Monitoring, Mitigation & Verification Project Fact Sheet List

Project Title	Primary Contractor	Fact Sheet Listing
Weyburn Carbon Dioxide Sequestration Project	Natural Resources Canada	M-3
Application and Development of Appropriate Tools and Technologies for Cost-effective Carbon Sequestration	The Nature Conservancy (TNC)	M-7
Development of a Carbon Management Geographic Information System for the US	Massachusetts Institute of Technology	M-9
Continuous, Non-Invasive, In Field Soil Carbon Scanning System	Brookhaven National Laboratory	M-11
National Carbon Sequestration Database and Geographical Information System (NATCARB)	University of Kansas Center for Research	M-13
Carbon Sequestration in Reclaimed Mined Soils of Ohio	Ohio State University	M-17
Geologic Sequestration of CO_2 in a Depleted Oil Reservoir	Sandia National Laboratories / LANL	M-21
GEO SEQ Project (Project in Sequestration Area)	LBNL, LLNL, ORNL	Factsheet in Sequestration
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Stored CO_2 & Methane Leakage Risk Assessment and Monitoring Tool Development: CO_2 Capture Project Phase 2	BP Corporation North America Inc	M-29
Assessing Fossil Fuel and Recent Carbon Pools in Reclaimed Mined Soils	Ohio State University Research Foundation	M-31
Low Cost Open-Path Instrument for Monitoring Atmospheric Carbon Dioxide at Sequestration Sites	California Institute of Technology	M-35
Application Of Low-Cost Digital Elevation Models To Detect Change In Forest Carbon Sequestration Projects	Winrock International	M-37
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Development of Comprehensive Monitoring Techniques to Verify the Integrity of Geologically Sequestered Carbon Dioxide	National Energy Technology Laboratory	M-41
Degradation of Wellbore Cement Due to CO_2 Injection	National Energy Technology Laboratory	M-43
Computed Tomography (CT) Scanning for Petrophysical Applications	National Energy Technology Laboratory	M-45
Leveraging Regional Exploration to Develop Geologic Framework for CO_2 Storage in Deep Formations	Battelle Columbus Laboratories	*
Geochemical Analyses of Surface and Shallow Gas Flux and Composition Over a Proposed Carbon Sequestration Site in Eastern Kentucky	University of Kentucky Research Foundation	*
Discrete Fracture Network Models for Risk Assessment of Carbon Sequestration in Coal	Geological Survey of Alabama	*
Geological Sequestration - Enhancement of Natural Seals	Albany Research Center	*
CO_2-Water-Rock Interactions and the Integrity of Hydrodynamic Fields	Los Alamos National Laboratory	*

* Factsheet Under Development

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Leveraging Regional Exploration to Develop Geologic Framework for CO2 Storage in Deep Formations	Battelle Columbus Laboratories	*
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Discrete Fracture Network Models for Risk Assessment of Carbon Sequestration in Coal	Geological Survey of Alabama	*
Geological Sequestration: Permanent Storage: Enhancement of Seals	National Energy Tech. Laboratory - Albany	*
CO2-Water-Rock Interactions and the Integrity of Hydrodynamic Fields	Los Alamos National Laboratory (LANL)	*
Basic Science of Retention Issues, Risk Assessment & Measurement, Monitoring, & Verification for Geologic CO2 Sequestration	Montana State University	*
Zero Emissions Research & Technology Center (PNNL)	Pacific Northwest National Laboratory (PNNL)	*
Zero Emission Technology Research: Fundamental Investigations of CO2 Storage in Sedimentary Basins	Lawrence Berkeley National Laboratory (LBNL)	*
Sequestration: Experiments, Simulations, and Field Projects	National Energy Technology Laboratory - Morgantown	*
Fossil Energy Technology Strategy (PNNL)	Pacific Northwest National Laboratory (PNNL)	*
Development of Novel Monitoring Tools for Geologic Sequestration	Los Alamos National Laboratory (LANL)	*
Regional Modeling of Large-Scale Hydrologic Impact of CO2 Storage	Lawrence Berkeley National Laboratory (LBNL)	*
Early Remote Risk Assessment Technology	Physical Optics Corporation	*
Field-Deployable Gas Analyzer for MMV Applications	Los Gatos Research	*
Geoscience Technology Development for Zero Emission Power Plants	Lawrence Livermore National Laboratory (LLNL)	*
Fault Geomechanics and Carbon Dioxide Leakage Applied to Geologic Storage	Lawrence Livermore National Laboratory (LLNL)	*
Geological Sequestration - Laboratory Studies	National Energy Technology Laboratory - Pittsburgh	*
Application of Cutting-Edge 3-D Seismic Attribute Technology to the Assessment of Geological Reservoirs for CO2 Sequestration	University of Houston	*
CO2SINK (German) Collaboration	Lawrence Berkeley National Laboratory (LBNL)	*
Modeling the Resolution of Inexpensive, Novel Non-Seismic Geophysical Monitoring Tools to Monitor CO2 Injection into Coal Beds	Lawrence Berkeley National Laboratory (LBNL)	*

* Factsheet Under Development

PROJECT facts

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

Carbon Sequestration

04/2008

WEYBURN CARBON DIOXIDE SEQUESTRATION PROJECT

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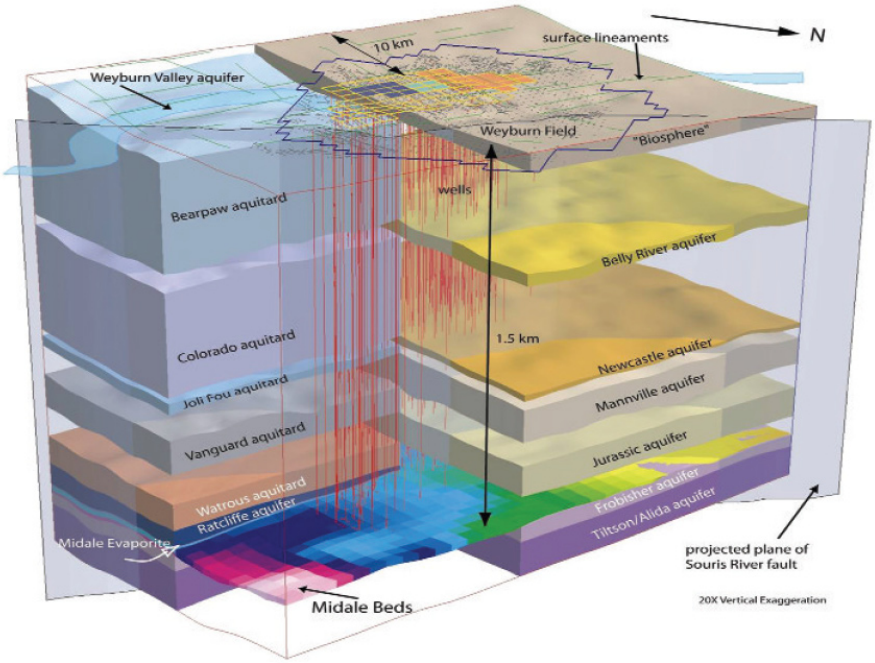
Background

Since September 2000, carbon dioxide (CO_2) has been transported from the Dakota Gasification Plant in North Dakota through a 320-km pipeline and injected into the Weyburn oilfield in Saskatchewan, Canada. The CO_2 has given the Weyburn field, discovered 50 years ago, a new life: 155 million gross barrels of incremental oil are slated to be recovered by 2035 and the field is projected to be able to store 30 million tonnes of CO_2 over 30 years. CO_2 injection began in October of 2005 at the adjacent Midale oilfield, and an additional 45–60 million barrels of oil are expected to be recovered during 30 years of continued operation.

A significant monitoring project associated with the Weyburn and Midale commercial oilfields has been designed to address both the long-term fate and the security of CO_2 storage in geologic formations. This project, divided into two phases, is the largest, full-scale, in-the-field scientific study ever conducted in the world involving carbon dioxide geologic storage.



A 3-D geologic model has been constructed from ~1,000 wells for an area extending 10km beyond the limits of the Weyburn field CO_2 injection area.

PARTNERS

- Alberta Energy Research Institute
- Apache Canada
- Aramco Services Company
- Chevron
- EnCana Corporation
- Natural Resources Canada
- OMV
- Research Institute of Innovative Technology for the Earth (RITE)
- Saskatchewan Industry and Resources
- SaskPower
- Schlumberger

The first phase of the project demonstrated that the natural geologic setting of the Weyburn field is highly suitable for long-term storage of CO_2. Phase I of the project culminated in release of the Summary Report (IEA GHG Weyburn CO_2 Monitoring & Storage Project Summary Report 2000–2004) and presentation of numerous technical papers at the GHGT-7 Conference in Vancouver in September, 2004. A final phase of the project was launched in 2005 to develop a Best Practices Manual for the widespread implementation of practical, safe, and reliable enhanced oil recovery (EOR)-based CO_2 geologic storage projects.

Primary Project Goal

The goal of the Weyburn CO_2 Sequestration Project is to enhance the knowledge and understanding of the underground sequestration of CO_2 associated with EOR. Understanding the mechanisms, the reservoir storage capability, and the economics of CO_2 sequestration requires mapping the migration and distribution of existing formation fluid as well as the injected fluids in the area of interest.

Objectives

The technical R&D program in the final phase is organized around five technical themes: geologic integrity, wellbore integrity, storage monitoring methods, risk assessment and storage mechanisms, and data validation and management. The technical objectives are to determine the long-term storage risks and monitoring requirements to mitigate such risks.

Theme 1—Geologic integrity (site selection):

- Develop firm protocols for selection of suitable sites for CO_2 geologic storage using full-cycle risk assessment and other means that integrate hydrogeologic, geophysical, and geologic data sets to create a complete picture of seal integrity.
- Summarize the predicted impact of CO_2 and CO_2-rich fluids on geochemical and geomechanical processes on regional reservoirs and seals.

Theme 2—Wellbore integrity:

- Complete the parameterization of wellbore integrity, develop a list of remediation activities that could be applied, and describe current well abandonment technology trends and how they may impact future abandonment requirements.
- Conduct Cased-Hole Dynamic Testing. This log can be used to test behind casing pressure and formation fluids. In unperforated zones, establish pressures and mobile fluids to look for CO_2 migration out of zone.
- Document safe practices of normal CO_2 EOR operations on wellbore integrity and geomechanics.

Theme 3—Storage monitoring methods:

- Characterize the accuracy of monitoring technologies for quantitatively predicting the location and volume-in-place of CO_2 and determine from the four-dimensional (4-D) seismic program interpretation results if multi-year programs are appropriate for ongoing monitoring and verification.
- Conduct in situ time-lapse well logging to calibrate seismic imaging and verify and constrain the results from seismic and other monitoring approaches, while continuing with a passive seismic program.
- Verify predictions through spinner surveys and selective drilling, coring and logging of vertical slim holes to determine CO_2 distribution.

Theme 4—Risk assessment and storage mechanisms:

- Complete the full-field risk assessment from Phase 1. All relevant storage and leakage mechanisms should be modeled and studied, with risk levels determined for various operations scenarios.
- Describe the ultimate fate of CO_2 in the Weyburn-Midale system, the relative volumes in each storage and trapping mechanism, the time to become trapped, and the factors which affect these. Study ways to stimulate and accelerate CO_2 mineral fixation (mineralization, mineral trapping) under these reservoir conditions.

Theme 5—Data validation and management

- Store the Weyburn-Midale data set at PTRC.

Benefits

The benefit of the first phase of the Weyburn project—benefit that will continue in the final phase of the Weyburn-Midale project. This includes establishment of comprehensive knowledge of (1) the geologic nature of the EOR reservoir and the region where the CO_2 is stored; (2) the movement and ultimate geochemical fate of the CO_2 within the reservoir; (3) the reservoir storage capacity; (4) the economic viability of CO_2 storage in the reservoir; and (5) the overall risk assessment, including probability and consequences of CO_2 leakage.

The monitoring, verification, risk assessment, and management technologies developed for Weyburn and Midale's geologic environments will be transferable to other sites and enable a startup of commercial-scale, EOR-based CO_2 geologic storage projects. These technologies will enable the geologic storage of significant quantities of CO_2 that would otherwise be emitted to the atmosphere and at the same time increase oil recovery and hence improve U.S. energy security.

Widespread CO_2 geologic storage is a transitional technology that will allow the world to meet climate change challenges and commitments while progressing to a more sustainable energy future that combines alternative and renewable energy technologies with zero-net-emission fossil energy technologies.

PERIOD OF PERFORMANCE

06/01/2005 to 09/30/2010

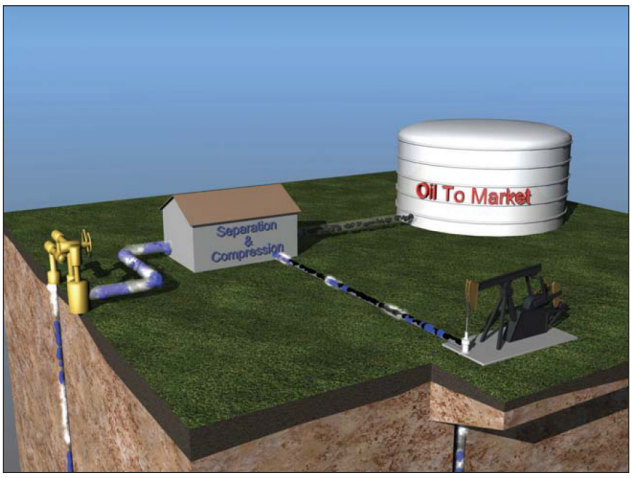
COST

Total Project Value
$40,000,000

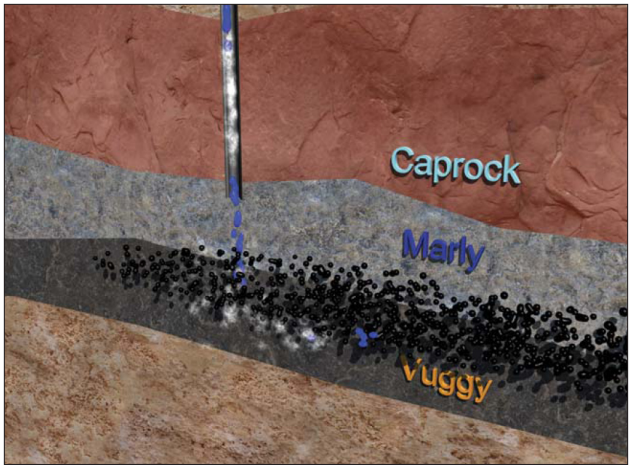
DOE/Non-DOE Share
$4,000,000 / $36,000,000

Accomplishments

During the Project's initial four-year study, researchers developed and evaluated a variety of monitoring technologies; conducted long-term risk assessments; completed frequent, regular seismic, ground water, and soil-gas surveys; matched reservoir modeling against production and injection statistics; and performed repeated and frequent reservoir fluid sampling to understand geochemical mechanism occurring in the reservoir. The regular frequency of geoscience surveys proved critical to tracking the movement of CO_2 in the Weyburn reservoir over the four years of the Phase I Project.



Water (blue) and CO_2 (white) are compressed and injected into soil reservoirs for enhanced oil recovery. Roughly 30% of the CO_2 returns to the surface with the oil (black), where it is separated and recycled.



Water (blue) and CO_2 (white) are used in the Weyburn and Midale fields for enhanced oil recovery in the Marly and Vuggy layers. Research shows the dense, impervious caprock is capable of securing CO_2 underground, in the Marly and Vuggy layers, post-production.

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Project282.indd

PROJECT facts

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

Carbon Sequestration

04/2008

Application and Development of Appropriate Tools and Technologies for Cost-Effective Carbon Sequestration

Background

According to the Intergovernmental Panel on Climate Change (IPCC), deforestation accounts for about 20 percent of annual global emissions of carbon dioxide (CO_2), the primary greenhouse gas (GHG). The IPCC estimates that 12–15 percent of the fossil fuel CO_2 emissions generated between 1995 and 2050 could be offset through slowing tropical deforestation, allowing these forests to regenerate, and engaging in plantation plantings and other forms of agroforestry.

There is great potential for such cost-effective carbon sequestration projects both in the United States and abroad. However, without the development and refinement of tools and technologies that allow accurate and cost-effective assessment of the amount of carbon sequestered, these approaches may not be recognized as credible means for reducing GHG. Through a cooperative agreement with the Department of Energy to explore the compatibility of carbon sequestration in terrestrial ecosystems with the conservation of biodiversity, The Nature Conservancy is participating in the ongoing development and implementation of carbon sequestration projects on a demonstration scale. The Conservancy's first involvement in assessing this approach came in 1994 with the development of the Rio Bravo Carbon Sequestration Pilot Project in Belize, in cooperation with several partners. Since then, several other projects have been initiated with a variety of partners.

This project will focus on gaining cost-effective, verified measurements of the long-term potential of various terrestrial carbon sequestration strategies and assessing land use practices that avoid emissions of CO_2. The project will use newly developed aerial and satellite-based technology to study forestry projects in United States and Belize to determine their carbon sequestration potential and will also test new software models to predict how soil and vegetation store carbon at sites in the United States and abroad.

Nature Conservancy scientist Patrick Gonzalez measuring white fir tree in a high-carbon area of the Tahoe National Forest.

Primary Project Goal

The primary goal of this project is to refine the tools and methodologies for cost-effective, verified measurements of the long-term potential of various carbon sequestration strategies and assess land use practices that avoid emissions of CO_2, using actual projects as proving grounds.

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PARTNERS

The Nature Conservancy (TNC)

Winrock International Institute for Agricultural Development

The Society for Wildlife Research (SPVS)

Programme for Belize Comite de Defensa de la Fauna y Flora (CODEFF)

Universidad Austral de Chile

Los Alamos National Laboratory

Colorado State University

Stephen F. Austin State University

Virginia Technical University

Michael Lefsky

Colorado State University

UC Berkeley

The Carnegie Institution of Washington

California Department of Parks

Stanford University

USDA Forest Service

ProNaturaleza

Ohio State University

Geographical Modeling Services, Inc.,

WestWater

Los Alamos National Laboratory

Century Ecosystem Services

PERIOD OF PERFORMANCE

07/11/2001 to 07/10/2008

COST

Total Project Value

$3,139,60

DOE/Non-DOE Share

$2,511,680 / $627,920

CUSTOMER SERVICE

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Objectives

- Improve carbon monitoring and lower its cost.
- Develop land use trend models to project potential CO_2 offsets.
- Evaluate and standardize carbon monitoring methods and procedures.
- Assess domestic land-use options for reducing greenhouse gases.
- Develop software for initial feasibility screening of potential domestic projects.

Accomplishments

- Advanced digital videography has been tested in pine-savannah and closed-canopy forests in Belize and the Lower Mississippi Alluvial Valley in the United States. Work has commenced in California to test the ability of high-resolution satellites QuickBird and Light Detection and Ranging (LIDAR) to quantify aboveground forest carbon. Signs of altitudinal shifting of vegetation have been observed in California.
- Feasibility studies in seven different U.S. ecosystems have been completed to determine for which of these ecosystem types carbon sequestration is a viable option.
- A feasibility study has been initiated in the United States northeast region in collaboration with Regional Greenhouse Gas Initiative stakeholders to determine the opportunity for forestry to sequester carbon. This project seeks to assess the cost and potential of carbon sequestration benefits on a multi-state level and learn more about how conservation and carbon sequestration projects may or may not be compatible. Large carbon mitigation potential through alteration of terrestrial land management has already been identified in the northeastern United States.
- The GEOMOD spatial analysis tool has been used to determine and validate baseline analyses. An alternative baseline method developed by TNC, called the Forest Restoration Carbon Analysis (FRCA) method, has been further refined and developed in Peru. Both spatially explicit baseline models, along with the historical trend baseline method, have been compared for a site in Valdivia, Chile.
- Technical advisory panels have been organized to share research and address the issues associated with baseline and leakage estimates.
- A soil monitoring workshop was held in Brazil to discuss the ability to measure changes in soil carbon at existing carbon sequestration projects.
- A new project software-screening tool has been completed and launched.

Benefits

This project will validate technology and develop protocols to measure carbon both in soils and in aboveground vegetation. The evaluation of sites both in South and North America make this project unique. Many of the existing voluntary exchanges and state initiatives allow for offset projects to occur both domestically and internationally.

ADDITIONAL SUPPORT

American Electric Power
Applied Energy Systems
General Motors
KeySpan
Mirant Corporation
NiSource
PSEG
Salt River Project
Texaco

Project231.indd

PROJECT facts

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

Carbon Sequestration

04/2008

DEVELOPMENT OF A CARBON MANAGEMENT GEOGRAPHIC INFORMATION SYSTEM (GIS) FOR THE UNITED STATES

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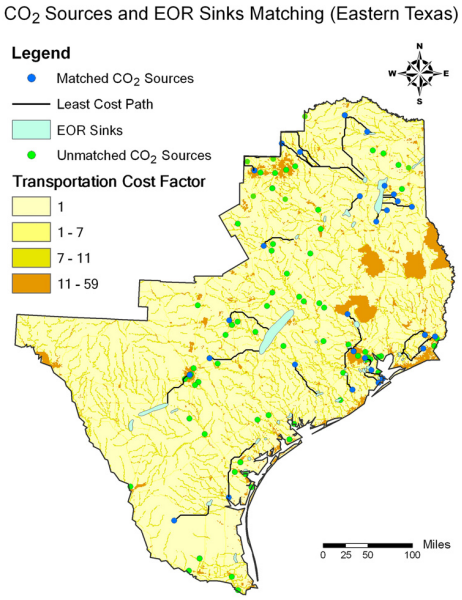
Background

This project is developing tools to provide U.S. Department of Energy (DOE) research and development programs and project managers with the capability for real-time display and analysis of carbon dioxide (CO_2) sources, potential sequestration sinks, and other data, such as transportation corridors, within a spatial database. This type of program can assist decision makers by providing visual access to high quality, current, consistent data obtained from distributed datasets. The main tool being used is a geographic information system (GIS) to model and analyze the data and to display their spatial relationships. The Massachusetts Institute of Technology's (MIT) Carbon Management (CM) system is employing GIS tools to support decision making within the CM system. MIT is using GIS software to prepare a user-friendly model. Various social, economic, regulatory, and political aspects of sequestration are also being considered as part of the project.

MIT is taking a top-down approach to analyzing the potential for CO_2 capture and storage in the United States. To avoid duplication of effort while conducting this project, MIT is working closely with the ongoing National Carbon Sequestration Database and Geographic Information System (NATCARB) project. The primary use of the Carbon Management GIS will be as a systems analysis tool that can be used on a local, regional, or national scale.



Primary Project Goal

The overall objective of this project is to develop an analysis tool to aid in the development and deployment of carbon capture and sequestration technologies within the United States.

PARTNERS

Massachusetts Institute of Technology

NATCARB Consortium

PERIOD OF PERFORMANCE

09/30/2002 to 12/31/2008

COST

Total Project Value

$1,587,503

DOE/Non-DOE Share

$1,270,002 / $317,501

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Objectives

- To define in detail the GIS data requirements, the types of analyses that can be conducted, and the forms of output that will be produced.
- To identify data sources and convert this data into a form accessible by the GIS.
- To incorporate social, economic, regulatory, and political data.
- To develop a series of scripts (i.e., computer code) to allow easy manipulation and data analysis.
- To add "help" files so that most of the documentation will be incorporated right into the GIS. The system will be put into a user-friendly form.
- To work with NATCARB to provide Internet access to the developed software in a manner similar to that already done by NATCARB.
- To generate carbon sequestration abatement curves for various technology and policy scenarios.
- To maintain the Carbon Management GIS system.

Benefits

One of the options for mitigating CO_2 emissions from power plants and other point sources is sequestration in geologic formations, whether solely for containment purposes, for enhanced oil recovery (EOR), or for enhanced gas recovery (EGR). However, to minimize transportation and other costs, sources and sinks should be in close proximity to each other. The software being developed in this project will permit rapid visualization of the relationship between CO_2 sources and potential sequestration sites. It will ultimately aid DOE in the development of meaningful and economically feasible sequestration demonstration projects. Such projects are essential if sequestration is to become a technically, economically, environmentally, and socially acceptable option that supports the continued use of our abundant domestic coal resources to help meet the near- and long-term energy needs of the United States.

Accomplishments

- Produced working analysis tools that include a storage capacity calculator, an injectivity and injection cost calculator, a transportation cost calculator, and a source-sink matching tool.
- Incorporated data into the system for major CO_2 sources and sinks as well as factors that affect sequestration costs.
- Used the system to perform preliminary but detailed carbon sequestration marginal abatement cost curves for California and eastern Texas.
- Used the system to perform additional analyses for the West Coast Regional Carbon Sequestration Partnership (WESTCARB) and South East Regional Carbon Sequestration Partnership (SECARB) regional partnerships.

Planned Activities

- Maintain user access to the Carbon Management GIS.
- Incorporate new data as it becomes available.
- Improve existing capabilities of the user interface and analysis tools.
- Continue collaboration with the Regional Carbon Sequestration Partnerships.
- Maintain and improve system documentation.

PROJECT facts

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

Carbon Sequestration

04/2008

CONTINUOUS, NON-INVASIVE, IN-FIELD SOIL CARBON SCANNING SYSTEM

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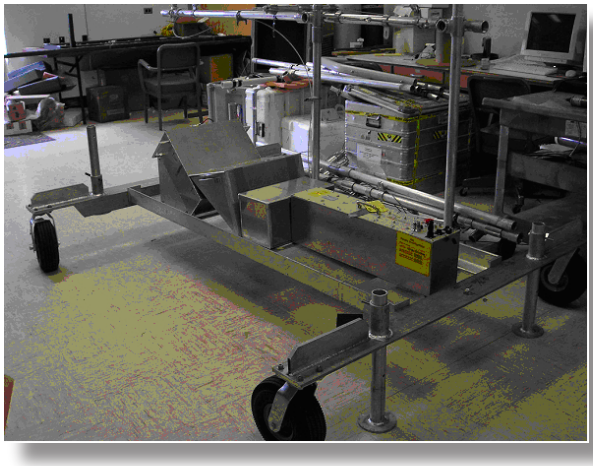
Background

Vegetation and soils serve as carbon storage sinks for the approximately 2 billion tons of carbon absorbed annually by the global biosphere. While global warming is promoted by anthropogenic carbon dioxide (CO_2) emissions into the atmosphere, it is partially mitigated by carbon sequestration in the terrestrial ecosystem. However, a better understanding and monitoring of the underground carbon processes is necessary for evaluating various strategies for terrestrial carbon sequestration and quantification of the carbon stores for carbon credits.

Description

Brookhaven National Laboratory (BNL) has developed a multi-elemental scanning instrument for determining carbon analysis in soil. The method is based on inelastic neutron scattering (INS), which offers a noninvasive means for continuous monitoring of the soil carbon and other elements in situ over both specific plots and large areas. This technique can significantly improve quantification of the efficacy of terrestrial carbon sequestration methodologies. The proposed instrument enables a continuous scan and evaluates the mean soil carbon content in the field to a depth of about 20 centimeters. The benefit from such a system is its capability to monitor belowground carbon processes without disturbing the soil, which allows for continuous scanning of large areas, thus providing a true mean carbon concentration in soil. The system also enables repetitive measurements of the same site, resulting in sequential monitoring of large areas. Proof-of-principle has been demonstrated in several double-blind field studies in which the INS results were calibrated successfully against chemical analyses of soil core samples taken from the same site. The results from feasibility studies suggested that the requirement to measure changes of as little as 100 grams of carbon per square meter could be met with about 5 percent accuracy.



Mobile INS System Developed by BN

PARTNER

Brookhaven National Laboratory

PERIOD OF PERFORMANCE

06/01/2003 to 09/30/2007

COST

Total Project Value

$1,290,200

DOE/Non-DOE Share

$1,290,200 / $0

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Primary Project Goals

The purpose of this project is the development of an instrument with the capability for safe, rapid, non-destructive, multi-elemental, in situ soil carbon quantification and profiling over large areas and soil volumes.

Objectives

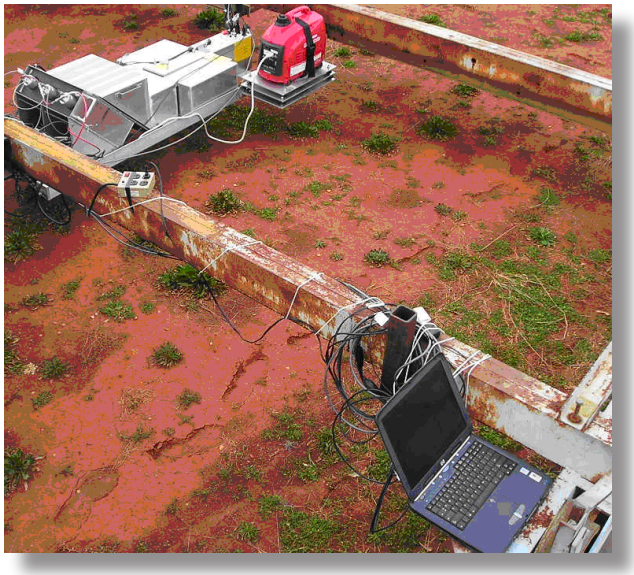
The objectives of this project were: (1) to design and construct an INS system for continuous soil carbon scanning in the field, and (2) to perform measurements in various soil types where the soil carbon content was well characterized. The system also allowed for comparison and development of conversion factors to scale specific point measurements obtained by techniques other than INS to large field values.

Benefits

This project succeeded in developing a robust, flexible, non-invasive, scanning system for in situ monitoring and in verifying temporal changes in soil carbon over large areas. The anticipated benefit from such a system is the ability to monitor belowground carbon processes without disturbing the soil. Furthermore, the system enables continuous scanning of large areas, thus providing a true mean carbon concentration in the soil. This soil carbon scanning system performed, uniquely and for the first time, repetitive measurement of the same site, thus allowing for sequential monitoring of large areas.

Accomplishments

- BNL researchers partnered with the U.S. Department of Agriculture to conduct measurements of soil carbon in Duke Forest in North Carolina and at the Auburn, Alabama, Agricultural Research Service (ARS) facility. Measurements showed relatively high correlation between traditionally measured values and INS system measurements.
- An INS system for non-destructive, in-field soil carbon analysis, in both static and scanning modes, has been constructed and tested. The results demonstrated the proof-of-principle and feasibility of using the system as intended.
- It was shown that elements such as nitrogen (N), potassium (K), calcium (Ca), and phosphorus (P) can also be measured with the INS system.
- The design of an upgraded INS beta prototype system has been completed, with new electronics capable of supporting 16 detectors.
- Software for spectral processing and analysis has been developed and implemented.
- A Monte Carlo N-Particle (MCNP) model of the system has been developed.



INS System at USDA Facility in Auburn, AL

Project266.indd

PROJECT facts

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

Carbon Sequestration

4/2008

NATIONAL CARBON SEQUESTRATION DATABASE AND GEOGRAPHICAL INFORMATION SYSTEM (NATCARB)

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Background

The National Carbon Sequestration Database and Geographical Information System (NATCARB) started as a joint project among the State Geological Surveys of five midwestern states (Illinois, Indiana, Kansas, Kentucky, and Ohio). The project was later expanded to include the seven Regional Carbon Sequestration Partnerships and a prototype to integrate databases for terrestrial carbon sequestration with databases on geologic sequestration. The purpose of NATCARB is to assess the carbon sequestration potential in the United States and to develop a national Carbon Sequestration Geographic Information System (GIS) and relational database covering the United States and parts of Canada. This digital spatial database allows users to estimate the amount of carbon dioxide (CO_2) emitted by sources (such as power plants, refineries and other fossil fuel consuming industries) in relation to geologic formations that can provide safe, secure sequestration sites over long periods.

Description

Allows users to identify, locate, and characterize large stationary CO_2 sources. It also allows users to determine the quality, size, and geologic integrity of potential CO_2 sequestration sites, including producing and depleted oilfields and gas fields, unconventional oil and gas reservoirs, unmineable coal seams, and saline water formations. All information can be accessed online through a single interface that will access multiple servers in various locations.

Primary Project Goal

The primary goal of this project is to construct a relational database management system with spatial query capabilities to evaluate the geographic distribution, physical characteristics, economic parameters, and potential geologic sequestration sites of CO_2 sources throughout the United States and parts of Canada.

PARTNERS

University of Kansas

West Virginia University

Kansas State University

The state geological surveys in: Illinois, Indiana, Kansas Kentucky, and Ohio

The DOE Regional CO_2 Partnerships

COST

Total Project Value
$5,934,736

DOE/Non-DOE Share
$4,548,688 / $1,386,048

Objectives

The objectives of this project are to:

- Develop a national carbon sequestration geographic information and relational database management system covering the U.S. and operating through a portal maintained by the National Energy Technology Laboratory website.
- Develop online tools to provide real-time display and analysis of CO_2 sequestration data.

Benefits

The NATCARB project will benefit the United States power industry by providing improved online tools for the real-time display and analysis of CO_2 sequestration data. The system links data on sources, sinks, and transportation facilities within a spatial database that can be queried online. NATCARB can assist decision makers by providing access to common sets of high quality data in a consistent manner. This database will prove invaluable should the nation reach the point were sequestration of CO_2 is necessary to prevent the buildup of greenhouse gases in the atmosphere.

Accomplishments

The NATCARB map server is active and currently running on the internet, and can be utilized by accessing the following web address: http://www.natcarb.org. Reliable communication among the various servers has been established, and tools have been developed to query, display, and analyze CO_2 source, sink, and transportation data.

Tools allow clients to query and plot emissions or production through time for a single source or a combination of sources across a region. Tools are also available to determine the solubility or physical properties of CO_2 under various conditions.

Not only is the NATCARB server connected to all seven Regional Carbon Sequestration Partnerships but data on states not included in any of the Partnerships has been entered into the database. To provide national coverage, data in real- time is being pulled from public servers including the U.S. Geological Survey's Center for Earth Resources Observation & Science (USGS-EROS) and from the Geography Network. Major CO_2 sources have been obtained from U.S. Environmental Protection Agency databases, and data on major coal basins and coalbed methane wells was obtained from the U. S. Department of Energy's Energy Information Agency. Though it is available through the NATCARB site, the databases are stored and managed by the Regional Partnerships.

Plans

NATCARB intends to generate high quality national sale maps and begin development of a new version of the Carbon Sequestration Atlas of the United States and Canada.

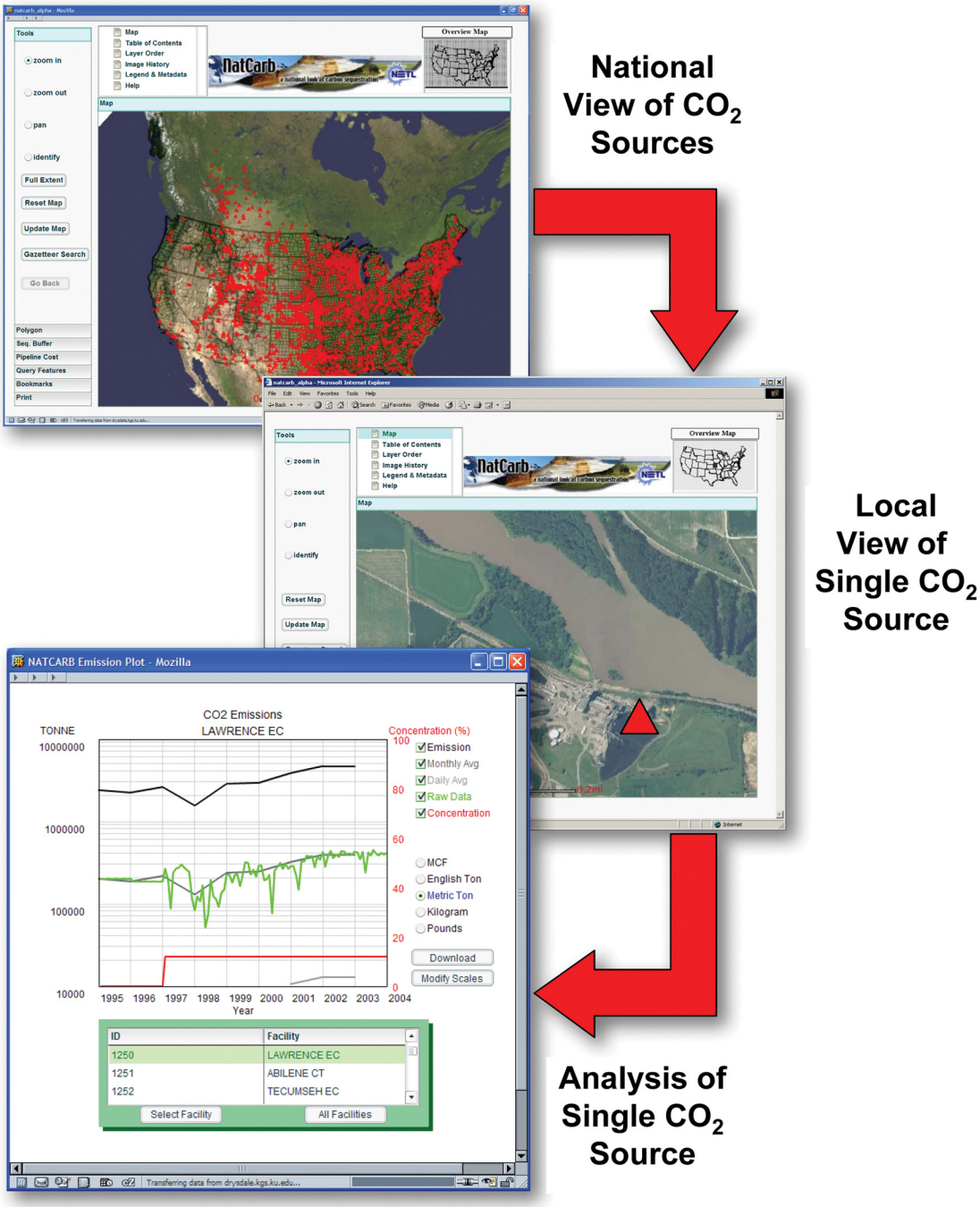

Figure 1. CO_2 Sources

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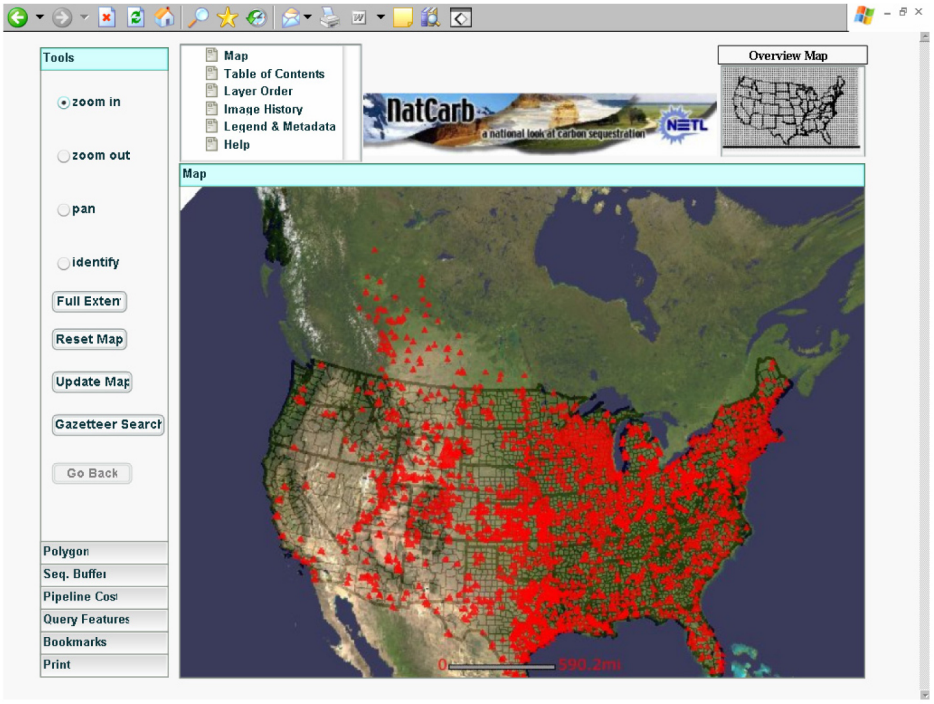

Figure 2. CO_2 Sequestration Sites

PROJECT facts

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

Carbon Sequestration

4/2008

CARBON SEQUESTRATION IN RECLAIMED MINE SOILS OF OHIO

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Background

Prior to 1972, surface coal mining in Ohio was performed by removing the soil and rock above the coal deposit (known as overburden) during mining operations. Because specific reclamation guidelines did not exist at the time, the overburden was not replaced and the mined site was simply planted to grass or trees, without performing grading or reclamation. After 1972, the Ohio Mineland Reclamation Act mandated that mined sites be graded to restore their original topography and reclaimed with topsoil application. In 1977, a Federal law was enacted, titled the Surface Mining Reclamation and Control Act (SMRCA), to regulate the effects of coal mining throughout the United States.

Description

This research project involved the assessment of the soil organic carbon (SOC) sequestration potential of reclaimed mined soils (RMS) at six sites in various counties in Ohio. The experimental sites were chosen at locations where mining occurred both prior to (without topsoil under grass or forest) and after the SMRCA regulation, which made application of topsoil mandatory for reclamation.

In revegetated reclaimed mine soil, the carbon sequestration from recent carbon inputs proceeds from the soil surface to deeper soil layers. Thus, in order to follow this process in a chronological sequence, approximately 50 soil samples were collected from depths of 1–15 centimeters and 15–30 centimeters and analyzed to determine SOC pool, total soil nitrogen pool, and the physical, chemical, and hydrologic properties. The sites received six different reclamation treatments to determine the spatial and temporal variations of SOC and the rate of sequestration in forest and pasture. The mechanisms of SOC sequestration and the potential of using biosolids for reclamation were assessed.

The data gathered were used to test the following hypotheses: (1) The potential of SOC sequestration in RMS depends on biomass productivity, root development in subsoil, and changes in mine soil properties resulting from the weathering of overburden material. (2) The increase in SOC over time is related to improvements in soil quality. (3) The capacity of RMS to sequester SOC is a function of the type and duration of land use. (4) The rate of SOC sequestration is related to changes

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PARTNER

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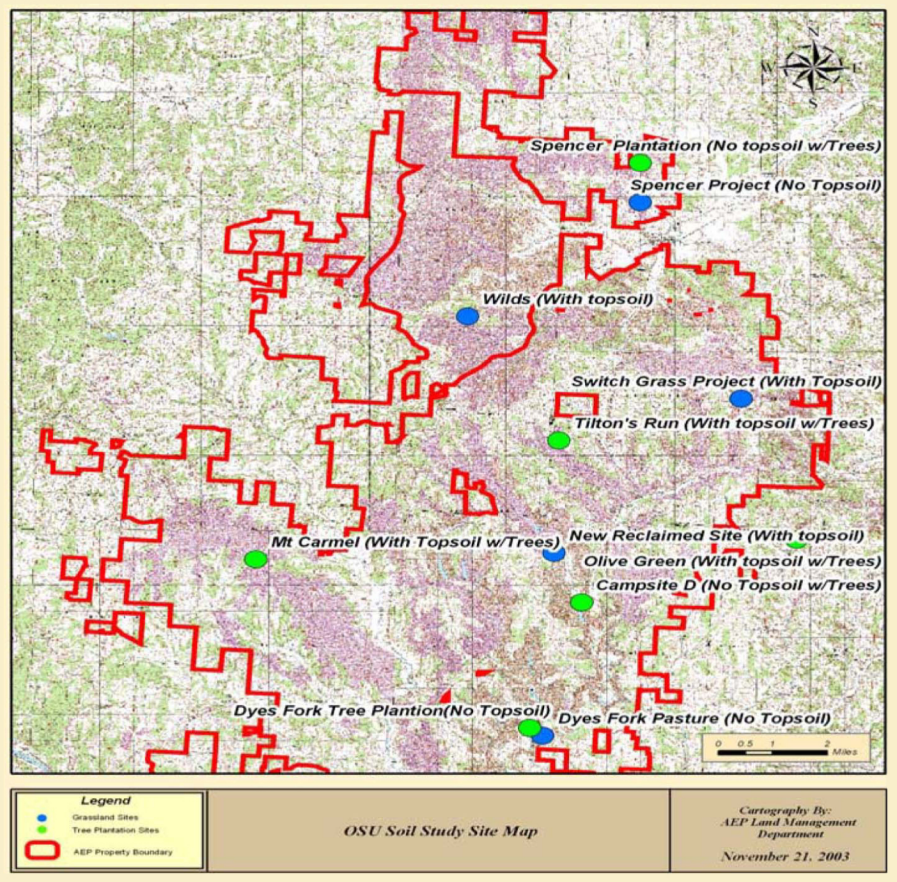
in soil structure. (5) Carbon aggregation is influenced by the interaction between SOC, the silt and clay concentration, and the mineralogical composition. (6) The rate of SOC sequestration increases linearly with the rate of biosolids application and is proportional to the total amount and rate of release of mineralizable nitrogen. (7) The rate of aggregation depends upon the mineralizable carbon and nitrogen in the biosolids. (8) The SOC sequestration potential is related to its mechanical (porosity, strength) and hydrologic (hydraulic conductivity, infiltration rate, available water capacity) properties.

Primary Project Goal

The primary project goal was to assess the degree to which soil carbon sequestration in RMS can offset fossil fuel emissions, provide additional income to land owners through trading carbon credits, and strengthen the terrestrial carbon sequestration database to assist policy makers on land use modifications to mitigate climate change.



This map shows the locations of experimental sites.

Objectives

- Assess the sink capacity of RMS of various ages to sequester SOC.
- Determine the rate of SOC sequestration and the spatial (vertical and horizontal) and temporal variations of SOC.
- Develop and validate a model for SOC sequestration rates.
- Identify the mechanisms of SOC sequestration in RMS.
- Assess the potential of different methods of soil reclamation to alter SOC sequestration rate, soil development, and soil mechanical and water transmission properties.
- Determine the relation between SOC sequestration rate and soil quality in relation to soil structure and hydrologic properties.

Benefits

Soils represent a huge potential sink for sequestering carbon, and carbon trading could provide an incentive for landowners to modify land management practices to increase carbon sequestration in soils. However, for this to be possible, techniques have to be developed to quantify carbon uptake by soils and the best treatments need to be determined to promote carbon accumulation by soils and their associated vegetation. This project addressed both of these issues, and has increased the understanding of the potential of both grassland and reforested minelands to sequester carbon.

Mine Land Without Topsoil Reclaimed to Forest in 1957.

PERFORMANCE PERIOD

09/22/2003 to 12/31/2007

COST

Total Project Value
$706,105

DOE/Non-DOE Share
$563,491 / $142,614

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Accomplishments

- Test sites, characterized by distinct age chronosequences of reclaimed mine soil, were selected. The criteria for selection was soil: (i) reclaimed prior to the 1972 Ohio Mineland Reclamation Act or the 1977 SMRCA and under continuous grass and forest and without topsoil application, and (ii) reclaimed after the 1972 Ohio Mineland Reclamation Act (which made application of topsoil mandatory for reclamation) and under continuous grass and forest and with topsoil application.
- Soil samples were collected from 0–15 cm and 15–30 cm depths and analyzed to determine SOC concentration, total soil nitrogen concentration, pH, and electrical conductivity for each sampling location.
- Results from soil sampling showed that SOC and total nitrogen (TN) concentrations increased with increase in time after reclamation in all three aggregates size fractions for both depths at the forest and grass sites, and that the effect of erosion on SOC and TN concentration was negligible.
- The higher SOC and TN concentrations in older sites demonstrated the sequestration potential of younger sites.
- The forested sites selected for sampling have higher SOC and TN than grassland sites of the same age.

Mine Land Reclaimed to Switchgrass in 1987.

Planned Activities

This project is now inactive and NETL is awaiting the final report.

PROJECT facts

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

Carbon Sequestration

4/2008

GEOLOGIC SEQUESTRATION OF CARBON DIOXIDE IN A DEPLETED OIL RESERVOIR: A COMPREHENSIVE MODELING AND SITE MONITORING PROJECT

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Background

The use of carbon dioxide (CO_2) to enhance oil recovery (EOR) is a familiar and frequently used technique in the United States. The oil and gas industry has significant experience with well drilling and injecting CO_2 into oil-bearing formations to enhance production. While using similar techniques as in oil production, this sequestration field test differs in that its purpose is to store rather than recycle the CO_2. However, CO_2 sequestration in oil reservoirs is a complex process spanning a wide range of scientific, technological, economic, safety, and regulatory issues. Detailed understanding of the many interactions is necessary before this option can become a safe and economic sequestration option, and its development requires a focused research and development effort by government and private industry.

Figure 1: Project field site for testing CO2 sequestration in a depleted oil reservoir nearHobbs, New Mexico.

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Description

Sandia National Laboratory and Los Alamos National Laboratory, along with New Mexico Tech, Colorado School of Mines, and Kinder Morgan, have partnered with an independent producer, Strata Production Company, to investigate down-hole injection of CO_2 into a depleted oil reservoir, the West Pearl Queen Field in New Mexico.

This project is using a comprehensive suite of computer simulations, laboratory tests, and field measurements to understand, predict, and monitor the geochemical and hydro-geologic processes.

Primary Project Goal

The overall objective of this project is to better understand, predict, and monitor CO2 sequestration in a depleted sandstone oil reservoir. Injection into this reservoir was through an inactive well, while a producing well and two shutoff wells are being used for monitoring.

Objectives

- Characterize the oil reservoir and its storage capacity to sequester CO_2.
- Predict multiphase fluid migration and interactions.
- Deploy and evaluate improved remote geophysical monitoring techniques.
- Conduct computer simulations and lab measurements of fluid flow.
- Assess and predict complex geologic sequestration processes.
- Inject several thousand tons of CO2 into a depleted oil reservoir.

- Establish a pre-injection baseline and assess post-injection reservoir conditions to validate model predictions.

Benefits

Science and technology gaps related to engineering aspects of injecting and sequestering CO_2 into a depleted oil reservoir are being identified in this study. Additional results will provide a better understanding of CO_2/reservoir interactions for improving EOR flooding practices.

Accomplishments

During the early field-site efforts, approximately 2,100 tons of CO_2, equivalent to one day's emissions from an average coal-fired power plant, were injected into the target formation. An extensive three-dimensional geophysical survey was conducted prior to CO_2 injection to provide the best possible subsurface image of the reservoir. The CO_2 entered the reservoir at a rate of about 40 tons/day and a pressure of 1,400 psi, and scientists used highly sensitive equipment to acquire micro-seismic signals to help track the movement of the plume. After the CO_2 was allowed to "soak" into the reservoir rock, a second 3-D seismic survey was taken. These observations tell scientists the fate of the CO_2 plume and will be used to calibrate, modify, and validate modeling and simulation tools. Analysis of the seismic data suggests that most of the injected CO_2 pooled in a relatively small area at the base of the injection well, although post-injection venting has recovered less than half of the injected volume.

Results to date show that geologic and preliminary flow simulation results indicate that the concept and feasibility of injecting CO_2 into a depleted oil reservoir has a level of merit for further field validation. In this particular project effort, the geologic characterization with subsurface data and available analogy to nearby relevant outcrops suggest that the reservoir is not entirely homogeneous. Computer simulations have predicted plume travel times and subsequently suggest that the combined saturation and pressure difference waves generated by injected CO_2 can be monitored through use of appropriate seismic surveys. Simulations of the project effort also provide guidelines for geophysical monitoring (e.g., spacing of sources and receivers). Geochemical experiments with Queen Sandstones have shown a better understanding of the potential for in situ mineralization.

Recent laboratory experiments were performed to determine the effect of CO_2 exposure on sandstone using core samples from the Wet Pearl Queen field. The experimental temperature and pressures mimicked the downhole conditions in the

PARTNERS

Sandia National Laboratory

Los Alamos National Laboratory

New Mexico Tech University

Strata Production Company

Kinder-Morgan CO_2 Company

Colorado School of Mines

PERFORMANCE PERIOD

5/01/2000 to 3/31/2008

COST

Total Project Value
$4,300,000

DOE Share/Non-DOE Share
$4,300,000 / $ 0

reservoir during field experiments, especially during the soak period. Multiple samples were exposed to CO_2 for six months. Analysis of the rock samples (pre- and post-soak) and fluid samples were collected during laboratory experiments to determine whether they show evidence of geochemical interactions due to CO_2 exposure. The preliminary mineral analysis does not show significant geochemical alteration of the reservoir core samples.

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Project229.indd

PROJECT facts

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

Carbon Sequestration

4/2008

DEVELOPMENT OF NOVEL MONITORING TOOLS FOR GEOLOGIC SEQUESTRATION

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Background

The main goal of the U.S. Department of Energy's (DOE) Carbon Sequestration Technology Roadmap is to "develop, by 2012, fossil fuel conversion systems that offer 90 percent CO_2 capture with 99 percent storage permanence at less than a 10 percent increase in the cost of energy services." To ensure 99 percent storage permanence, the current monitoring, mitigation, and verification (MMV) technologies must be advanced to be able to locate and quantify the CO_2 within a storage reservoir. If leaks do occur, they will need to be detected from above the storage reservoir (from the reservoir to the surface). However, current methods cannot achieve these metrics. For example, although seismic imaging shows promise for detecting CO_2 plumes, conventional approaches cannot sufficiently quantify the CO_2 content in large plumes. Field experience with enhanced oil recovery (EOR) and several large sequestration efforts (e.g., Sleipner and Weyburn projects) demonstrate clearly that seismic images are sensitive to the presence of injected CO_2, allowing rough delineation of plumes. Furthermore, seismic studies at small CO_2 test injections (e.g., Frio and Hobbs) demonstrate that seismic reflection is sensitive to plumes as small as a few thousand tonnes. However, this does not mean that seismic imaging can currently quantify a large plume to a precision of a few thousand tonnes.

Primary Project Goal

The primary focus of the current effort is to address specific monitoring challenges as opposed to specific monitoring technologies. These challenges will include:

- Quantifying and attributing stored CO_2 within a reservoir
- Quantifying and attributing stored CO_2 outside the reservoir
- Detecting CO_2 movement within and through a storage reservoir
- Detecting potential CO_2 flow paths
- Improving the accuracy of CO_2 seepage detection to better than 80 percent, and
- Improving the detectability of physical or chemical changes in rock matrices to better than 60 percent.

Objectives

The object of this research program is to quantify CO_2 within and leaking from geological storage reservoirs. The research aims to target the CO_2 storage reservoir and the soil surface to advance MMV tools to better assess CO_2 impacts to and leaking from a reservoir. Specifically, both direct and indirect CO_2 detection tools will be integrated to provide a high temporal and spatial resolution of CO_2 seepage at the soil surface and ultimately supply information regarding the mechanism of seepage. Novel seismic and acoustic imaging analyses will be performed to characterize the location of the CO_2 plume and determine any structural (caprock fracture) or chemical (mineralization or precipitation) changes to the storage reservoir. These MMV technologies will be advanced to better quantify the storage permanence of CO_2 within a storage reservoir. The research will be conducted in three phases.

Phase 1 consists of laboratory and modeling work to create in situ MMV systems. The primary objectives of this phase are to 1) create surface CO_2 detection systems that can operate and accurately detect CO_2 with high precision in varying environmental conditions (rain, snow, variable temperatures, pressures, and humidity); and 2) to create geophysical systems that can detect subsurface physical and chemical features through the coupling of P-P, P-S, S-P, and S-S waveforms.

Phase 2 consists of field deployment of MMV in situ systems and integration of data. The primary objectives of this phase are to 1) deploy the indirect and direct CO_2 analyzers collectively at a natural analog and an engineered CO_2 storage site once the in situ systems are shown to work in varying meteorological conditions; 2) determine the detection limits and sensitivity of the surface CO_2 detection tools in varying meteorological conditions; 3) accurately couple the data streams coming from the different MMV tools to temporally resolve and quantify CO_2 seepage in natural and engineered storage systems; and 4) integrate the surface and subsurface data to determine the seepage mechanism.

Phase 3 consists of expanding areas of analyses to large spatial scales. The primary objectives of this phase are to 1) use two-dimensional (2D) geologic models coupled with seismic waveforms collected from regions of known CO_2 storage to better determine CO2 plume characteristics and movement in three dimensions (3D); and 2) test and enhance laser systems to perform remote sensing of CO_2 in challenging field conditions.

Accomplishments

Novel monitoring systems that can detect CO_2 seepage at the soil surface have been engineered, tested in the laboratory, and are now being fitted for field deployment. The specific tools that have been created to detect CO_2 seepage are oxygen (O_2)/CO_2 measurement systems, radon (^{222}Rn) detectors – able to measure small amounts of ^{222}Rn continuously and used as a surrogate for advective flow, and portable stable isotope detectors of CO_2 that can be used for in situ analyses (high temporal resolution at one point location) and remote analyses (large spatial coverage over a field). The project has also created seismic imaging analyses using P- and S-waveform analyses to identify faults in modeled scenarios. The research will be expanded to real case studies of fault systems and engineered storage sites that will actively pump CO_2 down hole to image CO_2 plume movement and also faults in caprock.

Current accomplishments include:

- Creation of an in situ stable isotope analysis system
- Deployment of a ^{222}Rn system into the field and meteorological impact of the ^{222}Rn background (Figure 2)
- Creation of an O_2/CO_2 concentration system and laboratory testing of this system using standards
- Creation of a remote stable isotope analysis system and laboratory testing using standards, and
- 2D and 3D analyses of P- and S-waveforms used to detect faults in the subsurface using synthetic analyses on model generated faults (Figure 3).

Benefits

If this project is successful, it should be possible to quantify the surface CO_2 leakage over large spatial (100 m this year, as high as 1 km in future years) and temporal scales (1 second resolution), detect and locate caprock fractures, and detect and locate chemical changes within the reservoir rock over large spatial scales. The use of these new tools will help enable the 99 percent storage permanence that is targeted in the 2007 DOE Carbon Sequestration Technology Roadmap. The project will create an MMV tool set, assess multiple potential technologies or approaches, and prioritize research directions dynamically based on a specific pathway's likelihood of success.

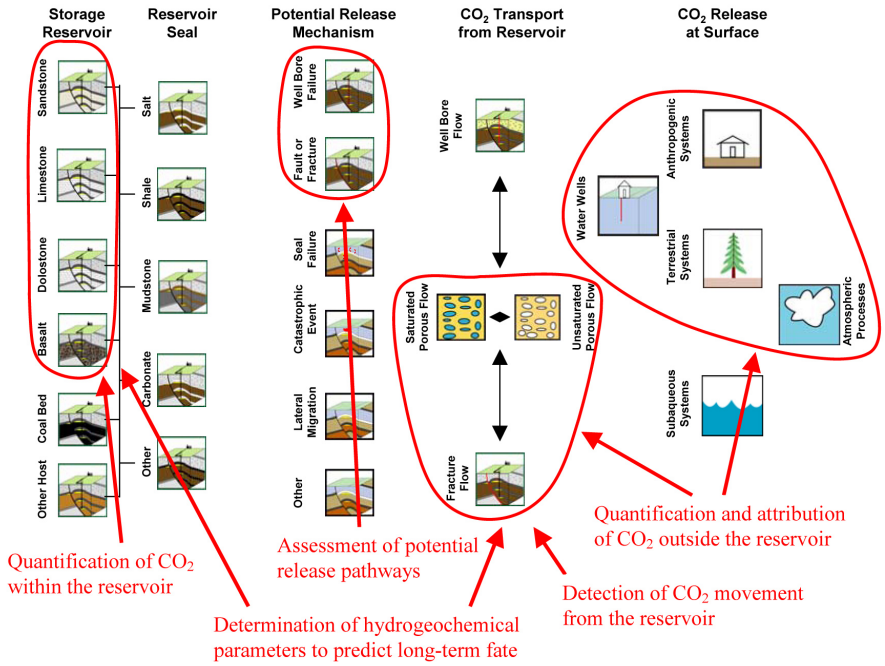

FIGURE 1. Schematic of CO_2-PENS Framework for understanding geologic storage systems and CO_2 release from these systems. Red circles and text indicate the objectives and target areas of this novel monitoring program and how these objectives can map into the DOE Carbon Sequestration Roadmap.

PERFORMANCE PERIOD

07/01/2007 to 06/30/2008

COST

Total Project Value

$900,000

DOE/Non-DOE Share

$900,000 / $0

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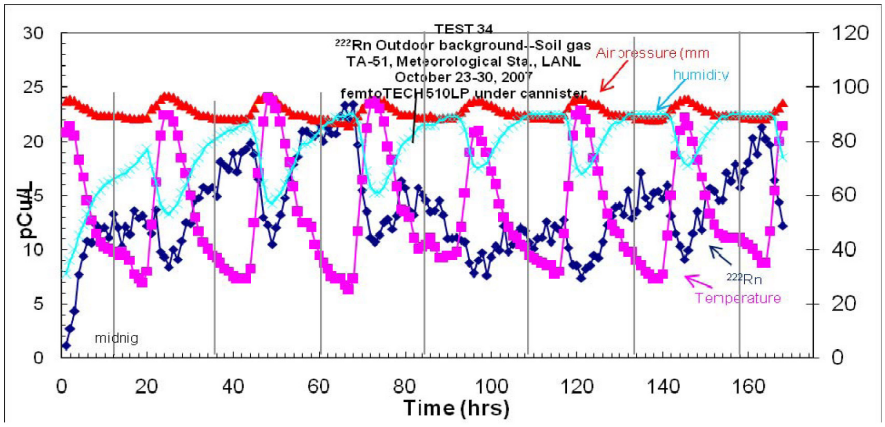

FIGURE 2. ^{222}Rn variation over 8 days in October 2007 at Los Alamos National Laboratory, Technical Area 51. Strong diurnal patterns are observed in the ^{222}Rn and the meteoric variables with highest correlations are observed between the ^{222}Rn concentration and the atmospheric pressure. This indicates that the natural background of ^{222}Rn leaving the soils is effectively pumped out of the soils due to regional winds and pressure highs.

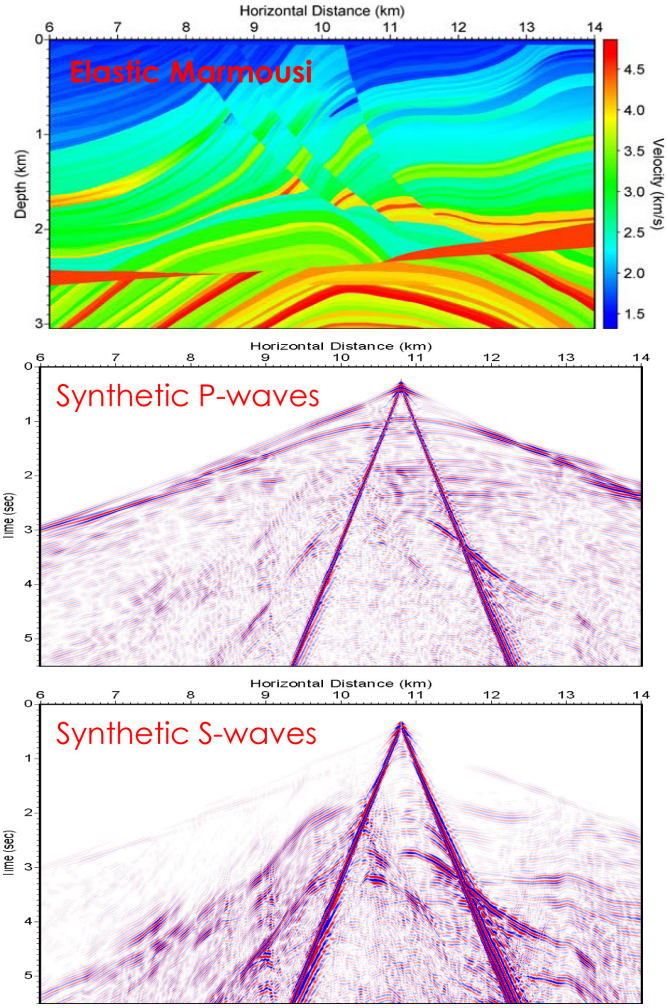

FIGURE 3. Synthetic P- and S-waveforms of the elastic Marmousi model containing three faults. These waveform analyses (P-wave, S-wave, PS-wave, SS-wave, SP-wave) will be used on known fault systems to image the faults in varying media types. Time-lapse seismic imaging of targeted fault systems will be used to identify faults and monitor potential leakage through faults over time.

Project337.indd

PROJECT facts

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

Carbon Sequestration

04/2008

Stored CO_2 and Methane Leakage Risk Assessment and Monitoring Tool Development: CO_2 Capture Project Phase 2

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Background

Unmineable coal seams at depths beyond conventional recovery limits are potential storage reservoirs for carbon dioxide (CO_2) and enhanced coalbed methane (ECBM) recovery operations. This project supports the U.S. initiatives for reducing greenhouse gas intensity and improving domestic energy security by enhancing the potential for carbon sequestration in deep, unmineable coal seams with ECBM recovery. It addresses three critical topics that require further work to gain broad public acceptance for geological sequestration in methane coalbeds: (1) integrity of coalbed methane (CBM) CO_2 geologic storage systems, (2) optimization of the ECBM recovery and CO_2 storage processes, and (3) reliable monitoring of these operations. This project builds on past CO_2 Capture Project- (CCP) sponsored work in this area.

The program addresses optimization of ECBM recovery using CO_2, in addition to monitoring, verification, and risk assessment of CO_2 geologic sequestration in coalbeds. A numerical modeling study is using a state-of-the-art CBM simulator to define the physical and operational boundaries and tradeoffs for safe and effective CO_2 storage accompanying CO_2 ECBM recovery. An innovative geophysical approach is assessing the ability of non-seismic techniques to adequately monitor gas movement in coal beds under CO_2 flood with techniques that offer considerable cost savings over more conventional seismic techniques. An aerial remote-sensing approach is using cutting-edge thermal hyperspectral imagery to test the feasibility of monitoring large surface areas for CO_2 and methane seeps. If successful, it could eliminate the need for an extensive ground-based monitoring system and associated operational costs. The potential advances in optimization of ECBM recovery and CO_2 storage operations in coalbeds, along with advances in monitoring these processes, will provide assurance and the basis for public acceptance of geologic storage in coalbeds. The two gas monitoring technologies—non-seismic geophysical techniques and hyperspectral imagery—are innovative approaches that offer considerable cost savings over conventional techniques.

Primary Project Goal

The primary project goal is to develop and test tools for optimization of ECBM recovery and geologic storage of CO_2 in coalbeds, in addition to tools for monitoring CO_2 sequestration in coalbeds to support risk assessment. Three critical topics identified are (1) the integrity of coal bed methane geologic and engineered systems, (2) the optimization of the coal bed storage process, and (3) reliable monitoring and verification systems appropriate to the special conditions of CO_2 storage and flow in coals.

Objectives

The objectives of this project are:

- To establish CO_2 injection and methane production procedures in deep,

PARTNERS

CO_2 Capture Project Phase 2/ BP America Inc.

Sproule Associates, Inc.

University of California – Santa Cruz

Lawrence Berkeley National Laboratory

PERIOD OF PERFORMANCE

03/09/2005 to 06/08/2008

COST

Total Project Value
$601,240

DOE/Non-DOE Share
$300,620 / $300,620

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unmineable coals that will avoid CO_2 and methane leakage by using a state-of-the-art CBM simulator to define the physical and operational boundaries and tradeoffs for safe and effective CO_2 storage.

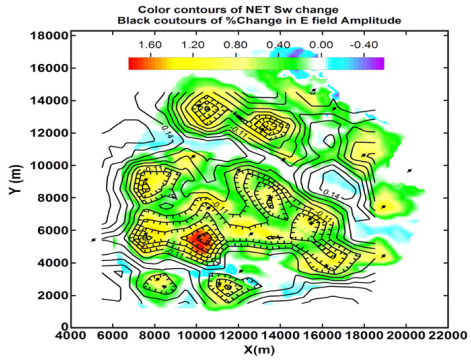
- To develop cost-effective technology to monitor the movement of CO_2 and methane (CH_4) in subsurface coals using an innovative geophysical approach based on electromagnetics (EM) and gravity at considerable cost savings over conventional seismic monitoring techniques.
- To develop technology for detecting CO_2 and CH_4 leakage at the surface using aerial imagery based on thermal hyperspectral monitoring that has the potential for evaluating large surface areas for seepage at considerable cost savings over ground-based surface monitoring systems.

Accomplishments

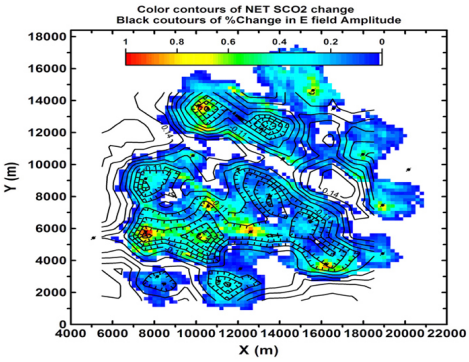
- Geologic and reservoir engineering data from a coalbed methane CO_2 storage pilot demonstration at the Deerlick Creek Field, Black Warrior Basin in Alabama were acquired, evaluated, and integrated into the reservoir simulation and geophysical study tasks.
- A ground-surface controlled leak experiment releasing CO2 and CH4 was conducted at the Naval Petroleum Reserve Site #3 in Wyoming in 2006. Aerial hyperspectral imagery based on MASTER technology was acquired and analyses of these data demonstrated that MASTER could identify CO_2 and CH_4 surface seeps at high concentrations.
- Based upon the Deerlick Creek Field, Black Warrior Basin pilot site in Alabama, sensitivity studies were conducted to model injection of CO_2 in coalbeds, and to compute resultant gravity and EM signals. Results of the sensitivity study indicate gravity and EM anomalies would result and could be detected by geophysical field surveys.

Benefits

Growing concern over the potential adverse effects of CO_2 buildup in the atmosphere leading to global climate change may require reductions in carbon emissions from industrial sources. One promising option is the capture of CO_2 from large point sources and subsequent sequestration in geologic formations. However, for this approach to achieve wide acceptance, there will need to be assurances that the sequestration projects can be monitored to ensure their safety. This work will advance optimization of CO_2 ECBM recovery and CO_2 coalbed storage operations and develop innovative technologies to monitor CO_2 in the reservoir and at the surface. These technologies will help expand the viable options for geologic storage of CO_2 emissions from coal-based energy and power.



Spectral monitoring equipment used to acquire aerial imagery during the CO_2 and CH_4 controlled surface leak experiment at the Naval Petroleum Reserve Site #3, Wyoming.



Electromagnetic surveying equipment and map showing electric field response to reservoir CO_2 saturation changes for a simulated field case study.

Project392.indd

PROJECT facts

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

Carbon Sequestration

4/2008

ASSESSING FOSSIL AND RECENT CARBON POOLS IN RECLAIMED MINED SOILS

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Background

There is ample indication that reclaimed mine lands have great capacity to be used to sequester carbon dioxide (CO_2) generated by coal-fired utility and industrial power plants. This carbon could offset CO_2 emissions associated with extraction and burning of coal and provide public utilities and other industries with carbon credits. However, the present estimates of carbon pools in reclaimed mined lands are uncertain. This uncertainty is linked primarily to failure to account for carbon (C) associated with coal particles and, given the variability of soil properties at reclaimed land sites, the lack of standardized sampling protocols in assessing carbon pools.

Organic carbon present in mined lands is a mixture of carbon from coal particles (old carbon) and carbon resulting from decomposition of plant residues (recent carbon). In these soils, carbon sequestration essentially refers to the increase in the new carbon pool. However, because of their high carbon content, coal particles represent a large carbon background against which detection of small increases in recent carbon are difficult to determine. This analytical challenge must be resolved in order to generate credible information on carbon sequestration rates in reclaimed mined lands.

Description

In nature, carbon occurs as stable isotopes carbon-12 (12C) and carbon-13 (13C) (1.12 percent of atmospheric CO_2) and as the radioisotope carbon-14 (14C), which has a half-life of 5,730 years. Given that coal was deposited several hundred million years ago, coal shows no radiocarbon activity. Thus, 14C activity recorded in soil samples from reclaimed mined lands can be attributed to new carbon. Although this approach has been successfully used in assessing the contribution of lignite to carbon pools in reclaimed lands, its high cost precludes widespread adoption of this technique. In this study, carbon that is the result of the decomposition of plant

PARTNERS

The Ohio State University
Research Foundation

residues (e.g., corn) is determined by a chemo-thermal procedure, making it possible to partition the total carbon pool in reclaimed soils into coal carbon and recent carbon. This chemo-thermal procedure assumes that coal carbon is less reactive than recent carbon. Therefore, a series of chemical and thermal treatments will be applied to selectively remove the new carbon from the sample so that the refractory coal carbon left behind can be quantified.

This project includes mining sites, reclaimed cropland with a recent corn crop, and reclaimed grassland at various locations across a 300-400 km transect spanning the Northern Appalachian coal basin in Ohio, West Virginia, and Pennsylvania. Topography and grid-based soil sampling is being conducted at selected reclaimed grassland sites and, through assessment of the spatial patterns of carbon distribution, a sampling design is being proposed to better estimate carbon in reclaimed mined lands. Radiocarbon activity will only be used to validate the proposed chemo-thermal and 13C -based procedures. The 13C approach exploits differences in 13C composition between coal and new carbon.

Primary Project Goal

The primary goal of this project is to develop and test several analytical procedures that can reliably determine the amount of coal-derived C in reclaimed mined lands.

Objectives

The objectives of this project are to:

- Develop and test a 13C-based procedure to determine the fraction of coal carbon present in reclaimed soils.
- Evaluate a chemo-thermal procedure, based on the lower reactivity of coal carbon compared to recent carbon, to partition organic carbon in reclaimed soils into coal-derived and newly deposited carbon fractions.
- Establish an optimum sampling protocol (intervals and number of sampling points) to produce an accurate assessment of carbon sequestration in reclaimed mined lands.

Benefits

One option for sequestering CO_2 is increasing the amount of carbon stored in reclaimed mined lands. However, the granting of credit for such sequestration hinges on the availability of replicable analytical techniques and methods to determine and verify the increased (recent) carbon content of the soil. A major problem, however, is the presence of coal carbon, which greatly increases the difficulty of accurately determining recent carbon. By addressing this problem, this project will make a significant contribution toward determining the viability and potential of carbon sequestration in reclaimed mined land to reduce greenhouse gas emissions in the United States.

FIGURES 1 & 2
Coal mined lands in southeastern Ohio

PERFORMANCE PERIOD

09/01/2004 to 09/30/2008

COST

Total Project Value
$551,719

DOE/Non-DOE Share
$425,532/$126,187

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Accomplishments

- Two chemical methods were modified and tested for selective removal of recent carbon in mine soils:
  - Sodium hydroxide (NaOH) extraction
  - Acidified chromium potassium oxide ($K_2Cr_2O_7$) oxidation
- Soil coal mixture analysis indicated that both methods were effective in removing recent carbon with little effect on coal carbon.
- An Evaluation determined that top soils appear to be losing density over time; this is attributed to the increasing concentrations of nitrogen (N) and carbon, whereas deeper soils are increasing in density with their N and C contents remaining relatively constant.
- Tests determined that the recent carbon concentrations vary by the type of agriculture occurring on the reclaimed mine lands, with forest areas having low concentrations and grazing areas having high concentrations of recent carbon.

PROJECT facts

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

Carbon Sequestration

04/2008

Low Cost Open-Path Instrument for Monitoring Atmospheric Carbon Dioxide at Sequestration Sites

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Background

Growing concern over the effect on global climate of the buildup of greenhouse gases (GHG), particularly carbon dioxide (CO_2), in the atmosphere may lead to the curtailment of CO_2 emissions. One potential course of action by industry to reduce GHG emissions is the subsurface disposal of CO_2. An important requirement of such disposal is verification that the injected gases remain in place and do not leak to the surface. Perhaps the most direct evidence of a successful sequestration project is the lack of a detectable CO_2 concentration above the background level in the air near the ground. Although measurement of CO_2 concentration can be performed, it is difficult to accomplish at a reasonable cost over the large area that is typical of large, subsurface gas injection projects. One technically attractive approach is to employ a so-called open-path device that uses a laser to shine a beam – with a wavelength that CO_2 absorbs – over many meters. The attenuated beam reflects from a mirror and returns to the instrument for determination of the CO_2 concentration. One instrument can sample a large area, if it can reflect from more than one mirror.

Current commercial instruments capable of this cost tens of thousands of dollars. The purpose of this project is to develop an inexpensive (instrument cost of no more than a few hundred dollars) open-path laser instrument to measure CO_2 concentration over the range of interest (300–500 ppmv). The low-cost target should be attainable by designing an instrument for this one specific application. In contrast, the expensive commercial units can measure the levels of multiple gases over a wider range of concentrations. The newest technology in the communications industry can be used to build a prototype with inexpensive, off-the-shelf components.

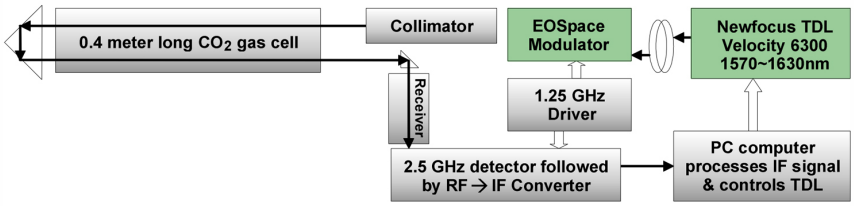

Figure 1. Schematic for bench top CO_2 measurement using FM spectroscopy.

PARTNERS

California Institute of Technology

PERFORMANCE PERIOD

09/30/2004 to 09/30/2008

COST

Total Project Value
$438,286

DOE/Non-DOE Share
$350,629 / $87,657

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Primary Project Goal

The primary goal is to develop and test an inexpensive open-path instrument that will measure and monitor atmospheric CO_2 concentrations within a range of 300-500 ppmv.

Objectives

The objectives of the project are the following:

- To develop a prototype instrument capable of measuring CO_2 concentration over a 5-kilometer path length with an update speed of once every several minutes and an accuracy of 98-99%.
- To test the prototype instrument over a short range (e.g., 100 m) and determine its performance range.
- To mount the prototype instrument on a rooftop and determine its performance over a range up to 5 km.
- To field test the monitor in an operating CO_2 geological sequestration site.

Benefits

One approach that is being seriously considered for alleviating the buildup of GHGs in the atmosphere is the capture of CO_2 from fossil fuel–fired power plants and sequestering the CO_2 in geologic formations. Although this approach appears to be technically feasible, the public will not accept it unless they can be assured that the sequestered CO_2 will remain in place and not leak to the surface. A vital part of providing this assurance is the ability to economically measure CO_2 concentrations over large areas so that any leaks can be quickly detected and remediation measures taken. The success of this project will go a long way toward providing an instrument to fill this monitoring need.

Accomplishments

- Specifications and testing protocols have been developed for the CO_2 monitor.
- 1% accuracy has been demonstrated in short period tests (~1 hour).
- Unattended system operation and stability over a period of a week has been demonstrated with and without EDFA (laser power amplifier). EDFA amplification can be further increased by a factor of 3-5, therefore, the operating rage of the instrument is estimated to be 2.5 km (5 km round trip).
- The sensitivity of the instrument to CO_2 leaks has been demonstrated.

PROJECT facts

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

Carbon Sequestration

04/2008

APPLICATION OF LOW-COST DIGITAL ELEVATION MODELS TO DETECT CHANGE IN FOREST CARBON SEQUESTRATION PROJECTS

Background

Although combustion of fossil fuels is the major contributor to the buildup of carbon dioxide (CO_2) in the atmosphere, deforestation also makes a significant contribution. According to the Intergovernmental Panel on Climate Change (IPCC), burning associated with deforestation accounts for approximately 20 percent of the annual global emissions of CO_2. The IPCC also estimates that 12 to 15 percent of CO_2 emissions from the combustion of fossil fuels could be offset for the period from 1995 to 2050 through decreasing the rate of tropical deforestation, regeneration of tropical forests, and engaging in various forms of agro-forestry. Thus, forest management holds significant potential for decreasing the rate of increase in the CO_2 content of the atmosphere.

The CO_2 sequestration potential of a forest, as a direct result of the photosynthesis of CO_2, can be related to the amount of biomass that the forest contains. Mathematical models have been developed relating the amount of biomass contained in a tree to parameters, such as the height or diameter of the tree. These parameters are typically measured from the ground, which is quite time-consuming and costly.

Digital elevation models (DEM) can reduce the time and cost of obtaining the data necessary to quantify the biomass content of a forest. This technology involves flying an aircraft over a forest and photographing the area using special photographic techniques. The photographic information can then be analyzed to obtain data on tree

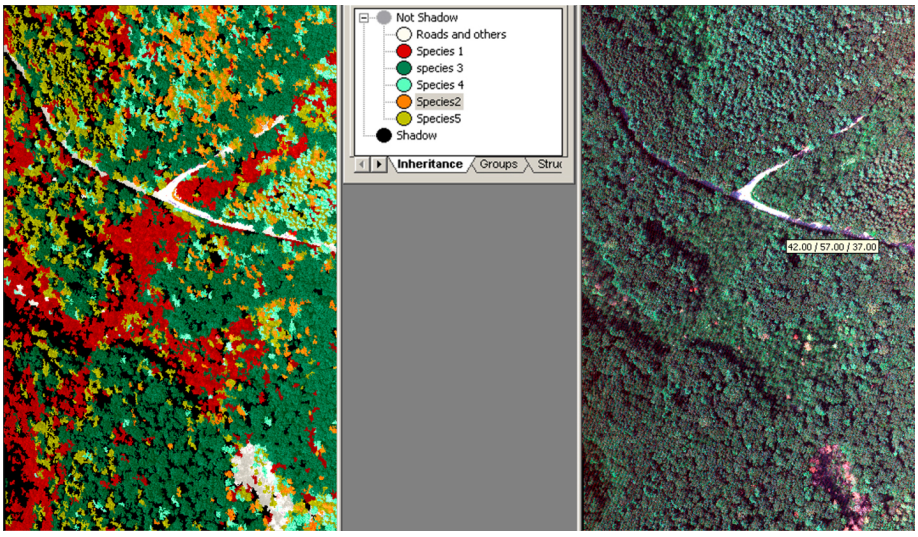

Figure 1 - Sample Output from Digital Elevation Model (DEM)

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PARTNERS

Winrock International
American Electric Power

PERIOD OF PERFORMANCE

07/29/2005 to 07/31/2007

COST

Total Project Value

$551,983

DOE/Non-DOE Share

$398,720 / $153,263

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height and crown area in a known area. This data can then be used with appropriate allometric equations to estimate the biomass and, consequently, the carbon inventory of the forest.

Primary Project Goal

The primary goal of this project is to develop, test, and apply new low-cost technologies using three-dimensional (3-D) terrain reconstruction with multiple ranging lasers and multispectral imagery to detect changes in the carbon inventory in mixed hardwood forests.

Objectives

The objectives of this project are to:

- Develop and test low-cost, optically derived Digital Elevation Models (DEM) of forest canopy using multiple ranging lasers.
- Develop and test software to detect changes in forest canopy by comparing DEMs produced at two different times on the same site to determine the effect of managed change.
- Assess the utility of the automated process in detecting carbon inventory changes.
- Estimate the cost of using this approach, compared to existing approaches, and the effect on the design and implementation of a monitoring and measurement plan.

Benefits

This project will provide multiple benefits by providing an economical tool for measuring the carbon content of trees and other vegetation. Besides providing information critical to assessing the sequestration potential of various terrestrial sinks, digital elevation models enable:

- Vegetation change tracking
- Detection of illegal logging
- Documentation of forest certification
- Forest inventory

This will be very beneficial in planning, assessing, and verifying terrestrial carbon sequestration projects. Credits for terrestrial carbon sequestration projects can only be assigned if the increase in carbon inventory due to management activities can be accurately determined and verifiable.

Accomplishments

- Completion of test measurements and comparative analysis.
- One test site had a difference of 3 percent between laser and ground-based measurements.
- Lasers allow for a true distribution of strata for a larger range than a ground-based plot.

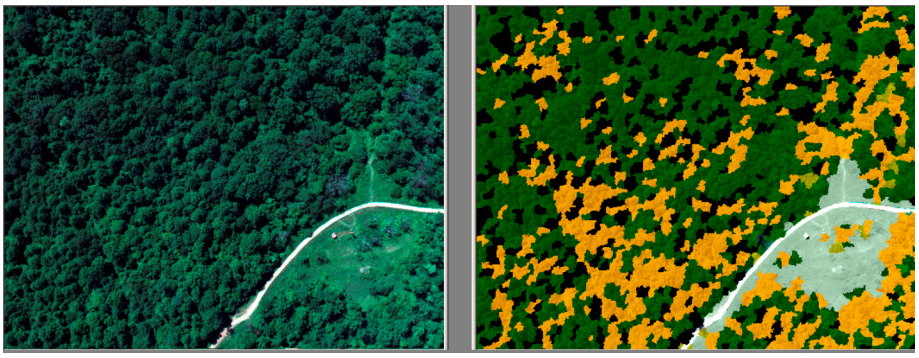


Figure 2 - Output from DEM

Project391.indd

PROJECT facts

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

Carbon Sequestration

04/2008

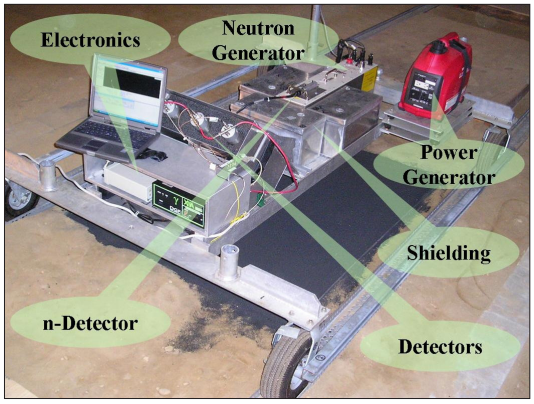
NEW APPROACH FOR LONG-TERM MONITORING OF CO_2 LEAKS FROM GEOLOGIC SEQUESTRATION

Background

Monitoring, mitigation, and verification (MMV) capabilities are critical in ensuring the long-term viability of carbon capture and storage (CCS) projects. MMV research is generally focused on developing techniques to provide an accurate account that the stored CO_2 will remain safely and permanently stored in suitable geologic formations. Furthermore, assuring human health and safety and preventing damage to the host ecosystem will be essential in obtaining permits for geologic sequestration projects.

Description

Brookhaven National Laboratory (BNL) developed a multi-elemental scanning instrument for determining carbon analysis in soil. The method is based on inelastic neutron scattering (INS), which offers a non-invasive method for continuous monitoring of the soil carbon and other elements in situ over both specific plots and large areas. In the original experiments, BNL researchers were able to effectively monitor underground carbon concentrations with INS and evaluate various strategies for terrestrial carbon sequestration. This new initiative will implement INS over the long term to effectively monitor near-surface carbon buildup resulting from the seepage of CO_2 sequestered in geological formations. This second generation of INS allows for an enhanced level of carbon detection in soil from the current detection limit of .5 percent to .01 percent. The project will also provide a new approach for monitoring changes in soil carbon sequestration for the purpose of trading with carbon credits.



Mobile INS system

Primary Project Goal

The purpose of this project is to test a new approach for the long-term monitoring of near-surface CO_2 buildup. Additionally, this project will enable a new approach for monitoring land remediation of coal mine lands for possible carbon credit trading. This new approach is based on a new INS technology that was tested in field measurements in static and scanning modes. This technology is non-destructive, multi-elemental,

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PARTNERS

Brookhaven National Laboratory

PERIOD OF PERFORMANCE

10/01/2007 to 09/30/2008

COST

Total Project Value
$250,000

DOE/Non-DOE Share
$250,000 / $0

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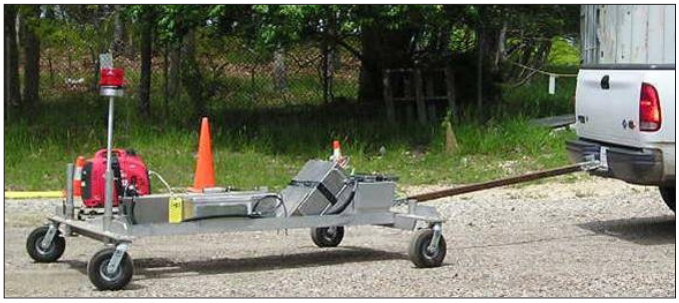
and analyzes large soil masses greater than 300 kg in situ. The INS fills a specific gap in below-ground measurement by scanning large areas and monitoring the cumulative buildup of CO_2, thus increasing the sensitivity for leak detection.



INS system ready for deployment in the field

Objectives

The short-term objectives of this project are to:

- Modify the INS's power generator with a battery setup to eliminate exhaust CO_2 emissions in the field and thus avoid inaccuracies in the experimental data
- Integrate the INS system with the planned experiments at the Zero Emissions Research and Technology (ZERT) facility at Montana State University
- Evaluate the effects of soil moisture and density on the system response
- Evaluate the effect of varying soil carbon profiles on INS calibration
- Perform Monte Carlo simulations and system analysis for soil carbon build-up
- Establish INS baselines at two mine reclamation sites (Ohio and Pennsylvania) with two different land remediation protocols

The long-term objectives are to:

- Complete INS system characterization and deploy it to additional geologic sequestration project sites, such as the Frio Brine Pilot test facility
- Implement the INS system for systematic soil carbon monitoring at CO_2 injection facilities
- Complete follow-up monitoring of mine land reclamation
- Complete calibration of the image pixels from aerial spectral scans with INS scans

INS system in use in a wheat field in Montana

Benefits

The anticipated benefit of such a system is the ability to monitor critical MMV issues associated with CCS projects. DOE's Carbon Sequestration Program is working to develop technologies to promote the cleaner use of coal and for capturing and permanently storing CO_2, a greenhouse gas that can contribute to global climate change. This new adaptation of the INS system will enhance long-term monitoring of CO_2 at geologic sequestration sites by improving the ability to detect the unlikely occurrence of a CO_2 leak.

R & D facts

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

Carbon Sequestration

04/2008

Development of Comprehensive Monitoring Techniques to Verify the Integrity of Geological Sequestration Reservoirs Containing Carbon Dioxide

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Background

Research aimed at monitoring the long-term storage stability and integrity of carbon dioxide (CO_2) sequestered in geologic formations is one of the most pressing areas of need if geologic sequestration is to become a significant factor in meeting the United States' stated objectives to reduce greenhouse gas emissions. The most promising geologic formations under consideration for CO_2 sequestration are active and depleted oil and gas formations, brine formations, and deep, unmineable coal seams. Unfortunately, the long-term CO_2 storage capabilities of these formations are not yet well understood.

Primary Project Goal

The goal of this effort is to develop and demonstrate advanced monitoring techniques to assess the capacity, stability, rate of leakage, and permanence of CO_2 storage in geologic formations.

Soil-gas monitoring conducted by NETL personnel at an enhanced coalbed methane recovery site (Southwest Regional Sequestration Partnership) located at the San Juan Basin in northern New Mexico.

PARTNERS

Carnegie Mellon University

Los Alamos National Laboratory

Midwest Geological Sequestration Consortium

Midwest Regional Carbon Sequestration Partnership

Sandia National Laboratory

Southeast Regional Carbon Sequestration Partnership

Southwest Regional Partnership on Carbon Sequestration

West Virginia University

PERFORMANCE PERIOD

10/01/2007 to 09/30/2008

COST

$1,940,000

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Objectives

The primary objective of this project is to apply a complementary suite of surface and near-surface monitoring techniques to detect short-term, rapid loss, or long-term intermittent leakage of CO_2 from geologic storage formations. These techniques include monitoring perfluorocarbon tracers added to the injected CO_2 that can be detected in soil-gas at parts-per-quadrillion levels, shallow water aquifer chemistry changes, fluxes of CO_2 at the surface, and natural tracers (e.g., radon and light hydrocarbons) in soil-gas.

Additional objectives are to:

- Perform geophysical site analysis using ground-based measurements and remote sensing that combines satellite-visible and infrared views with optical aerial photography.
- Monitor for long- and short-term leakage during the Regional Carbon Sequestration Partnerships' (RCSPs) Phase II and Phase III projects.
- Locate abandoned wells using airborne and ground-based magnetometry, while simultaneously evaluating the leakage potential using radiometry and methanometry.
- Evaluate the degradation of well-sealing cements under downhole conditions of temperature and pressure.

Benefits

The development of techniques to monitor the integrity of geologically sequestered CO_2 is needed to assure public health and safety and gain public acceptance of geologic sequestration technology. Active and depleted oil and gas formations, brine formations, and deep coal seams that were previously unused now have the potential to serve as sinks for CO_2 sequestration. Additionally, harmful emissions, which may contribute to global warming, are prevented from entering the atmosphere.

Accomplishments

The United States Department of Energy's (DOE) National Energy Technology Laboratory (NETL) is currently involved in collaborations with the seven RCSPs to monitor Phase II and Phase III pilot- to intermediate-scale field tests. These tests involve injection into unmineable coalbeds and saline formations, with injections ranging from hundreds of tons to a million tons of CO_2. For this effort, NETL is employing a large suite of complementary surface and near surface monitoring techniques as mentioned in the objectives statement above, developing risk-assessment software that will be applied to field sites, and performing geo-mechanical stress tests on RCSPs' reservoir and cap rock samples.

NETL participated in the ZERT field verification experiments, which injected small amounts of tracer-spiked CO_2 just below the soil from vertical and horizontal wells. Surface flux and tracer mappings were in agreement and provided complementary information for modeling CO_2 movement near the surface. Resistivity surveys were used to image subsurface features, including the development of the CO_2 plume. NETL successfully developed methods for finding and evaluating abandoned wells using ground-based and aerial magnetometry and methanometry surveys. The helicopter well-finding technology was selected by R&D Magazine as "one of the 100 most technologically significant products introduced into the marketplace over the past year." The precise location of abandoned wells and the evaluation of their leakage potential is an essential component of NETL's sequestration monitoring program. High-pressure and temperature tests with brine and CO_2 were performed to characterize the chemical reactions involved in the degradation of well-bore cements under simulated sequestration conditions. Finally, a detailed mechanism and the long-term kinetics of the chemical process were determined by NETL for the first time.

R&D056.indd

R & D facts

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

Carbon Sequestration

04/2008

Degradation of Wellbore Cement Due to CO_2 Injection

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Background

The majority of locations that are being considered for carbon dioxide (CO_2) injection and sequestration are typically found in areas that have a history of oil, natural gas, and/or coalbed methane production. This is due to value-added opportunities such as enhanced oil recovery (EOR), enhanced gas recovery (EGR), and enhanced coal bed methane (ECBM) recovery. There also exists a greater knowledge base for saline formations that lie either above or below oil and gas reservoirs due to well logging and exploration activities. As a result of human activity, these formations are typically punctured by a significant number of wells from both exploration and production. No matter how impermeable an overlying caprock is, the sealing integrity may be compromised by the presence of wells. Well bores thus represent the most likely route for leakage of CO_2 from geologic carbon sequestration.

Abandoned wells are typically sealed with cement plugs intended to block vertical migration of fluids. In addition, active wells are usually lined with steel casing, with cement filling the outer annulus (Note: in oilfield terminology, an annulus is a ring-shaped hole which extends the length of the well bore) in order to prevent leakage between the casing and formation rock. The permeability and integrity of the cement will determine how effective it is in preventing leakage.

After CO_2 is injected into a saline formation, it may continue as a separate free-gas phase, a supercritical phase, or dissolve in the formation water. When CO_2 is in a separate free-gas phase, if the density of the CO_2 is less than that of the formation water—and even at depths equal to or greater than 800 m where CO_2 is supercritical—the buoyancy of the CO_2 will cause the it to rise and spread laterally beneath the reservoir caprock. When the CO_2 contacts the formation water, it will dissolve and lower the pH of the solution. The exposure experiments of this study have been structured to study both of these processes since both types of "plumes" can come into contact with existing wells.

It is very important to understand the chemical interactions between injected CO_2 and existing cements that could potentially lead to leakage. Monitoring efforts need to focus on wells as likely sources of leakage. In addition to locating and focusing monitoring efforts on existing wells, it is necessary for the process of cement degradation to be studied. This information will factor into sequestration site-selection decisions. In some cases, it may be necessary to recomplete wells that will be particularly vulnerable to leakage, based on cement type and expected exposure conditions. All of these issues must be considered prior to injection of CO_2 in order to mitigate the risk of leakage.

Primary Project Goal

The goal of this project is to determine the risk to the storage integrity of CO_2 from existing deep wells—more specifically, risk from the cement that is in place in deep wells to prevent vertical migration.

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PRIMARY PARTNERS

National Energy Technology Laboratory

Carnegie Mellon University

RJ Lee Group, Inc.

COST

Total Estimated Cost
$450,000 over 3 years

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Objectives

- To determine the effect of CO_2 exposure to the physical and chemical properties of cements under deep-well conditions (e.g., elevated pressure, temperature, and salinity).
- To determine the rate of CO_2 attack on Class H well cement under geologic sequestration conditions.
- To determine how cement degradation depends on cement type and typical additives used in the field.

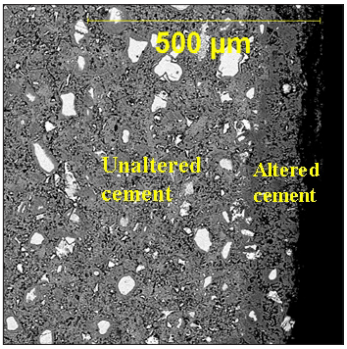
High-pressure vessels for CO_2 exposure

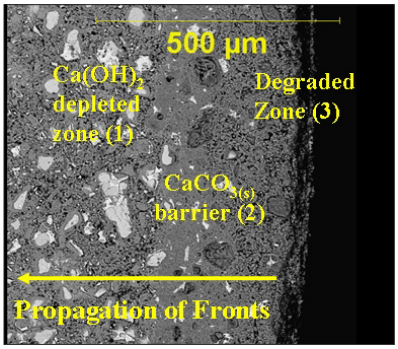
Accomplishments

Experiments have been conducted that involve curing cement samples and exposing them to high pressure CO_2 under geologic sequestration conditions. Based on the experiments carried out in the NETL Core Flow Laboratory, an understanding has been developed of the chemical dynamics of neat (absence of additives) cement alteration upon exposure to sequestered CO_2, as well as how the cement's curing temperature and pressure influence that alteration. Extrapolation of penetration rates measured for 1-year exposure experiments for neat cement suggest penetration depths limited to about 1 cm after 50 years. However, bentonite, a commonly used additive, was determined to dramatically decrease the cement's resistance to acid attack. More work on additives is forthcoming.

Benefits

The main benefit is developing a greater understanding of the factors affecting wellbore integrity in a geologic carbon sequestration project. This will be a key factor in site characterization and evaluation for large-scale sequestration projects. Potential weaknesses in a site may be addressed before they become a problem.





Images of degraded cement samples.

R&D044.indd

R & D facts

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

Carbon Sequestration

4/2008

Computed Tomography (CT) Scanning for Petrophysical Applications

Background

Traditional core-evaluation techniques evaluate minerals from exterior properties until all testing is concluded and the rocks can be sectioned and observed by a microscope. For real-time evaluations or in situ observation, an alternative is to use X-rays to see inside the cores. A good technique to observe the actual progression of fluids (movement) inside rocks is to use computer tomography (CT), scanning at successive time intervals to record the displacement or flooding process. Since the CT scanner procedure uses three-dimensional (3-D) coordinates that do not change unless the sample is removed from the instrument, changes in the conditions of each 3-D "voxel" can be recorded versus time. The "slices" can be reconstructed to provide 3-D images of scanned objects from many perspectives.

Sometimes minerals have interactions with fluids contained inside them. Although the mechanisms and causes are not completely known, it is well established experimentally that coal reacts with both methane and carbon dioxide (CO_2) to alter the nature of some of its minerals. It has been observed that coal swells upon adsorption of CO_2. Loss of permeability from coal swelling is a serious issue in carbon sequestration in unmineable coal seams. In situations where the desire is to use CO_2 to displace coal-bed methane, significant complications may arise due to the shrinking and swelling interactions.

Description

Regardless of which in situ processes are under consideration, it is necessary to evaluate the suitability of the selected site (site characterization) for application of the process. One of the techniques used to characterize the internal reactions

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and/or behavior of coal with CO_2 is dual-energy CT scanning. The core is scanned at two different (high and low) X-ray tube voltages. By comparing these scans to known standards, changes in effective atomic number can be determined. Knowing that simultaneous changes in density (from CT number) and atomic number (dual energy results) occur, important and necessary information is made available for every internal voxel to simulate numerical efforts. Since it is possible to simultaneously vary experimental simulations of in situ stresses on the cores and fluid pressures, site characterization is greatly enhanced.

Figure1. Computed Tomagraphy Scanner

For evaluation of carbon sequestration in inert rocks (such as displacement of brine from sandstone), or oil and/or gas production by displacement (e.g. waterflood), real time in situ progress of fluid displacement can be observed. Since the voxels are all recorded in a 3-D coordinate system, quantitative, volumetric, and linear measurements are all available for retrieval by using the software.

Primary Project Goal

To evaluate target carbon sequestration or hydrocarbon production cores from in situ real time perspectives. This will allow for the possibility of more accurate numerical simulations and economic evaluations, as well as enhancing the assessments of project feasibility.

Objectives

The CT scanner test results on coal will be used in conjunction with results from the Geologic Sequestration Flow Lab (GSCFL) at NETL to help determine behavior of coal when CO_2 is injected into deep coal seams for geologic sequestration of the CO_2. More specifically, objectives are—

- To use the data to assist computer simulations of CO_2 injection and the development of coal-swelling models for realistic evaluation of technical and economic feasibility of CO_2 sequestration in coal seams.
- To obtain real-time in situ images with the CT scanner of CO_2 injection in a sandstone core with total brine saturation, until CO_2 breakthrough occurs.
- To obtain data that will assist computer simulation efforts of CO_2 sequestration in brine-saturated sandstone formations
- To observe the fingering in high-permeability strata as well as core anomalies that can be discerned in situ while testing is progressing.
- To test identical cores in both NETL's Morgantown and Pittsburgh laboratories, which will allow more complete evaluation of the cores.

Benefits

Reservoir cores can be evaluated at realistic confining pressures while simultaneously observing in situ changes in pore fluids and mineral densities and/or effective molecular weights. This information is essential to realistic numeric simulation, economic evaluations, and site characterization efforts.

PARTNERS

University of Pittsburgh

Carnegie Mellon University

Georgia Institute of Technology

West Virginia University

COST

PROJECT TOTAL

$220,000

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Numeric modeling can project the volumes of CO_2 that can be sequestered in each potential reservoir in an area adjacent to older power plants. Estimates of the number of porous and permeable lithologic units required to sequester and store CO_2 will be useful in controlling greenhouse gases.

Accomplishments

Coal is being scanned with dual energy settings to evaluate coal interactions with CO_2 at varying pore fluid and confining pressures.

Development of brine displacement models for CO_2 sequestration in brine-sandstone formations has proceeded using idealized two-dimensional flat plates that were visually transparent. While this effort has provided valuable information on fractal behavior, fingering, breakthrough, etc., advancement of simulation capability requires that actual brine-saturated sandstone cores be tested using actual sandstone in 3-D configurations. NETL's CT scanner will obtain sequential real-time, in situ images of brine displacement by injected CO_2 from a no-saturation to full-saturation condition until after breakthrough. This work will be coordinated with a cooperative research effort being initiated among Carnegie Mellon University, West Virginia University, and NETL.

Planned Activity

- Evaluate mineral cores for the Carbon Sequestration Partnerships, both for target and cap and/or seal rock properties.
- Evaluate methane hydrate formation and decomposition in a variety of geologic conditions.
- Evaluate cement degradation upon exposure to CO_2.
- Evaluate the process of electromagnetic radiation used for retorting of oil shale and heavy oil.