Sequestration in the Ocean	University of Massachusetts	S-33
Enhancing Carbon Sequestration and Reclamation of Degraded Lands with Fossil Fuel Combustion Byproduct	PNNL/ORNL	S-37
Carbon Dioxide Storage in Coal Seams	NETL	S-41
Geologic Sequestration Core Flow Lab	NETL	S-45
Geoscience Technology Development for Zero Emission Power Plants*	LLNL	*
Sorption/Desorption and Swelling/Shrinkage of Coal at In Situ Lithostatic Pressures*	NETL	*
Simulation for Retention of Geologically Sequestered CO_2*	NETL	*
Measurement of Hydrocarbon Evolution from Coal and Petroleum Reservoirs Under Carbon Dioxide Floods	University of North Dakota Energy and Environmental Research Center	*

* Factsheet Under Development

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PROJECT facts

U.S. DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

Carbon Sequestration

4/2008

OPTIMAL GEOLOGICAL ENVIRONMENTS FOR CARBON DIOXIDE STORAGE IN SALINE FORMATIONS

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Background

For carbon dioxide (CO_2) sequestration to be a successful component of the United States emissions reduction strategy, there will have to be a favorable intersection of a number of factors, such as the electricity market, fuel source, power plant design and operation, capture technology, a suitable geologic sequestration site, and a pipeline right-of-way from the plant to the injection site. The concept of CO_2 sequestration in saline water-bearing formations (saline reservoirs), isolated at depths below potable aquifers, became of widespread interest in the early 1990s. It is now in the process of maturing from a general concept to one of the options available to reduce the amount of CO_2 released as a result of fossil fuel combustion at a variety of stationary sources.

Description

The Bureau of Economic Geology (BEG) at the University of Texas at Austin is developing criteria for characterizing optimal conditions and characteristics of saline formations that can be used for long-term storage of CO_2. Phase I of this project included identifying prospective regional locations for CO_2 injection wells and better defining saline-formation conditions suitable for CO_2 disposal and sequestration. During Phase II, injection and seal properties of a selection of representative saline water-bearing formations of on-shore U.S. sites were characterized in a geologic information system (GIS) database.

Recent research and development (R&D) efforts have demonstrated the technical feasibility of the process, defined costs, modeled the evolution of the CO_2 plume in the subsurface, and inventoried the appropriate monitoring technology needed to sequester CO_2 in saline formations. Still, field demonstration is needed to validate these understandings and increase public confidence. Phase III efforts have focused on field testing the R&D findings by injecting small amounts of CO_2 into a deep saline reservoir within the state of Texas, using the best available tools to measure what happened in the subsurface, and matching modeled to observed subsurface plume evolution.

PARTNERS

University of Texas at Austin

BP America

Schlumberger

Austin Texas

Lawrence Berkeley National Laboratory (LBNL)

Lawrence Livermore National Laboratory (LLNL)

Oak Ridge National Laboratory (ORNL)

Core Labs

Paulsson Geophysical

Praxair

Sandia Technologies

PERFORMANCE PERIOD

07/15/1998 to 05/30/2008

COST

Total Project Value
$5,756,553

DOE/Non-DOE Share
$5,756,553 / $0

Primary Project Goal

This project has developed and applied criteria for characterizing saline formations for long-term sequestration of CO_2. The first injection experiment (October 2004) was focused on conducting an early successful injection into a high-permeability, high-volume sandstone. This site was representative of a broad area that is an ultimate target for large-volume sequestration and monitoring, and also for modeling the resulting subsurface plume of CO_2. The second injection and monitoring period (May 2006–2007) further refined the quantification of key rock-fluid properties and tested additional monitoring technologies.

Objectives

- Demonstrate to the public and other stakeholders that CO_2 can be injected into a brine formation without adverse health, safety, or environmental effects.
- Measure subsurface distribution of injected CO_2 using diverse monitoring technologies.
- Test the validity of conceptual, hydrologic, and geochemical models.
- Develop experience necessary for the development of the next generation of larger-scale CO_2 injection experiments.

Benefits

Nonproductive brine-bearing formations, below and hydrologically separated from potable water, have been widely recognized as having high potential for very long-term (geologic time scale) sequestration of greenhouse gases. However, before such formations can be utilized, robust models must be developed to predict the behavior of CO_2 injected into them. Also required are monitoring techniques which can follow the spread of CO_2 in the formation and detect any leaks that might occur. The whole concept of carbon capture and storage (CCS) will benefit from this project through the modeling and monitoring capabilities being developed. This project is the first field-scale test with intense monitoring.

Phases I and II of this project have provided data on basins that have been refined by the Regional Carbon Sequestration Partnerships to extend the national inventory of geologic sinks in the National Carbon Sequestration Database and Geographical Information System (NATCARB). The results of the Frio Brine Pilot test have provided data for the development of the next generation of CO_2 injection tests to be conducted within the Partnerships. Confidence in the correctness of conceptual and numerical models and the effectiveness of monitoring tools tested will encourage the next pilots to investigate more complex factors, such as stratigraphic and structural heterogeneity, and upscaling. The Frio Pilot results provide a model for participants in the Partnerships, as well as international collaborators, to design test programs in various settings.

Accomplishments

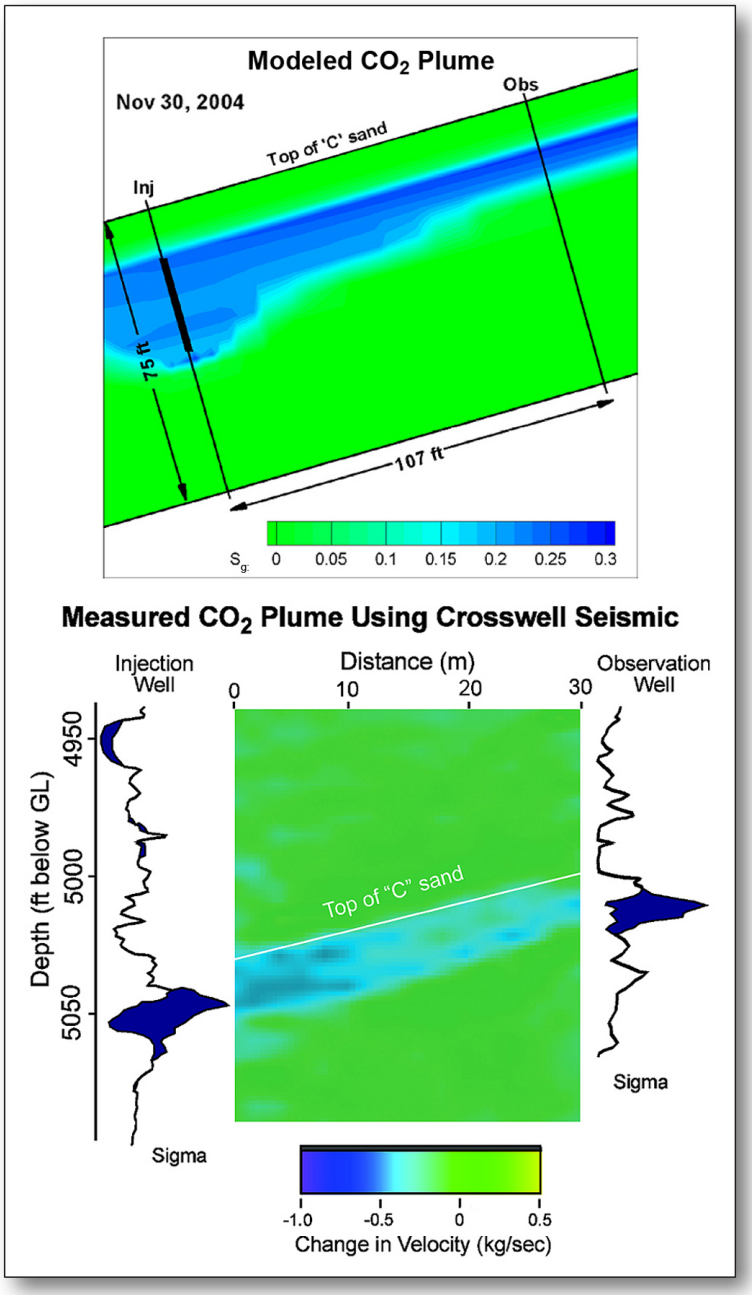
Phase I of the project developed a first set of geologic screening criteria for identifying suitable saline water-bearing formations for CO_2 sequestration. The pilot study confirmed that information is available, either as basin-specific data sets or as products of geologic analogs and play analysis.

Phase II involved a regional inventory of geological properties of saline water-bearing formations targeted for CO2 injection. This effort compiled data at basin scale to describe the injectivity and isolation of 21 diverse and representative saline formations in 19 onshore U.S. basins, and served as a precursor to NATCARB.

The Phase III field test, known as the Frio Brine Pilot Test, involves 20 research institutes and corporate collaborators and is conducting 2 short test injections. The contributors to this project include: four Department of Energy National Laboratories (Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Oak Ridge National Laboratory, National Energy Technology Laboratory); the U.S. Geological Survey (USGS); two international collaborators (Alberta Research Council and the Cooperative Research Centre for Greenhouse Gas Technologies (CO_2 CRC) from Australia; and industry collaborators Texas American Resources, Sandia Technologies, LLC, Praxair, Schlumberger, BP, Paulsson Geophysical, and Core Labs.

From October 4–14, 2004, the Frio Brine Pilot team injected 1,600 tons of CO_2 1,500 meters (m) below the surface into steeply-dipping, high permeability brine-bearing "C" sandstone of the Frio Formation beneath the Gulf Coast of Texas, USA. A dedicated bottom-hole sampler, the U-tube, was developed by LBNL to allow high frequency collection of high quality samples of multiphase fluids supporting a tracer and geochemical program. Analysis completed during the 15 months following the end of injection showed that by using wireline reservoir saturation tool (RST) pulsed-neutron techniques, a high percentage of CO_2 is retained and immobilized by two-phase capillary effects.

A second injection test was initiated on September 25, 2006. The Frio-II test injected 250 tons of CO_2 into the Frio "Blue" sandstone at 1650 m underground, and researchers closely monitored the CO_2 flow for the next 12 months. The low injection rate was selected to simulate processes at the edge of the plume, where attenuated injection pressure has a significant influence of buoyancy on flow processes, as observed in the results. The project used an array of techniques to provide information about CO_2 flow, trapping, and dissolution: wireline saturation logs, cross well seismic, downhole pressure and temperature monitoring, geochemical sampling with U-Tube, and a tracer program. One new tool tested, a tubing-conveyed source and receiver string (continuous active source seismic monitoring—developed by LBNL—was designed to fully integrate seismic measurements with other downhole data. In this application of seismic tomography, the seismic source is fixed downhole, above the packer. Since the seismic source is fixed,



Schematic of Frio-II Continuous Active Source Seismic Monitoring (CASSM)

error from the placement and replacement of equipment using traditional means is minimized. In addition, real-time data is collected every 10 seconds, allowing researchers to know exactly when CO_2 breaks a given ray-path between the source and receiver as it rises in the reservoir.

The first objective was accomplished through outreach, which included site visits by researchers, local citizens, and environmental groups; media interviews; an online log (www.gulfcoastcarbon.org); a technical e-newsletter; and an informal non-technical "neighbor newsletter." Public and environmental concerns were moderate, practical, and proportional to minimal risks taken by the project, and included issues such as traffic and potential risks to water resources. Press coverage was balanced and positive toward research goals. Professional vendors provided safe site operation.

The second objective, which was the measurement and monitoring of the subsurface CO_2 plume, was accomplished using a diverse suite of technologies in both the injection zone and in the shallow near-surface environment. Each monitoring strategy used pre-injection and post-injection measurements.

Wireline logging, pressure and temperature measurement, and geochemical sampling were also conducted during injection. In-zone objectives were to measure changes in CO_2 saturation through time, in cross section, and areally, and to document accompanying changes in pressure, temperature, and brine chemistry during the months following injection. The in-zone measurement strategy was designed to test the effectiveness of selected suites of monitoring tools in measuring these parameters. A feasibility test of near-surface monitoring in this setting measured soil gas fluxes and concentrations, introduced tracers, and shallow aquifer response. High complexity was noted in this high-water-table, warm, perturbed environment. Introduced tracers were used to document no leakage to the surface using Praxair Seeper Trace technology.

The third objective is to test the validity of conceptual hydrologic and geochemical models. Reservoir characterization by BEG to provide inputs to the simulations used existing and newly collected wireline logs, an existing three-dimensional seismic survey, baseline geochemical sampling by USGS and Schlumberger, and core analyses by Core Labs. A drawdown interference test and a dipole tracer test conducted by LBNL researchers provided interwell permeability estimates and confirmed the critical importance of good reservoir characterization for model validation. Using TOUGH2, detailed modeling by LBNL supported all phases of the project and yielded good matches between modeled and observed CO_2 saturation, the test conclusions improved and validate model approaches to prediction of CO_2 movement and permanent storage.

As the Frio experiment analysis and modeling is completed, it supports the fourth objective, which is the development of the next generation of larger-scale CO_2 injection experiments. Extensive presentations and publication have supported this effort.

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Carbon Sequestration

4/2008

THE COAL-SEQ CONSORTIUM: ADVANCING THE SCIENCE OF CARBON DIOXIDE SEQUESTRATION IN DEEP, UNMINEABLE COAL SEAMS

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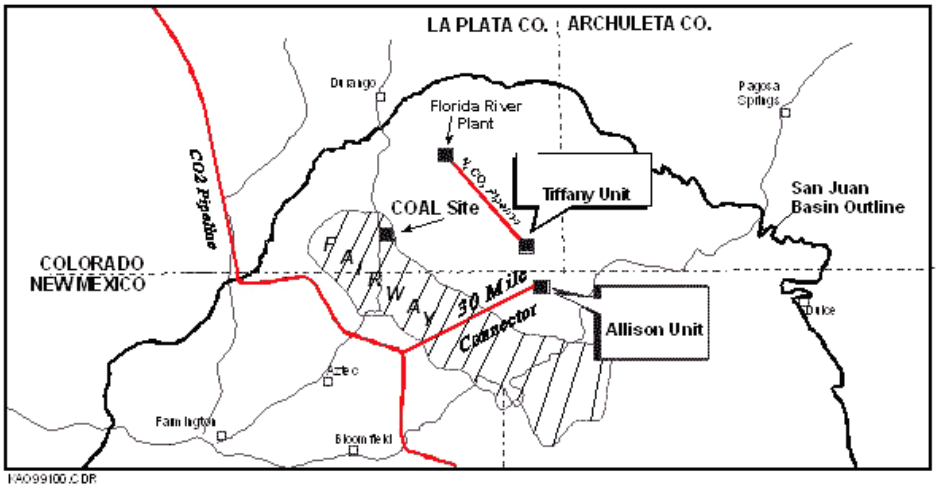
Background

One of the few value-adding approaches to sequestering carbon dioxide (CO_2) is to inject it into deep, unmineable coal seams. The advantage of coal seam sequestration is that CO_2 more readily adsorbs to coal than methane, thus resulting in a greater volume of CO_2 adsorbed. In addition, methane is displaced and can be recovered and sold to help offset costs. This process is known as enhanced coalbed methane recovery, or ECBM.

During Phase I of the Coal-Seq project, Advanced Resources International and its partners teamed with the industry operators of the only long-term, multi-well ECBM projects that have been performed in the world (the Allison and Tiffany Units in the San Juan basin) to evaluate the viability of storing CO_2 in deep, unmineable coal seams. The knowledge gained from studying those projects was coupled with laboratory research to verify and validate gas storage mechanisms in coal seams, and a screening model was developed in order to assess CO_2 sequestration potential in other promising coal basins of the United States.



PARTNERS

Advanced Resources International (performer)

Oklahoma State University (performer)

Southern Illinois University (performer)

Electrochemical Systems (performer)

Higgs-Palmer Technologies, LLC (performer)

BP (sponsor)

CO_2-CRC (sponsor)

Illinois Clean Coal Institute (sponsor)

Japan Coal Energy Center (sponsor)

Shell International Exploration & Production (sponsor)

Schlumberger Limited (sponsor)

Repsol YPF (sponsor)

ConocoPhillips (sponsor)

The potential CO_2 sequestration capacity of deep, unmineable coal seams was also assessed (~90 billion tons), as was the concomitant ECBM recovery (~150 trillion cubic feet [Tcf]). Importantly, the project identified numerous important sub-surface reservoir mechanisms that were not clearly understood, and that have an important impact on industry's ability to predict the performance of integrated ECBM/ sequestration projects. Specifically, it was discovered that multi-component sorption, diffusion, and fluid behavior in coal seams was much more complex than previously thought. In response, the Coal-Seq Consortium was formed with the objective of establishing a better predictive capability of such projects to promote investment in them.

Primary Project Goal

The primary goal of the Coal-Seq Consortium is to develop a technical understanding of the CO_2-sequestration / ECBM process by performing experimental and theoretical research and development on coal reservoir behavior, and validating the findings against the results from the field projects studied in Phase I.

Objectives

Below are the specific objectives of the Coal-Seq Consortium:

- Develop new, advanced predictive models for multi-component sorption, bi-directional diffusion, and CO_2-mixture PVT (pressure/volume/temperature) behavior.
- Couple with permeability model, incorporate into dynamic flow simulator, and validate against laboratory flow experiments and field data.
- Perform sensitivity analysis to better understand best geologic/reservoir environments and development strategies.
- Provide a knowledge base on global activities regarding CO_2 sequestration in deep, unmineable coals to consortium membership.

Accomplishments

- Initial field studies have demonstrated that ECBM via carbon dioxide-nitrogen (CO_2/N_2) injection and CO_2 sequestration in coal seams is technically feasible.
- Developed an understanding of the technical and economic performance of gas injection into coal via detailed studies of two multi-well, multi-year ECBM field pilots in the San Juan basin – the Allison Unit CO_2-ECBM pilot and the Tiffany N_2-ECBM pilot.

- Analysis of field and laboratory data showed the tendency for coal to "swell" when it comes into contact with CO_2, reducing injectivity.
- Developed new, more accurate multi-component gas sorption and diffusion models.
- Uncovered new evidence of coal-weakening behavior with CO_2 injection.
- Performed comparative analysis of coal permeability models.
- Performed sensitivity studies to identify best coal reservoir environments for CO_2-sequestration/ECBM.
- Began development of an internet-accessible knowledge base.
- Developed a model for screening potential CO_2-ECBM/sequestration projects.
- Assessed CO_2 sequestration and concomitant ECBM recovery potential of coal basins in the United States.
- Created a field "best practices" manual based on the experience gained from the ECBM pilots.
- Evaluated the applicability of commonly used (i.e., Langmuir) isotherm models when applied to multi-component gaseous systems.

The detailed results from the work sponsored by the COAL-SEQ consortium are proprietary. Selected accomplishments from this phase included:

- A significantly expanded CBM adsorption database, which includes valuable data for pure-gas adsorption on six wet coal matrices and activated carbon.
- An improved model and the attendant computational algorithms to estimate sorption capacity for coalbed gases based solely on readily accessible coal characterization.
- Development of a new multi-component counter diffusion model (yet to be tested).
- A theory-based adsorption modeling capability, including further development of the simplified local–density framework for describing CBM adsorption equilibrium of pure fluids and mixtures.

Plans for future activities include the following:

- Completion of equation-of-state work undertaken in the current project, and extension to full methane-carbon dioxide-nitrogen ternary gaseous systems with moisture.
- Selected laboratory experiments to understand the conditions and nature of coal weakening and/or mechanical failure, and/or plasticization, with CO_2 injection.
- Development of a robust algorithm to account rigorously for water as a separate adsorbed component.
- Incorporation of each of these theoretical advancements into a reservoir simulator such that predictive modeling can be performed with the benefit of the most advanced knowledge of reservoir process.

The final report of the project effort will be completed in the fall of 2008.

PERFORMANCE PERIOD

9/30/2000 to 9/30/2008

COST

Total Project Value

$7,395,575

DOE/Non-DOE Share

$ 2,636,323 / $4,609,252

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Benefits

The technical knowledge base gained from this project effort will benefit the energy and environmental industries by providing verifiable and valid CO_2 storage mechanisms in coal reservoirs, as well as a new source of clean natural gas supply. The ability to take advantage of these opportunities will be facilitated by the development of a screening model to assess CO_2 sequestration and ECBM potential.

PROJECT facts

U.S. DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

Carbon Sequestration

4/2008

ENHANCED COALBED METHANE PRODUCTION WHILE SEQUESTRATING CO_2 IN UNMINEABLE COAL SEAMS

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Background

CONSOL Energy Inc. is demonstrating a novel drilling and production process that reduces potential methane emissions from coal mining, produces usable methane (natural gas), and creates a sequestration sink for carbon dioxide (CO_2) in unmineable coal seams. The project team anticipates the test will provide the needed data to formulate effective CO_2 injection procedures, evaluate the CO_2 adsorption capacity of an Appalachian coal seam, and assess the economic feasibility of this potential greenhouse gas (GHG) mitigation approach.

Description

CONSOL's project employs horizontal drilling to drain coalbed methane (CBM) from a mineable coal seam and an underlying unmineable coal seam. Upon drainage of 50–60 percent of the coalbed methane, some of the wells will be used for CO_2 injection to sequester the CO_2 in the unmineable seam, while stimulating additional methane production. The technique starts with a vertical well drilled from the surface followed by a guided borehole that extends up to 3,000 feet horizontally in the coal seam, allowing for production over a large area from relatively few surface locations.

The project involves development of a 200-acre area involving two coal seams. The lower, unmineable seam will be degassed and eventually injected with CO_2. The upper, mineable seam will be degassed to produce coalbed methane, thus avoiding methane emissions when the seam is mined. The upper, mineable seam will be isolated from the lower, unmineable seam to prevent CO_2 migration from the unmineable seam into the mineable seam.

PARTNERS

CONSOL Energy, Inc.

PERFORMANCE PERIOD

9/21/2001 to 12/31/2008

COST

Total Project Value
$13,278,483

DOE/Non-DOE Share
$8,964,176 / $4,314,307

Primary Project Goal

This project is intended to evaluate the effectiveness and economics of carbon sequestration in an unmineable coal seam. Of particular interest will be the enhancement of coal seam methane recovery by the injection of CO_2 and the issues surrounding the injection and monitoring of CO_2 left in the coal seam for a several year period. The project is located in Marshall County, West Virginia.

Objectives

Project objectives are to recover CBM from a series of wells extending up to 3,000 feet horizontally in two stacked coal seams, while measuring the impact of carbon storage in the unmineable coal seam. Horizontal drilling techniques, which disturb less land surface, were used to recover CBM from both seams. After partial CBM drainage, the lower seam will become a sink for CO_2 sequestration.

- Sequester CO_2 in a degassed, unmineable coal seam.
- Demonstrate the economic benefit of this concept by producing coalbed methane (natural gas) to reduce the cost of CO_2 sequestration.
- Demonstrate that CO_2 remains sequestered in the coal seam in which it was injected.
- Demonstrate the application of coal seam methane production technology using horizontal drilling to degasify an unmineable coal seam.

Benefits

This project will provide a documented case study of the effectiveness and economics of carbon dioxide sequestration in an unmineable coal seam. The results can be used by mining and power generation companies that wish to sequester CO_2 in unmineable coal seams and by regulatory agencies and the public to aid in policy and permitting decisions.

Accomplishments

- Vertical wells have been drilled and completed at three sites, designated south, central, and north, with the mineable seam being the Pittsburgh seam, and the unmineable seam the Upper Freeport seam.
- South Well Site: At the south well site, the horizontal drilling of both the Pittsburgh seam and Upper Freeport seam is complete. The Pittsburgh seam's horizontal legs were 3,000 ft. and the upper Freeport seam horizontal legs were 2,500 and 1,500 ft., shorter than planned due to thinning of the coal seam.
- Central Well Site: At the central well site, two wells each with two horizontal legs were drilled in the Upper Freeport seam and completed at 1,000 ft. each, as planned.

- North Well Site: Two north site Pittsburgh seam wells were completed at 3,000 ft. each, as planned, and one north site Upper Freeport seam well was completed at 2,200 ft., shorter than planned due to thinning of the coal seam.
- An amine plant was installed at the south well site. The amine plant removes CO_2 from the CBM gas and also dries the CBM gas to pipeline quality. Methane-gathering piping was installed from the north, center, and south well sites to the amine plant.
- NETL onsite researchers, in collaboration with the Zero Emission Research and Technology team and West Virginia University, conducted the essential computational modeling and monitoring for pre-test injection simulations. Simulations enable researchers to determine reservoir properties, CO_2 injection and CBM production rates, and structural responses of the reservoir. Simulations also dictate what monitoring networks are needed to predict both the migration of CO_2 within the coal seam and the recovery of methane from the coal seam.
- Two observation wells were drilled, and core samples were collected for laboratory analysis. The core samples help determine coal seam properties that can be used in simulations of CO_2 injection and CBM production.
- The monitoring-and-simulation procedure is an iterative process; information from the monitors will be fed back into the simulators to help update predictions. This cycle, which could last up to a year, will provide better understanding in a short period of time of what is required for the injection process. Data, such as the amount, rate, and pressure of the injected CO_2, will be collected. Surface tilt meters will also be used in a recently implemented process to help measure reservoir deflection and track plume movement.

Planned Activities

- The CO_2 injection system has been installed and will be operational once a UIC permit is received. Bulk liquid CO_2 will be pumped up to injection pressure, then vaporized. Gaseous CO_2 will be injected in the center wells. CO_2 will be metered as it is injected into the unmineable seam through both wells, while CBM recovery will continue at the peripheral production wells. The CO_2 injection rate will be closely monitored and adjusted to maintain a pressure balance in the target coal. CO_2 is projected to permeate through the coal while displacing CBM and adsorbing onto the coal.
- A pre- and post-injection monitoring program will be conducted on the effectiveness of the CO_2 sequestration. Issues to be evaluated include integrity of the target reservoir over time, confinement of CO_2 within the reservoir, and pressure changes in the coal and surrounding geologic strata. The monitoring program is to continue for two years after injection of CO_2.

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Carbon Sequestration

04/2008

CO_2 Sequestration Potential of Texas Low-Rank Coals

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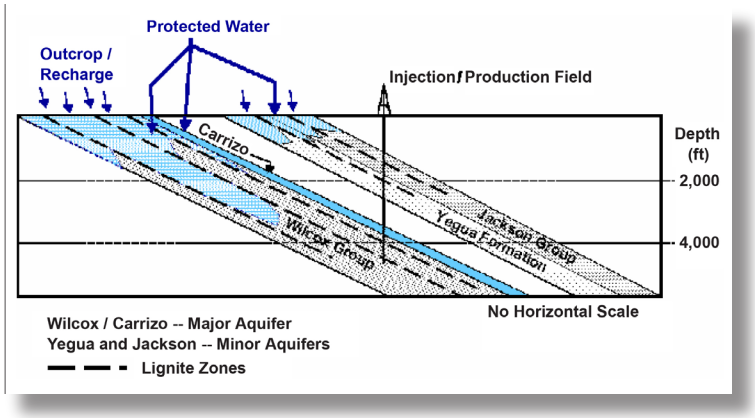
Background

Fossil fuel combustion is the primary source of emissions of carbon dioxide (CO_2), a major greenhouse gas. Sequestration of CO_2 by injecting it into geologic formations, such as coal seams, may offer a viable method for reducing atmospheric CO_2 emissions. Injection into coal seams has the potential added benefit of enhanced coalbed methane recovery. The potential for CO_2 sequestration in low-rank coals, while as yet undetermined, is believed to differ significantly from that for bituminous coals. To evaluate the feasibility and the environmental, technical, and economic impacts of CO_2 sequestration in Texas low-rank coal beds, the Texas Engineering Experimental Station is conducting a four-year study to characterize coals located near major electrical power plants. Potential CO_2 sequestration sites have been identified in coals near three Texas power plants. These power plants emit over 30 million metric tons of CO_2 annually, accounting for nearly 15 percent of Texas' point-source emissions.

It has been widely reported that coals will adsorb approximately twice as much CO_2 as methane, but tests of a limited number of samples from the northern Great Plains and Texas indicate that low-rank coals may adsorb 6-18 times as much CO_2 as methane. CO_2 injection can improve methane recovery and help maintain reservoir pressure, thus offsetting operating costs by reducing the amount of gas compression required.

Primary Project Goal

The primary goal of this project is to evaluate the feasibility and environmental and economic impacts of sequestration of CO_2 in Texas low-rank coal seams.



Schematic presentation of multizone sequestration/production potential at some sites.

PARTNERS

Texas Engineering Experiment Station

Anadarko Petroleum Corporation

PERFORMANCE PERIOD

09/01/2002 to 08/31/2006

COST

Total Project Value
$450,000

DOE/Non-DOE Share
$360,000 / $90,000

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CUSTOMER SERVICE

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WEBSITE

www.netl.doe.gov

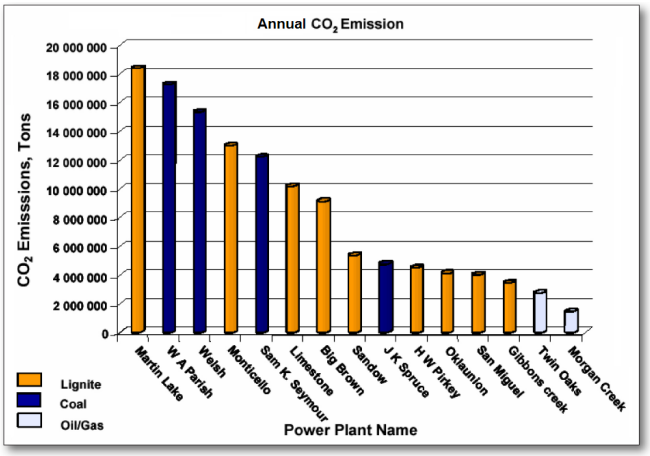
Objectives

Specific project objectives are to:

- Determine the technical and economic feasibility and volume of CO_2 that could be sequestrated in Texas coal seams.
- Determine locations and quantities of anthropogenic CO_2 sources near possible coal injection sites.
- Determine the potential for enhanced coalbed methane recovery as an added benefit of sequestration.

Benefits

Texas is one of the largest emitters of CO_2 in the United States. However, Texas also has huge reserves of low-rank coal, and much of this coal is in deep seams in close proximity to large power plants. Thus, there is great potential for sequestering CO_2 in these coal seams while simultaneously producing large volumes of coalbed methane to help offset sequestration costs. Such projects could make a significant contribution towards meeting the goal of reducing greenhouse gas intensity (pounds of CO_2 emitted per dollar of Gross Domestic Product) by 18 percent by 2012.



Amount of CO_2 emitted and fuel type by power plant, 15 largest Texas CO_2 emitters.

Accomplishments

Potential sites for geologic sequestration of CO_2 with possibilities for enhanced recovery of coalbed methane near three of Texas' largest power plants have been identified. In cooperation with Anadarko Petroleum, core samples were obtained and analyzed to determine gas content and sorption properties, and permeability tests were conducted in Wilcox coals in the vicinity of the Sam K. Seymour power plant in East-Central Texas. Probabilistic reservoir modeling studies of injection of gas compositions ranging from 100 percent CO_2 to flue gas (87 percent N2-13 percent CO_2) indicate that methane resources and CO_2 sequestration potential in East-Central Texas low-rank coals are significant, with potential produced methane volumes of 0.3 to 1.3 billion cubic feet (Bcf) and potential CO_2 sequestration volumes of 0.3 to 3.0 Bcf per 80-acre 5-spot pattern. Economic modeling studies indicate that CO_2 sequestration and enhanced coalbed methane production are marginally economic to uneconomic at current U.S. conditions (gas price of $7 to $8 per million standard cubic foot (Mscf) and CO_2 sequestration credits of $0.07 per Mscf), and that moderately higher gas prices and/or CO_2 sequestration credits are required for economic projects.

PROJECT facts

U.S. DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

Carbon Sequestration

4/2008

STORAGE OF CO_2 IN GEOLOGIC FORMATIONS IN THE OHIO RIVER VALLEY REGION

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Background

The storage of carbon dioxide (CO_2) in a dense, supercritical phase in deep saline sandstone formations is deemed to be a promising long-term option for safe sequestration. Deep saline formations are among the largest and most widely available potential reservoirs for long-term storage. Battelle researchers, supported by the U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL), proposed to explore the potential of using deep geologic formations as a means of sequestering CO_2. This phased project, with competitive down-selection during each phase, was funded as part of the "Global Climate Change—Novel Concepts for Management of Greenhouse Gases (GHG)" Program.

AEP's Mountaineer Power Plant in New Haven, West Virginia

The selection of this project for continuation to Phase III in 2002 underscored the progression of DOE's geologic sequestration program from computer and laboratory assessments toward pilot-scale testing and verification. Phase III is focused on a site characterization (surface and subsurface) for possible injection of CO_2 into a suitable formation. In this project, the research team has conducted a field study to determine whether the deep rock layers in the Ohio River Valley are suitable for storing CO_2.

PARTNERS

American Electric Power (AEP)

British Petroleum (BP)

Ohio Coal Development Office (OCDO)

Ohio Geological Survey

Pacific Northwest National Laboratory (PNNL)

Schlumberger

West Virginia Geologic & Economic Survey

West Virginia University

PERFORMANCE PERIOD

4/28/2005 to 5/31/2008

COST

Total Project Value
$4,172,441

DOE/Non-DOE Share
$3,151,441 / $1,021,000

Description

The objectives of the project are to conduct seismic, drilling, logging, and coring analyses so that the following can be determined: 1) the potential for long-term sequestration of CO_2 in a deep, regional sandstone saline formation and 2) the integrity of overlying caprock, with regard to its effectiveness to prevent CO_2 from escaping. The tested media was obtained from multiple sandstone formations and the overlying impermeable caprock. The Mt. Simon Sandstone and the overlying confining formations were the original target formation, but after coring and logging through this zone it was determined that the Mt. Simon site is unsuitable for storing CO_2, because it is thin at the spot for potential injection. However, several other potential sandstone formations noted in the geophysical well logs were found to be overlain by extensive low-permeability confining layers that prevent the upward movement of injected fluids.

To date, project efforts show that the deep rock layers in the Ohio River Valley are suitable for storing CO_2. The effort focused on addressing future CO_2 emissions from the many coal-based electricity power plants in West Virginia and Ohio. Results indicate that storing CO_2 deep underground in the Ohio River Valley may be a safe, practical, and effective way to reduce large sources of GHGs in the United States.

Primary Project Goal

The project involved site assessment to develop the baseline information necessary to make decisions about a potential CO_2 geologic storage test and verification experiment at the site. This project is focused in the Ohio River Valley, which is home to the largest concentration of fossil-fuel-fired electricity generation in the nation. Additionally, the potential for long-term sequestration of CO_2 in deep, regional sandstone formations and the integrity of overlying caprock is being evaluated for future sequestration projects. No CO_2 injection is planned during this phase; however, the findings of this work have been used by the host site to develop plans for future deployment. The project goals have been met through the regional geologic study: seismic survey of the area; drilling, coring, logging, and testing a deep well through the entire sedimentary column at the power plant property; reservoir modeling and risk assessment; stakeholder outreach; and CO_2 capture.

Objectives

- Thoroughly assess the surface and subsurface environment in the Ohio River Valley to ascertain a viable field test site.
- Obtain all permits from agencies (Federal and state) to drill and core an exploratory deep well at the project site.
- Conduct a two-dimensional (2-D) seismic survey to delineate subsurface geologic structures.
- Drill an exploratory deep (~9,200 foot) well to collect scientific data to assess the potential for conducting a CO_2 storage test at the site.

- Design, coordinate, and conduct field tests to comprehensively characterize the underlying reservoirs, caprocks, and overlying layers, thereby developing a thorough understanding of the geology, hydrogeology, and geochemistry at the site.
- Prepare the necessary permits and regulatory documents to allow use of the deep well to inject CO_2 captured from a nearby coal-fired power plant.
- Develop and apply a comprehensive risk analysis and stakeholder involvement process for the capture, transport, injection, and long-term storage of CO_2 at the field demonstration site.
- Develop a comprehensive monitoring, mitigation, and verification (MMV) plan to ensure the safe, long-term storage of CO_2 in deep geologic formations.

Accomplishments

- Regional geologic data, reservoir and geochemical simulations, geochemical experiments, and seismic aspects reports with specific focus on Ohio River Valley Region were all assessed.
- A detailed report on engineering and economic aspects for CO_2 capture and storage was written.
- Laboratory geochemical experiments on interactions between CO_2, rocks, and brine were evaluated.
- Regional-scale assessments in the Midwest that showed a large potential storage capacity in sedimentary basins with proximity to CO_2 sources were accomplished. However, site-specific tests and characterization are needed to determine injection potential at individual locations.
- A geologic framework of the region was constructed from existing wells in a 20-mile radius of the power plant.
- A 9,200-foot exploratory well was drilled through the underlying formations to ascertain the potential for storage potential for CO_2.
- A seismic survey of the surrounding area on both sides of the Ohio River was conducted to evaluate the integrity of underlying formations and any existing fracture/fault systems.
- A pipeline system (slip stream) was installed from the main stack at the power plant to the well head location for future testing of CO_2 injection into targeted deep formations.
- A project Site Characterization Report was completed.
- A topical report on risk assessment and modeling, titled, "The Ohio River Valley CO_2 Storage Project—Numerical Simulation and Risk Assessment Report" was completed.
- A topical report discussing potential capture technologies, titled, "The Ohio River Valley CO_2 Storage Project—Capture and Feasibility Report" was completed.

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Benefits

The project has met all of its technical objectives and based on the findings, the host company is moving forward with the next steps at the Mountaineer Power Plant site. On March 15, 2007, AEP announced an aggressive, multi-dimensional initiative to develop and deploy carbon capture and storage (CCS) technologies at selected AEP plants in collaboration with several companies, including Battelle. The first step in this initiative involves integrating CO_2 capture using Alstom's Chilled Ammonia Process and geologic storage assessment effort at the Mountaineer Power Plant. The next step will include implementation of an injection and monitoring program with more than 100,000 tonnes of CO_2 to be supplied annually for several years. The test at the Mountaineer Plant will be followed by a larger-scale retrofit at a plant in Oklahoma. This progression exemplifies the success of the Mountaineer project and related research. Evaluating the feasibility of CO_2 storage will allow the energy industry to prove the viability of an evolving U.S. technology that will allow fossil-fuel fired power plants to continue operating well into the future. It will be especially beneficial to states that heavily depend on coal for electricity generation, such as West Virginia, Ohio, and many of the large, industrial Midwest states.

PROJECT facts

U.S. DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

Carbon Sequestration

04/2008

GEOLOGICAL SEQUESTRATION OF CO_2: THE GEO-SEQ PROJECT

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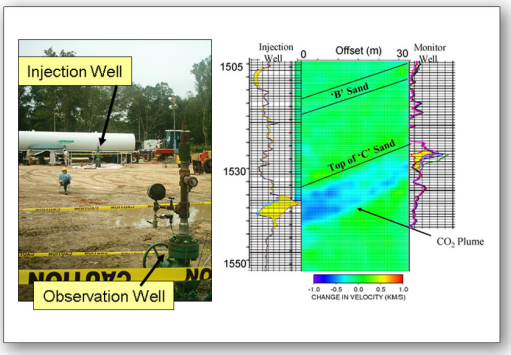
Background

Growing concern over the potential adverse effects of carbon dioxide (CO_2) buildup in the atmosphere leading to global climate change may require reductions in carbon emissions from industrial, transportation, and other sources. One promising option is the capture of CO_2 from large point sources and subsequent sequestration in geologic formations. For this approach to achieve wide acceptance, t assurances that safe, permanent, and verifiable CO_2 geologic storage is attained during sequestration operations must be made. Project results are made available to potential CO_2 storage operators and other interested stakeholders.

The primary performing organizations of the GEO-SEQ project team are Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, and Oak Ridge National Laboratory. The team participates in three world-class CO_2 storage projects that are endorsed by the Carbon Sequestration Leadership Forum, to conduct studies in geologic environments that span a wide range of formation types relevant to geological storage in the United States. Project expertise and resources are leveraged with investments made by the collaborators conducting the storage projects that include Frio Brine Formation Pilot Tests, South Liberty Field, Texas; Otway Basin Project, Australia; and In Salah Gas Field, Algeria Commercial-Scale CO_2 Storage Project. Technologies developed and tested will be applied to other geologic storage operations.

GEO-SEQ's three primary performing organizations contribute expertise and perform tasks in areas that include, but are not limited to, the following:

- Downhole fluid and gas sampling of reservoir using the novel U-tube sampling system developed in the project
- Design and deployment of geophysical monitoring techniques using active and passive seismic methods



Frio brine pilot test site (l) and crosshole seismic

Otway Naylor-1 monitoring well completed (top) with seismic (l), geochemical (r), and other reservoir monitoring instrumentation.

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PARTNERS

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Lawrence Livermore National Laboratory (LLNL)

Oak Ridge National Laboratory (ORNL)

Texas Bureau of Economic Geology-University of Texas at Austin

Stanford University

CO2CRC

BP

Chevron Texaco

PROJECT DURATION

05/01/2000 to 09/30/2008

COST

Total Project Value
$25,140,000

DOE/Non-DOE Share
$13,340,000 / $11,800,000

CUSTOMER SERVICE

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www.netl.doe.gov

- Design, fabrication, and deployment of innovative downhole instrumentation based on temperature, pressure, and other properties for high-resolution monitoring
- Isotopic, tracer, and reservoir geochemistry techniques to establish pre-injection baseline conditions and to monitor spatial/temporal changes in the reservoir with CO_2 injection
- Reactive chemical transport experiments and simulations to predict rock-fluid-cement-CO_2 interactions to address issues such as permanence of storage and integrity of caprock and engineered barriers

Primary Project Goal

The overall goals of the GEO-SEQ project are to gain knowledge of geologic CO_2 storage processes and mechanisms, monitor CO_2 injection operations, and to simulate reservoir conditions to support storage operations. Project results are made available to potential CO_2 storage operators and other interested stakeholders. The project has two primary objectives: (1) to develop ways to improve predictions of injectivity, capacity, and integrity of saline formations and depleted hydrocarbon reservoirs and (2) to develop and test innovative field-based methods for monitoring CO_2. Field demonstrations provide opportunities to develop and test methodologies in situ, and laboratory experiments and modeling are used to support field predictions and observations.

Objectives

- To provide an optimized set of monitoring technologies ready for full-scale field demonstration in oil, gas, and brine formations
- To improve reservoir simulation models for predicting the performance of CO_2 sequestration in oil, gas, and brine formations
- To improve the methodology and information base for assessing the sequestration capacity, injectivity, and integrity of oil, gas, and brine formations
- To conduct an outreach program to stakeholders

Benefits

Early opportunities to participate in pilot CO_2 injection demonstrations and large-scale storage operations provide field data to assure safe and permanent geologic storage of CO_2 that is verifiable. Innovative monitoring technologies, simulating and predicting reservoir storage conditions, and refining knowledge of reservoir capacity, injectivity, and integrity will lead to confidence in and wide public acceptance of geosequestration. Other benefits of the project will be improvement in the performance and economics of future commercial geologic storage operations that will lead to also decreasing geosequestration risk.

Accomplishments

- Issued a GEO-SEQ Best Practices Manual for Geologic Carbon Dioxide Sequestration: Site Evaluation to Implementation.
- Designed, acquired, and analyzed seismic field data for the Frio brine pilot tests to monitor injected CO_2 plume.
- Designed, acquired, and analyzed geochemical field data for the Frio brine pilot tests to monitor injected CO_2 plume and establish performance of sequestration operations.
- Provided reactive transport modeling support for the Frio brine pilot tests.
- Completed design of a multi-level U-tube geochemical sampler and seismic monitoring system for use at the Naylor-1 monitoring well at the Otway Basin Project.
- Completed Otway project Naylor-1 monitoring well installation that incorporated seismic detectors, U-tube geochemical samplers, and pressure/temperature sensors. Acquired baseline pre-injection data.

PROJECT facts

U.S. Department of Energy
Office of Fossil Energy
National Energy Technology Laboratory

Carbon Sequestration

04/2008

Strategies for Controlling Coal Permeability in CO_2-Enhanced Coalbed Methane Recovery

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Background

Rising levels of atmospheric carbon dioxide (CO_2), caused primarily by combustion of fossil fuels for power generation and transportation, are considered to be leading contributors to global warming. Geologic sequestration offers an option that will keep a large quantity of CO_2 out of the Earth's atmosphere for hundreds to thousands of years, thus permitting continued use of high-carbon fossil fuels to generate electrical power, while ensuring that CO_2 releases to the atmosphere are reduced.

Previous studies to determine the feasibility of geologic CO_2 sequestration have focused on oil and gas fields and deep brine formations. However, four characteristics of deep unmineable coalbeds make them extremely attractive for wide-scale CO_2 sequestration:

(1) Unmineable coal seams are widely distributed across the United States.

(2) When injected into a coalbed, CO_2 efficiently displaces adsorbed methane (CH_4). Therefore, CO_2 sequestration and coalbed methane (CBM) production are synergistic technologies, with the extra natural gas produced offsetting some of the costs of CO_2 injection.

(3) After injection, CO_2 remains tightly bound to coal surfaces; therefore, there is little risk that, over time, it will leak to overlying strata or to the surface.

(4) Many unmineable coal seams are located near coal-fired power plants, which are large CO_2 point sources. Thus, minimal pipeline transport is required to deliver CO_2 to a suitable injection site.

CBM recovery, accomplished principally by pumping formation water out of coalbeds, is a mature technology. In contrast, CO_2-enhanced CBM (CO_2-ECBM) recovery is a recent concept that has been demonstrated at only a few sites. Therefore, vigorous fundamental and applied research programs are needed to fill major knowledge gaps.

At full fruition, CO_2-ECBM could become a leading technology for combined CO_2 sequestration and enhanced methane recovery. However, the effects of CO_2 injection rate, formation temperature, total gas pressure, and gas composition on coal swelling and shrinkage, and sorption/desorption of gases on coal surfaces, must be known quantitatively for reliable numerical modeling of CO_2-ECBM production. The impacts of these effects cannot be predicted accurately by current methods of reservoir modeling and simulation.

Description

This project evaluated factors affecting coal permeability when CO_2 is injected into a subsurface coalbed. The major permeability-affecting parameters are initial coal porosity and permeability; formation temperature; CO_2 injection rate; time-dependent local gas composition, including moisture content; and characteristics of the organic and inorganic surfaces of the coal into which mixed CO_2-CH_4-H_2O gas penetrates. Results of CO_2 influx will include sorption/ desorption of gas species, coal swelling and shrinkage, migration of CH4 toward production wells

PARTNERS

Oak Ridge National Laboratory (ORNL)

PERIOD OF PERFORMANCE

03/15/2002 to 03/31/2008

COST

Total Project Value

$1,350,000

DOE/Non-DOE Share

$1,350,000 / $0

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and other regions of lower gas pressure, and drying of the coal near the point of CO_2 injection. These effects have time varying, interacting impacts on coal permeability. Therefore, sorting out the individual and collective effects of factors affecting coal permeability during CO_2-ECBM operations is essential for reliable prediction and full optimization of CO_2 sequestration in, and enhanced methane recovery from, subsurface coalbeds.

Absorption kinetic behavior of pure and mixed gases – CO_2, CH_4, a CO_2-CH_4 mixture (~50 mole percent CO_2), and helium (He) – was conducted on Mary Ruth coal zone samples from the Black Warrior Basin. Experiments were conducted using three crushed coal fractions (45-150 µm, 1-2 mm, and 5-10 mm) at 40 and 35 °C over a pressure range of 1.4 -6.9 MPa (200-1500 psi) to simulate Black Warrior Basin coalbed methane reservoir conditions. Experiments were conducted in a custom designed large-volume, high-velocity air bath utilizing infrared lamps to heat the air circulated over the pressure components.

Primary Project Goal

The primary goal is to acquire the critically important technical information needed to assess CO_2 sequestration in deep unmineable coalbeds.

Objectives

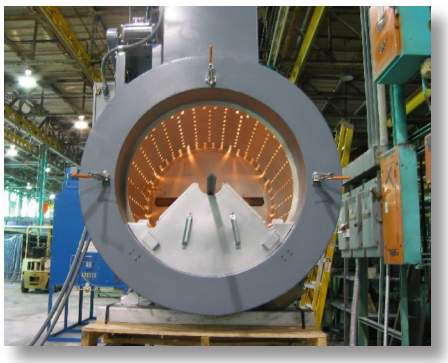
- Acquire and characterize sections of coal core obtained from the Black Warrior Basin in west-central Alabama.
- Complete a set of sorption/desorption experiments on Black Warrior Basin powdered coal samples.
- Conduct gas permeability experiments on uncrushed Black Warrior Basin coal samples to determine the effects of: (1) the rate of CO_2 injection; (2) adsorption of CO_2 onto, and desorption of CH_4 and H_2O from, coal surfaces; (3) coal swelling and shrinkage due to gas adsorption and desorption; and (4) drying of moist coal near the site of CO_2 injection.

Benefits

One very promising technique for sequestering CO_2 from fossil fuel-fired power plants is CO_2-ECBM production. This project will develop much of the needed data on the behavior of coalbeds during and after CO_2 injection required to model CO_2-ECBM. These modeling efforts, along with demonstration programs, will establish the CO_2-ECBM feasibility and the amount of natural gas that can be produced from such projects. Coalbed CO_2 sequestration will help to enhance new field production and extend production in existing fields.

Accomplishments

Experimental analyses observations have positive implications for CO_2-ECBM and CO_2 sequestration: (1) CO_2 absorption on both dry and saturated coal is more rapid than CH_4 absorption; (2) water saturation decreases CO_2 and CH_4 absorption rates on coal surfaces, but appears to have minimal effects on the final magnitude of CO_2 and CH_4 absorption if the coal has no previous CO_2 exposure; (3) adsorbed CO_2 retention on coal surfaces is significant even with extreme pressure cycling; and (4) adsorption is much faster on the smallest size fraction (45-150 µm) than the other two larger fractions. Experimental results with moderately course coal particles (5-10 mm) having dimensions of the same order as coalbed cleat spacing, indicate relatively rapid CO_2 absorption can be expected at 35 °C and 375-490 psi for dry and wet pure CO_2 and a (1:1) CO_2-CH_4 mixture.



End-view of a 30-inch I.D., infrared forced-air convection oven custom designed and constructed for heating powdered and solid coal samples to temperatures attained in deep unmineable coalbeds.

Project314.indd

PROJECT facts

U.S. DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

Carbon Sequestration

04/2008

FEASIBILITY OF LARGE-SCALE CO_2 OCEAN SEQUESTRATION

Background

The increase of carbon dioxide (CO_2) and other greenhouse gas emissions, due in large part to the burning of fossil fuels for energy consumption, has spawned debate over global climate change and prompted the emergence of various remediation strategies. The option of ocean sequestration involves capturing and separating CO_2 from the flue gas of fossil fuel-burning power plants and then converting it into a liquid state that is then transported by a submerged pipeline for injection into the deep ocean. Oceans offer enormous potential as carbon storage sinks, but the current level of scientific understanding to support ocean sequestration as a major CO_2 storage option remains uncertain. DOE had ocean sequestration as one of its research pathways in the past but, due to the need for further understanding, concluded projects in its portfolio in this area.

The Monterey Bay Aquarium Research Institute (MBARI) developed a novel set of experimental techniques for the deployment of small quantities of liquid CO_2 in the deep ocean in order to investigate the fundamental concepts of CO_2 ocean sequestration, particularly the behavior of CO_2 hydrates. Using an advanced Remotely Operated Vehicle (ROV) technology, MBARI carried out controlled releases of CO_2 to observe and measure the processes taking place.

Description

Through a series of experiments conducted offshore California and at the MBARI, researchers investigated the physical, biological, and chemical behavior of CO_2 hydrates on the seafloor at depths up to 3,600 meters. Similar to methane hydrates—the ice-like complexes of water and methane—CO_2 can also form hydrates, and the storage of CO_2 in hydrate pools at the bottom of the ocean were investigated. A number of research cruises using the ROV to study the ocean storage of CO_2 hydrate off Monterey Bay have been completed. The physical chemistry and the biological effects of hydrate formation in the deep ocean were examined by means of small-scale batch experiments.

The research group at Washington University, with MBARI, used in situ Raman spectroscopy to carry out the first direct in situ analysis of CO_2 hydrates on the ocean floor, in the entrained and surrounding fluids, and in the sediments adjacent to the hydrates. Information on hydrate-sediment interaction is essential for the evaluation of ocean sequestration of CO_2.

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PARTNERS

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Washington University at St. Louis

PERIOD OF PERFORMANCE

09/18/2000 to 03/31/2008

COST

Total Project Value

$1,593,777

DOE/Non-DOE Share

$1,270,041 / $323,736

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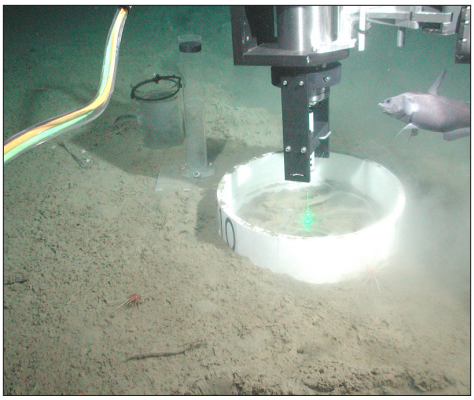
Primary Project Goal

The primary goal of this project is to investigate the chemical, physical, and biological behavior of CO_2 hydrates in the deep ocean. These data are necessary to help evaluate the storage of CO_2 in hydrate pools at the bottom of the ocean, an option that has been considered for long-term CO_2 storage.



Testing the waters: An experiment to investigate the fundamental science of ocean CO_2 sequestration at a depth of 3,600 meters off the coast of California. A small pool of liquid CO_2 is sensed by the beam of a laser Raman spectrometer to record the chemical status of the material. This sea floor laboratory is controlled by a remotely operated vehicle.

Objectives

- Determine the long-term fate of CO_2 and CO_2 hydrates on the sea floor.
- Study biological responses to the disposed material.
- Examine geochemical interactions with sediments and pore waters.

Benefits

This project will provide further understanding of the behavior of CO_2 within the ocean environment and will afford individuals interested in ocean engineering and the study of CO_2 and methane hydrates with useful information. The research will demonstrate that hydrate pools at the bottom of the ocean have the potential for long-term storage of large quantities of CO_2.

Formation of CO_2 hydrate mounds at 3,610 meters.

Accomplishments

MBARI used a small-scale delivery system with a capacity of 56 liters to study CO_2 interactions in the ocean. Five controlled delivery dives were executed, with the CO_2 delivered to a central corral complex. Results showed a strong tidal periodicity in the water plume of lowered pH and a complex set of biological responses. Below a depth of about 3,000 meters, the density of liquid CO_2 exceeds that of seawater, and the CO_2 is quickly converted into solid hydrate by reaction with the surrounding water. An analysis of the acoustic detection and modeling of a rising deep-sea liquid CO_2 plume was also completed. The results are applicable to detection of leakage of CO_2 from the sea floor, either from natural CO_2 vents or from purposefully disposed CO_2 in sub-sea geologic formations. Research results have been published in peer-reviewed literature and disseminated at scientific meetings, symposia, and conferences.

Planned Activities

The research team will prepare the final project report, as well as articles for publication in the scientific literature.

Project237.indd

PROJECT facts

U.S. DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

Carbon Sequestration

04/2008

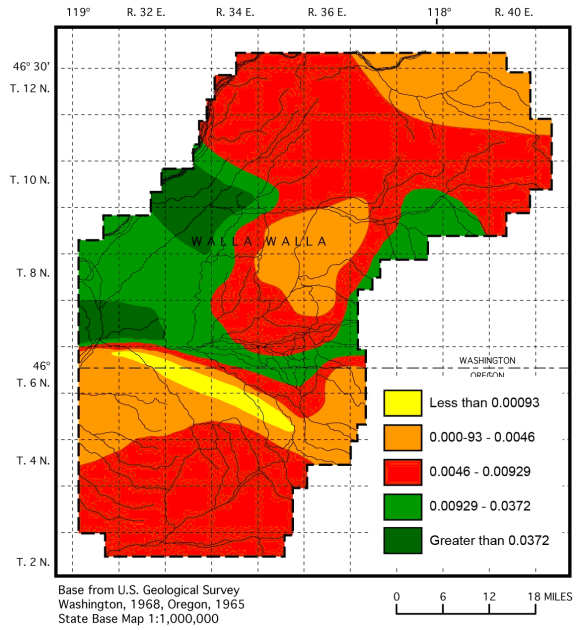
CO_2 SEQUESTRATION IN BASALT FORMATIONS

Background

There is growing concern that buildup of greenhouse gases, especially carbon dioxide (CO_2), in the atmosphere is contributing to global climate change. One option for mitigating this effect is to sequester CO_2 in geologic formations. Numerous site assessments for geologic sequestration of CO_2 have been conducted in virtually every region of the United States. For the most part, these studies have involved storing CO_2 in saline formation, deep coal seams, and depleted oil and gas reservoirs. Another option, however, is basalt formations. Basalt is a dark-colored, silica-rich, volcanic rock that contains cations—such as calcium, magnesium, and iron—that can combine with CO_2 to form carbonate minerals. Basalt formations have not received much attention with respect to their potential for permanent sequestration of anthropogenic CO_2. Major basalt formations that may be attractive for carbon sequestration occur in the Pacific Northwest, the southeastern and northeastern United States, and at several other locations around the world. Unlike sedimentary rock formations, basalt formations have unique properties that will result in chemically trapping injected CO_2, thus effectively and permanently isolating it from the atmosphere.

Because of the very limited study of basalts for carbon sequestration, basic information on injectivity, storage capacity, and rate of conversion of gaseous CO_2 to solid carbonates is not available. Experiments conducted at Pacific Northwest National Laboratory (PNNL) have confirmed that carbonate mineral formation occurs when basalts from the Columbia River Basalt Group (CRBG), Central Atlantic Mafic Province, and Newark Basin are exposed to supercritical CO_2. However, insufficient data have been generated from these experiments to permit reliable projections of CO_2 conversion rates under large-scale sequestration conditions. Information is also lacking on the ability of basalts from other parts of the world to support in situ mineralization reactions.

In this project, a hydrogeological survey will be conducted of basalt formations in the United States and India to provide a best estimate of the transmissivity of these formations and their suitability for geologic sequestration of CO_2. Similar information exists for the CRBG, which serves as a regional aquifer for the eastern portion of the state of Washington. Similar



Basalt aquifer map

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Pacific Northwest National Laboratory (PNNL)

PROJECT DURATION

06/01/2003 to 09/30/2008

COST

Total Project Value
$1,510,000

DOE/Non-DOE Share
$1,510,000 / $0

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hydrogeological information obtained for other flows will be used to estimate CO_2 capacity and injectivity rates.

The remaining components of this project are designed to determine the formation conditions expected to occur after the injection of CO_2 and provide the fundamental data necessary to better estimate rates of mineralization in different basalts. Dissolution rates for different basalts from around the world will be measured and compared to the CRBG. In situ pH measurements of the CO_2-saturated pore fluid in contact with basalt will be determined at formation conditions.

A specially-designed pressure cell will be used to determine the rates of CO_2 mixing and movement through actual CRBG core under realistic conditions of pressure and temperature.

Primary Project Goal

The goal of the work is to better understand the properties of basalt formations that would make them suitable for carbon storage by identifying mechanisms controlling post-CO_2 injection mixing behavior, formation pH, and mineralization rates.

Objectives

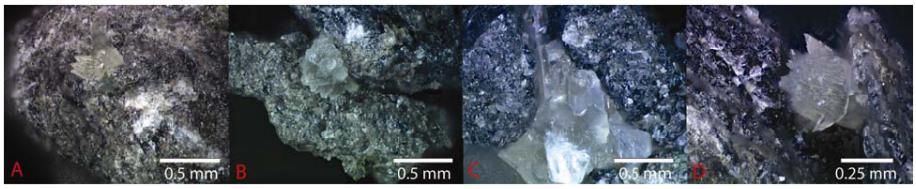
The objective of this project is to evaluate formation suitability for CO_2 storage and the rate of conversion of injected CO_2 to carbonates for basalts, with a principal focus on basalt formations in the United States and India.

Accomplishments

- A set of dissolution kinetics measurements was completed as a function of temperature and pH on basalt samples from the United States and India.
- Basalt grains from the United States, Africa, and India were reacted with supercritical CO_2 and water at 100 °C and 1500 psi for up to 1,334 days. Carbonate precipitation was identified on the post-reacted grains by optical and scanning electron microscopy, x-ray diffraction, and Raman spectroscopy. Rates of CO_2 conversion were variable based on basalt location.
- A CO_2 formation capacity assessment for the CRBG was estimated using existing geologic data obtained from prior Department of Energy studies.
- A first-order CO_2-formation capacity assessment conducted for major basalt formations in the United States conservatively estimates a CO_2 storage volume of 240 $GTCO_2$.
- Direct pH measurements of basalt and water mixtures reacted with supercritical CO_2 show a range of pH conditions from mildly acidic to slightly basic.

Benefits

Because of concern over the impact of greenhouse gases, particularly CO_2, on global climate change, considerable effort is being expended to evaluate the potential of CO_2 sequestration to mitigate the buildup of CO_2 in the atmosphere. Success of this project will expand the viable geologic options for CO_2 sequestration in the continental United States and provide heretofore unexplored options for CO_2 sequestration in developing countries, such as India. Basalt formations have a unique chemical makeup that could potentially convert all of the injected CO_2 to a solid mineral form, thus isolating it from the atmosphere permanently.



Columbia River Basalt and carbonate precipitates after exposure to CO_2 for a) 86 days, b) 377 days, c) 777 days, and d) 1,334 days

Project277.indd

PROJECT facts

U.S. DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

Carbon Sequestration

4/2008

INTERNATIONAL COLLABORATION ON CO_2 SEQUESTRATION

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Background

Research has shown that the concentration of carbon dioxide (CO_2) in the atmosphere has been increasing since the start of the Industrial Revolution, possibly due, in large part, to increased fossil fuel combustion. Because CO_2 is a greenhouse gas, its increased atmospheric concentration has generated concern about global climate change. One suggestion to address this issue is to capture CO_2 from stationary power sources and introduce it directly into the oceans, thus bypassing the slower biological and solubility cycles by which approximately 80 percent of the CO_2 that we currently emit will ultimately be absorbed by the oceans.

Among the issues requiring consideration before sequestering CO_2 in the oceans would become feasible is the need to obtain high initial dilution of CO_2 in ocean water in order to minimize the excess concentration of dissolved inorganic carbon and, hence, the associated increase in pCO_2 and decrease in pH to which the aquatic biota would be exposed.

Description

Although the overall project involved eleven tasks, the emphasis at the Massachusetts Institute of Technology (MIT) was on the following four tasks: (1) preparation and testing of equipment for measurement and monitoring; (2) observing the performance of ocean field experiments; (3) analysis of data acquired during the experiments; and (4) collation of overall results obtained in the field experiments. This international effort involved five nations (the United States, Japan, Norway, Canada, and Australia) and one private corporation (ABB of Switzerland). In the project agreement, MIT was designated as the Implementing Research Organization for the Department of Energy (DOE).

Two-phase plumes play an important role in various scenarios for ocean sequestration, i.e., dispersing CO_2 as a buoyant liquid from either a bottom-mounted or ship-towed pipeline or as a negatively buoyant hydrate from a ship. Despite much research on related applications, understanding of these CO_2 flows is incomplete, especially concerning the phenomenon of plume peeling in a stratified ambient environment. To address this deficiency, a laboratory facility was built to obtain fundamental measurements of CO_2 plume behavior in the ocean.

PARTNERS

Massachusetts Institute of Technology

Research Laboratories in Japan, Norway, Canada, and Australia

PERFORMANCE PERIOD

08/24/1998 to 06/30/2007

COST

Total Project Value
$1,100,000

DOE/Non-DOE Share
$1,100,000 / $0

An additional task was added to update the assessment of the environmental impacts of direct ocean sequestration to reflect the substantial body of research that has taken place over the past eight years. This effort included a substantial portion conducted by researchers associated with this project. This update represents a valuable summary of the current research in ocean sequestration of CO_2.

Primary Project Goal

The overall goal of this international effort toward reduction of greenhouse gases via ocean sequestration of CO_2 was to (1) investigate the technical feasibility of this approach to carbon management, (2) improve our understanding of the potential environmental impacts of ocean sequestration of CO_2, and (3) to minimize impacts associated with this sequestration technology on the marine biota.

MIT's primary activity, as part of this overall effort, was to conduct a series of laboratory experiments and to develop a mathematical model to describe a plume of liquid CO_2 dispersed from a nozzle in the deep ocean (greater than 2000 meters).

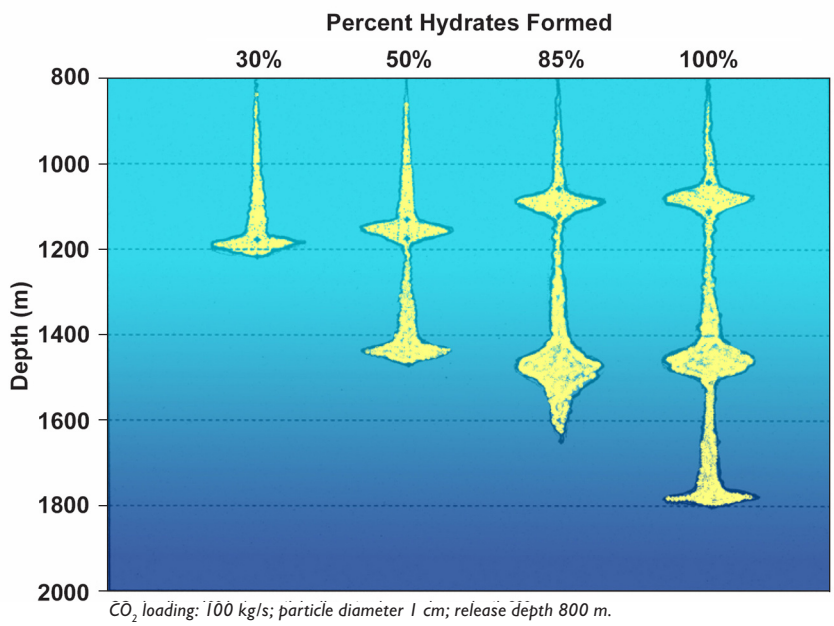
Objectives

The objectives of this international research effort were to:

- Prepare and test instrumentation for the measurement and monitoring of CO_2 injection into the oceans.
- Better understand the phenomena occurring in two-phase plumes.
- Observe the performance of ocean field experiments.
- Analyze data acquired during field experiments.
- Collate overall results obtained from field experiments.
- Develop and validate a model of the behavior of CO_2 injected into the ocean.
- Participate in project management as a member of the Technical Committee.
- Update the assessment of environmental impacts associated with direct ocean sequestration.

Benefits

The consequences from global climate change are potentially severe. Therefore, it is important to explore all options for mitigating the buildup of greenhouse gases in the atmosphere. One possibility is sequestration in the oceans. However, much more complete understanding of the environmental effects of this option needs to be developed before ocean sequestration of CO_2 can be implemented. This project is aimed at providing that understanding.



A schematic depicting plume model results for sinking plumes of different hydrate composition.

Accomplishments

Quantitative data were compared with a new analytical model which treated the CO_2 flow as an upward-moving inner plume, coupled with an annular, downward flowing outer plume. The model included CO_2-specific features, such as bubble/droplet mass transfer, solute dissolution effects on plume buoyancy, and change in total CO_2 concentration and pH. This double plume model was used to explore the fate of solid CO_2 hydrate particles released into the ocean for the purpose of CO_2 sequestration. Previous modeling results have been compared with those of researchers from Japan and Norway.

Mathematical models were used to examine three CO_2 dilution strategies that promote mixing in the longitudinal, lateral, and vertical directions. A point release of negatively buoyant solid CO_2 hydrate particles from a moving ship would achieve acceptable dilution near the source, while subsequent concentrations would be very low due to longitudinal mixing afforded by the ship's speed. A long, bottom-mounted diffuser, discharging buoyant liquid CO_2 droplets, can be designed for high

lateral mixing, resulting in arbitrarily small near-source concentrations but, because the resulting near field plume would be very wide, subsequent dilution would be slow. A stationary point release of CO_2 hydrate particles would achieve good vertical mixing due to the negatively buoyant plume effect, resulting in intermediate local and subsequent concentrations.

An assessment of environmental impacts associated with direct ocean sequestration was completed as an add-on task. The assessment reviewed available literature on both acute and chronic effects of CO_2 on deep-sea aquatic organisms. The researchers concluded that ocean discharge scenarios can likely be designed to largely avoid acute (short-term) impacts, but that more information is needed to fully address chronic (long-term) impacts. The researchers concluded that although the potential for impacts is a controversial subject, ocean sequestration should not be dismissed at this time from future consideration as a mitigation option for CO_2 reduction.

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PROJECT facts

U.S. DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

Carbon Sequestration

4/2008

LABORATORY INVESTIGATIONS IN SUPPORT OF CARBON DIOXIDE-LIMESTONE SEQUESTRATION IN THE OCEAN

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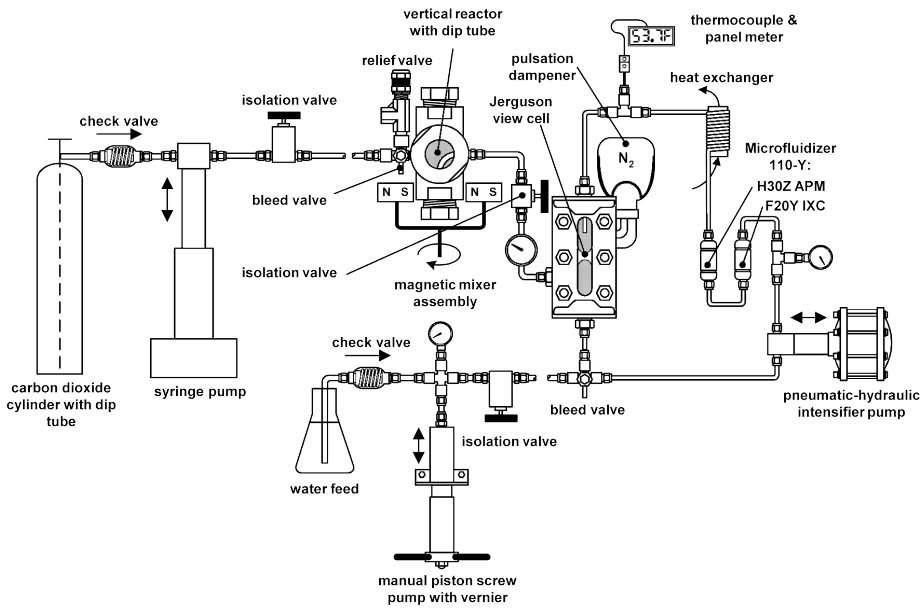
Background

Many approaches have been proposed for the sequestration of carbon dioxide (CO_2); one being considered is storing CO_2 in the ocean. However, because liquid CO_2 is less dense than water and poorly miscible with water, it must be injected at sufficient depth so it will not buoy upward. At approximately 500 meters depth, it would flash into vapor and reemerge into the atmosphere. Furthermore, when CO_2 dissolves in water, it forms carbonic acid, which lowers the pH of seawater, and may have adverse effects on marine biota. To circumvent these problems, researchers proposed to inject into the ocean an emulsion of CO_2 in water stabilized by limestone (calcium carbonate, $CaCO_3$) particles. The emulsion is heavier than seawater, and sinks deeper from the injection point rather than buoying upward. The $CaCO_3$-coated CO_2 droplets will not acidify the seawater.

Description

Under specific conditions, liquid CO_2 will form an emulsion in water in the presence of powdered limestone, and the globules of CO_2 are denser than water. Researchers plan to optimize the conditions for globule formation, including the CO_2 to $CaCO_3$ ratio and $CaCO_3$ particle size, as well as globule stability over long periods. They also plan to study the effect of impurities and ion strength on globule formation, as well as the possibility of using particles other than $CaCO_3$ for globule formation, including fly ash and various minerals. The stability of globules will also be investigated in the National Energy Technology Laboratory's High Pressure Water Tunnel Facility. Data collected will facilitate model development for future scale-up work.



Schematic of the microfluidizer with auxiliary feed mechanism and Jerguson view cell.

Primary Project Goal

The general objective of this work is to establish a database to enable the evaluation of an improved process for the deep water ocean sequestration of CO_2. The process forms globules of liquid CO_2 in water, with the globules being stabilized by limestone particles at the CO_2/water interface.

Objectives

The research objectives for this project are to:

- Construct a batch high-pressure reactor to mix CO_2, water, and fine limestone mixed at elevated pressure.
- Analyze emulsions in-situ using light microscopy and light scattering to determine their structural properties.

- Determine the effects of varied initial conditions (pressure, temperature, ingredients, water type, particle size, etc.) on an emulsion's physical and chemical characteristics.

- Convert reactor into a flow system in which liquid CO_2 and pulverized limestone can be fed continuously and thoroughly mixed to form a stable emulsion.

- Use the flow system to investigate the physical and chemical characteristics of the emulsions as a function of time while varying initial conditions.

- Analyze the data to report findings on observed relationships between measured characteristics and operating conditions.

- Perform a simple economic analysis of the costs associated with the process, expressed as the cost of sequestering one ton of CO_2 in the ocean. Factors will include: amounts and costs of raw materials and the energy required to pulverize, mix and transport the emulsion to the deep ocean.

PERFORMANCE PERIOD

07/09/2002 to 03/31/2008

COST

Total Project Value

$853,030

DOE/Non-DOE Share

$668,208 / $184,822

Benefits

Concerns about the contribution of greenhouse gas emissions to global warming have led to the study of ways to capture and sequester CO_2 at major emitting sources (e.g., fossil fueled powerplants and industrial boilers) to prevent release to the atmosphere. One potential sink for CO_2 is the oceans of the world, with almost unlimited capacity to sequester CO_2. If this project is successful, it could provide a method for ocean sequestration of CO_2, thus making it possible to continue the use of cheap and abundant coal and other fossil fuels until other non-CO_2 emitting energy sources become available.

Accomplishments

A high-pressure batch reactor with view window was constructed and used to conduct a wide range of tests using various proportions of liquid CO_2, water, and pulverized limestone to form emulsions of CO_2 droplets in water stabilized by $CaCO_3$ particles. After thorough mixing, a stable emulsion was formed, with globules consisting of an inner core of liquid CO_2 coated with a sheath of $CaCO_3$

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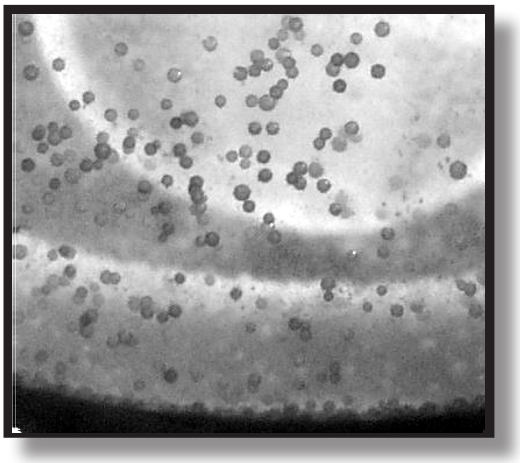
particles dispersed in water. Using limestone particles with a size range of 6-13 microns and the proper stirring conditions, globules of 100-200 microns diameter were formed; denser than water, they sank to the bottom of the reactor. The globules were observed for more than 24 hours and appeared to be stable. Water in the reactor had a pH of 7-10, compared to a pH of 3-4 for carbonic acid. Research also demonstrated that artificial seawater (3.5 percent sodium chloride solution) can be used instead of de-ionized water to form a stable emulsion. Researchers estimated that about 0.5 to 0.75 tons of pulverized limestone would be required per ton of CO_2 to form stable emulsions.

The microfluidizer was successfully used to create liquid CO_2-in-water and water-in-liquid carbon dioxide emulsions using fine particles as stabilizers. For CO_2-in-water emulsions, hydrophilic particles of finely milled $CaCO_3$ were used as stabilizers; for water-in-liquid carbon dioxide emulsions, hydrophobic pulverized Teflon particles were used as stabilizers. The $CaCO_3$-sheathed CO_2 globules were lighter than water, and floated on top of the water column – a process called creaming. The Teflon-sheathed water globules were heavier than liquid carbon dioxide, and sank to the bottom of the liquid CO_2 column – a process called sedimentation.



Close-up view of CO_2 globules coated with a sheath of limestone particles and settling out of suspension.

Planned Activities

Remaining experimentation will focus on operation of the microfluidizer to investigate factors limiting production of stable micro-emulsions. It may be possible to create a homogeneous micro-emulsion without creaming and sedimentation by increasing the shear force imparted by the microfluidizer on the interacting liquids and decreasing the stabilizing particle size. This may be necessary to ensure that the micro-emulsions penetrate the pore spaces of geologic formations for geologic sequestration applications. A final report will be submitted after completion of this research in March 2008.

PROJECT facts

U.S. DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

Carbon Sequestration

04/2008

ENHANCING CARBON SEQUESTRATION AND RECLAMATION OF DEGRADED LANDS WITH COAL-COMBUSTION AND BIOMASS-PYROLYSIS PRODUCTS

Background

Terrestrial sequestration of carbon can occur by three mechanisms, all of which first require "capture" or fixation of atmospheric carbon by photosynthesis into plant tissues. If captured by herbaceous plants, much of the carbon is quickly returned to the atmosphere by microbial activity when the plant dies, but a small percentage of it is incorporated by the humification process into soil humic material that may have a mean residence time of 25–50 years. If captured as woody tissue by trees, carbon sequestration on the order of tens to a hundred years can be achieved. The third terrestrial mechanism that can store carbon—which has only recently been recognized—is photosynthetic carbon in herbaceous or woody plants (i.e., biomass) and occurs when the biomass is heated under oxygen-limited conditions (i.e., pyrolysis) to produce bio-liquids and bio-gases that can be used to generate energy. In contrast to combustion, the pyrolysis process does not consume all the biomass carbon, and thus a solid residue or "char" is produced. The amount of char produced can be as much 50–60 percent of the initial carbon present in the biomass. Significantly, the char is highly resistant to decomposition and thus may have a residence time in soil of hundreds to thousands of years. While some biomass pyrolysis does occur naturally in wildfires, pyrolysis under controlled conditions can yield a significant amount of energy and also optimize the properties of the char that is produced. In addition to its high resistance to microbial and chemical degradation, some of the desirable properties in char include high ion-exchange capacities and substantial microporosity, which allow it to retain nutrients and water and thereby make it a useful additive to increase the fertility of soil. Also, because energy is produced at the same time that recently fixed atmospheric carbon (as opposed to fossil carbon) is being sequestered, the biomass pyrolysis process can be considered "carbon negative" and is the only form of energy production that inherently has this distinction (biomass combustion, for example, can at best be "carbon neutral" unless additional steps are taken to capture and sequester the recently fixed atmospheric carbon that is re-released as CO_2 during combustion). Technical estimates of the potential for biomass pyrolysis coupled with soil storage to sequester carbon suggest that several hundred gigatons of carbon emissions could be sequestered or offset by 2100, which is a large fraction of the total needed to mitigate global climate disruption.

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Description

The FY 08 research focus is on the characterization of unburned carbon present in fly ash from coal-fired power plants and in the residue from the pyrolysis of biomass to determine their suitability as soil additive, both alone and in various combinations with other coal combustion products. The following will be determined: 1) the physical and chemical properties of several types of char derived from each of the principal sources (coal char and biomass char); 2) the stability of selected chars towards oxidation when used as a soil additive; 3) the impact of the char-based additives (CBAs) on the production of greenhouse gases (N_2O and CH_4) by soil; 4) the impact of CBAs on the composition of the soil microbial community; and 5) the potential toxicity (if any) of CBAs towards plants and microbes, as well as the potential beneficial effects of CBAs on plant growth. Based on the results of these laboratory tests, in FY 09 one or more additive protocols will be recommended and an experimental plan for a subsequent field trial will be developed where the protocol(s) can be tested under realistic conditions.

Primary Project Goal

The overall goal of this project is to study the use of coal-combustion and biomass-pyrolysis products to foster carbon sequestration in degraded lands. This has the triple benefits of carbon storage, byproduct utilization, and land reclamation.

Objectives

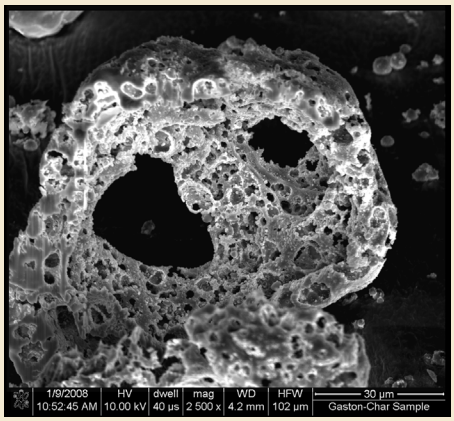
The current objectives are—

- To contrast the characteristics of coal-char and bio-char.
- To explore the potential usefulness of soil additives containing various combinations of fly ash and char (either from coal or biomass) to promote soil carbon sequestration and the restoration of degraded lands.

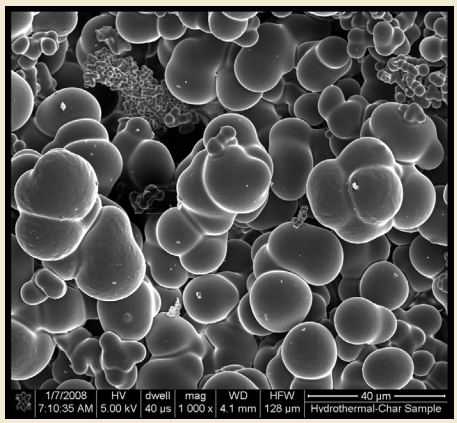
Benefits

The successful use of coal ash to enhance poor soil will benefit carbon sequestration efforts, utilize a coal waste product, and increase soil fertility.

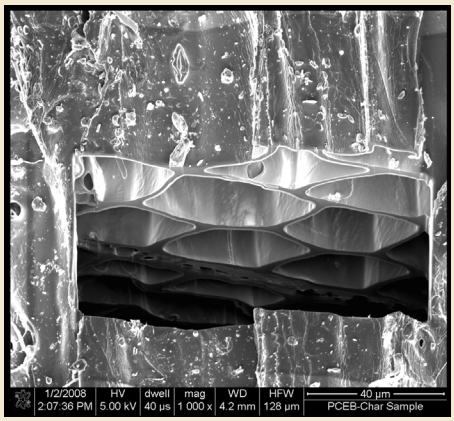
Focused ion beam (FIB) section of coal char from Alabama.



Hydrothermal char from cellulose (sample courtesy of Max Planck Institute, Potsdam, Germany).



FIB section of char from pine wood (sample courtesy of Eprida Corporation, Athens, GA).



Electron micrographs of three chars.

PARTNERS

Oak Ridge National Laboratory (ORNL)

Pacific Northwest National Laboratory (PNNL)

Virginia Polytechnic and State University

PERIOD OF PERFORMANCE

01/01/2000 to 09/30/2009

COST

Total Project Value
$1,815,000

DOE/Non-DOE Share
$1,815,000 / $0

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Accomplishments

To date, the project has accomplished the following:

- Laboratory experiments have shown that fly ash's alkalinity, porosity, and organic sorbent properties significantly promote the humification reaction.
- Observations have shown that increasing soil pH alone may lead to less carbon near the surface but may also lead to a beneficial mobilization of carbon to deeper soil levels.
- Laboratory testing of metal releases stemming from fly ash additives to soils have shown very low potential for leaching of metals and no toxicity of the leachates when measured using the Microtox technique.
- Sampling of field sites where fly-ash additives have been used have shown that after 15–30 years lands treated with fly ash have higher levels of carbon in the soil.
- Laboratory studies of additives involving fly ash and biosolids have shown that biosolids do not necessarily increase carbon sequestration and often increase the risk of leaching of toxic metals.
- Laser-induced breakdown spectroscopy has been found to be adaptable into a rapid-analysis field instrument.
- Extensive characterization of a variety of chars derived from coal or biomass has been initiated. Significant chemical and morphological differences have been observed.
- Eleven journal articles, abstracts, reports, and conference papers have been published.

R & D facts

U.S. Department of Energy
Office of Fossil Energy
National Energy Technology Laboratory

Carbon Sequestration

04/2008

Carbon Dioxide Storage in Coal Seams

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Background

The Department of Energy's (DOE) National Energy Technology Laboratory (NETL) is engaged in a broad research and development (R&D) effort to develop and assess technology that will be used to safely and reliably store carbon dioxide (CO_2) in coal seams, oil reservoirs, and saline formations, and to monitor sequestration effectiveness.

The following three tasks of this project address the storage capacity of coal seams and the trapping mechanism in which CO_2 is stored in the coal seam:

- **Task 1:** Explore coal structure changes under CO_2 sequestration conditions via scanning electron microscopy (SEM).
- **Task 2:** Probe the direct physical and chemical interaction of CO_2 sorption on coals provided by field projects using in situ infrared spectroscopy.
- **Task 3:** Conduct the gravimetric-volumetric analysis of coal swelling and shrinking at high CO_2 pressures.

Description

Task 1

The results of attenuated total reflection Fourier transform infrared (ATR-FTIR) spectroscopy results suggest that the coal undergoes a structure rearrangement in the presence of CO_2. If this is true, the data obtained using fresh (unexposed to CO_2) coal samples may likely be irrelevant to CO_2 sequestration because exposure to CO_2 may induce structure changes and the coal may be different before and after the initial CO_2 exposure. The ATR-FTIR measurements provide an indirect measurement of this structure rearrangement. NETL plans to use SEM to directly study the rearrangement of the coal. This information will be valuable for predicting what will happen to the coal seam when CO_2 is injected for long-term storage.

Task 2

The results of the interlaboratory comparison of the CO_2-coal sorption isotherm have suggested that the reproducibility of CO_2-coal isotherm is within 30 percent in the subcritical regime of pressures up to 8 MPa (orders of magnitude). However, once the supercritical boundary is crossed, the sorption isotherms begin to deviate substantially. We plan to use ATR-FTIR to study the interaction between CO_2 and coals in the supercritical regime while constructing a sorption isotherm. The isotherm in the supercritical regime is important especially when deep, unmineable coal seams are targeted for carbon storage purposes. The isotherm must be understood well enough to have reliable predictive value; otherwise the CO_2 storage capacity of potential candidate coal seams must be measured experimentally. This redundancy needs to be addressed

Task 3

The interaction between CO_2 and coals provides a thermodynamic driving force for CO_2 dissolution in coals. CO_2 dissolves in coals and swells them at higher pressures. This must be understood well enough to have reliable predictive value; otherwise the CO_2 storage capacity of each potential candidate coal seam must be measured experimentally. Without knowing the swelling amount, accurate measurements of CO_2 sorption by coals are not possible. Traditional experimental methods do not account for the related changes in void volume. New methods should be developed to account for swelling and shrinking of coal in response to sorption. The study should address how the CO_2-coal interactions change with coal rank and maceral type and how they affect the structural changes in the CO_2-coal system.

Primary Project Goal

The project will address the trapping mechanism and storage capacity for CO_2 storage in coal seams. The project will also provide insight into how coal swelling may restrict flow of CO_2 into coal seams and suggest injection techniques that will enhance CO_2 contact within the coal seam.

This project supports the Carbon Sequestration Program's Goals of demonstrating the ability to predict CO_2 storage capacity with +/-30 percent accuracy by 2012. The tasks will also help to develop an understanding of trapping mechanism for coal seams and target unmineable coal seams (those too deep and too thin to be mined economically), aid in providing an improved understanding of coal properties and their changes with CO_2 sorption under reservoir conditions, and improve predictive modeling capability for CO_2 injection in coals.

Objectives

- **Task 1 –** To explore coal structure changes that occur when coals are exposed to CO_2. Data obtained using fresh (unexposed to CO_2) coal samples may likely be irrelevant to CO_2 sequestration because exposure to CO_2 may induce structure changes and the coal may be different before and after the initial CO_2 exposure.

- **Task 2** – To measure CO_2 sorption isotherms on coals at pressure greater than 8 MPa. Special effort will be made to measure CO_2 sorption on field site samples. This data is necessary for estimating coal seam capacity for CO_2 and isotherms needed to model in CO_2-coal uptake and permeability.

- **Task 3 –** To provide accurate storage capacity estimates for non-rigid materials by measuring swelling of the samples in situ with combined volumetric and gravimetric techniques.

Benefits

The project has resulted in development of a new theory of coal swelling and how the CO_2 adsorption process affects swelling. It will provide guidelines for both efficient sequestration of carbon dioxide in coal seams and enhanced methane production. Through a better understanding of the fundamental chemistry involved in the CO_2 adsorption/methane (CH_4) desorption process, it will be possible to select optimum conditions for CO_2-enhanced coalbed methane production/ sequestration. The enhanced methane production associated with CO_2 sequestration will help to defray sequestration costs. Additionally, capturing carbon dioxide and sequestering it will prevent harmful emissions into the atmosphere that may further increase global warming.

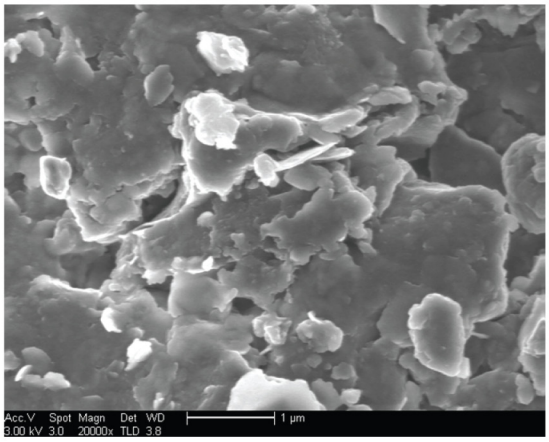
Accomplishments

Task 1

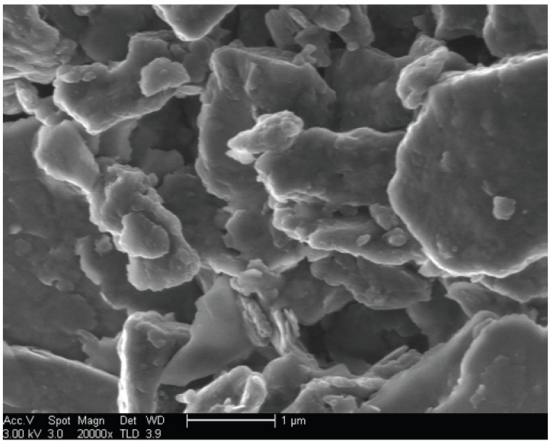
Preliminary measurements with SEM on powdered coals have been collected (see figures below). The SEM images suggest that the surface area of the coals has increased upon CO_2 exposure. We plan to continue the measurements with chunk coals to simulate intact coal that would be found in a coal seam.

Task 2

Sorption isotherms, which describe the coal's gas storage capacity, are important for estimating the carbon sequestration potential of coal seams. Sorption isotherms will be measured with a new ATR-FTIR spectroscopic cell purchased for the Pittsburgh NETL campus. This cell is similar to the one described in the ACS journal, Journal of Physical Chemistry B 2002, 106,754-759, where supercritical interactions on polymers are discussed.



Before CO_2 exposure



After CO_2 exposure

Figure 1. SEM images of coal powder. Left side: coal before CO_2 exposure. Right side: Coal exposed to 1400 psig CO_2 at 40 °C.

Current measurements for CO_2 interactions with coal samples from the Argonne National Laboratory's premium coal bank, field samples, and activated carbon at pressures up to 20 MPa are in progress.

Task 3

NETL has developed an R&D framework for improving conventional geo-mechanical approaches to modeling carbon sequestration in coal beds by taking into account coal properties at the macromolecular level. The framework accomplishes this by incorporation of the local porosity changes driven by macromolecular thermodynamics of plastic deformations. The model of sorption-induced coal swelling, published in the ACS journal (Romanov, 2007), serves to provide a new direction for those modelers who are interested in the predictive rather than correlative power of their models. The proposed strain-volume fraction relationship for osmotically driven network relaxation offers a direct way of taking into account the molecular level interactions and incorporating them into the geomechanical models. Improved modeling could avoid costly and unexpected problems, such as coal swelling around injectors and reduced injection efficiency that can stall or even terminate site development.

Many types of materials (polymer, coal, clay, etc.) change their volume and structure after absorption of gaseous and liquid substances. Various types of volume changes affect the accuracy of sorption measurements by two major methods – gravimetric and manometric. NETL onsite researchers investigated the errors associated with the volumetric effects, specifically, the case of carbon dioxide sorption on coal. It was demonstrated that the resulting error in buoyancy correction in the gravimetric method is equivalent to the corresponding error in assumed void volume in the manometric method. With a volumetric apparatus, the coal swelling will change the ratio of container volume to sample volume, thus introducing error. In a gravimetric apparatus, coal swelling will alter the buoyancy of the sample, thus introducing error. Data on coal swelling as a function of CO_2 pressure are needed. Once obtained, they can be used to correct the published CO_2 sorption data. If the molar volume of the CO_2 dissolved in coals can also be measured, a complete picture of CO_2 on and in coals can be assembled. The study suggests that the integration of the two methods, combined with the binary gas mixture technique of in situ volume measurement, will dramatically improve the accuracy of sorption measurements for materials such as coal and clay.

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R & D facts

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Carbon Sequestration

04/2008

Geologic Sequestration Core Flow Laboratory

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Background

Sequestration of CO_2 and production of coalbed methane (CBM) can affect the strata in various ways. For example, coal can swell or shrink, depending on the specific adsorbed/absorbed gas. In turn, this can affect permeability and porosity (flow properties), depending on the amount of sorption/desorption. If the geological formations of interest are deep and have high lithostatic pressures, high laboratory confining pressures are needed to realistically simulate in situ conditions in the lab. Deep formations also have elevated formation temperatures; hence, temperature control of laboratory test equipment is required. The same parameter evaluations are required for assessment of overburden/underburden strata sealing ability for preventing fugitive emissions from target sequestration strata.

Description

The National Energy Technology Laboratory's (NETL) Geological Sequestration Core Flow Laboratory (GSCFL) was established to evaluate rock-fluid interactions at depth and to determine how a particular stratum will be affected by adsorption/desorption of gas at various temperatures, pressures, and degree of saturation. It can be used to measure porosity, permeability, Young's Modulus, Poisson's ratio, and stress and strain. However, complete evaluation of a core, particularly coal, which swells/shrinks upon sorption/desorption of a fluid and can change permeability and effective molecular weight during testing, requires additional evaluation. The GSCFL work complements the examination of cores using NETL's CT Scanner, which can be used to see inside a core while it is being tested; this enables one to evaluate fluid flow in a core in real time. These results can then be compared with those predicted by modeling experiments and then used to improve the models. Closely linking the laboratory, field, and modeling activities in an iterative relationship will ensure accurate results and optimize progress. In addition, independent reactors are used to test fluid/mineral interactions at high pressures and temperatures.

Primary Project Goal

The goal is to be able to simulate the conditions found in all of the major potential geological sequestration sites including oil and gas fields, unmineable deep coal seams, brine formations, and natural gas hydrates. The data obtained from laboratory tests of various rock types under a variety of controlled conditions and environments will provide information on the geotechnical effects and chemical interactions that occur when CO_2 is injected into natural rock. The data will also be used to predict potential problems that might be encountered in field-scale investigations.

PERFORMANCE PERIOD

10/1/2007 to 9/30/2008

COST

Total Project Value
$400,000

DOE/Non-DOE Share
$400,000 / $0

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Objectives

- Obtain representative strata samples per program/project constraints, working cooperatively with Regional Carbon Sequestration Partnerships (RCSP).
- Prepare cores for testing to desired physical specifications and determine initial porosity and permeability.
- Use AutoLab testing instrument or high pressure reactors to simulate specified conditions of confining pressures, temperature, and pore pressures and determine porosity, permeability, Young's Modulus, Poisson's ratio, and stress and strain; coordinate appropriate tests with CT scanning evaluation of the same core samples.
- Use sensors installed on the AutoLab testing equipment to collect initial P-wave velocity structure of core samples at appropriate pressure and temperature conditions.
- Present test results to modelers at NETL and to the relevant regional partners; publish technical papers.

Benefits

The type of information that can be determined in the GSCFL is essential to realistic evaluation of the potential of CO_2 geologic sequestration, as well as CBM production. Much of this data is not currently available.

Accomplishments

The NER AutoLab 1500 unit, which is used to measure permeability and geo-mechanical property measurements at elevated pressure and temperature conditions, has been mechanically modified to reduce the time required for measurements. It is also being equipped with sensors that will allow researchers to assess seismic velocities in a particular core, which will improve the ability of NETL and the RCSPs to evaluate seismic investigations of potential field sites.

NER AutoLab 1500 unit

R&D054.indd