the ENERGY lab

PROJECT FACTS

Carbon Storage – RCSP

Midwest Geological Sequestration Consortium—Validation Phase

Background

The U.S. Department of Energy Regional Carbon Sequestration Partnership (RCSP) Initiative consists of seven partnerships. The purpose of these partnerships is to determine the best approaches for permanently storing carbon dioxide (CO_2) in geologic formations. Each RCSP includes stakeholders comprised of state and local agencies, private companies, electric utilities, universities, and nonprofit organizations. These partnerships are the core of a nationwide network helping to establish the most suitable technologies, regulations, and infrastructure needs for carbon capture, utilization, and storage (CCUS). The RCSPs include more than 400 distinct organizations, spanning 43 states and four Canadian provinces, and are developing the framework needed to validate carbon storage technologies. The RCSPs are unique in that each one is determining which of the numerous CCUS approaches are best suited for their specific region of the country and are also identifying regulatory and infrastructure requirements needed for future commercial deployment. The RCSP Initiative is being implemented in three phases, the Characterization Phase, Validation Phase, and Development Phase. In September 2003, the Characterization Phase began with the seven partnerships working to determine the locations of CO_2 sources and to assess suitable locations for CO_2 storage. The Validation Phase (2005–2013) focused on evaluating promising CO_2 storage opportunities through a series of small scale field tests in the seven partnership regions. Finally, the Development Phase (2008-2020) activities are proceeding and will continue evaluating how CO_2 capture, transportation, injection, and storage can be achieved safely, permanently, and economically at large scales. These tests are providing tremendous insight regarding injectivity, capacity, and containment of CO_2 in the various geologic formations identified by the partnerships. Results and assessments from these efforts will assist commercialization efforts for future carbon storage projects in North America.

The primary objective of the DOE's Carbon Storage Program is to develop technologies to safely and permanently store CO_2 and reduce Greenhouse Gas (GHG) emissions without adversely affecting energy use or hindering economic growth. The Programmatic goals of Carbon Storage research are: (1) estimating CO_2 storage capacity in geologic formations; (2) demonstrating that 99 percent of injected CO_2 remains in the injection zone(s); (3) improving efficiency of storage operations; and (4) developing Best Practices Manuals (BPMs).

CONTACTS

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PARTNERS

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American Water Works Association
Archer Daniels Midland Company
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Baker Hughes, Inc.
Biorecro
Blue Source
BP America
Caterpillar, Inc.
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U.S. DEPARTMENT OF ENERGY

PARTNERS (CONT.)

Drummond Coal Company
Duke Energy Corporation, Inc.
Edison Mission Energy
Electric Power Research Institute (EPRI)
Environmental Defense
GE Energy
Halliburton
Illinois Clean Coal Institute
Illinois Corn Growers Association
Illinois Department of Commerce and Economic Opportunity, Office of Coal Development
Illinois Department of Natural Resources, Office of Scientific Research and Analysis
Illinois Department of Transportation
Illinois Oil and Gas Association
Illinois State Geological Survey
Indiana Gasification, LLC
Indiana Oil and Gas Association
Interstate Oil and Gas Compact Commission (IOGCC)
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Louisville Gas and Electric, LLC (LG&E)
Natural Gas Pipeline Company of America, LLC
Natural Resources Defense Council (NRDC)
NiSource Gas Transmission and Storage Company
Peabody Energy
Peoples Gas
Power Holdings, LLC
Praxair, Inc.
Schlumberger Carbon Services
Spectra Energy Corporation
Tenaska Taylorville, LLC
Total Gas and Power Ventures USA, Inc.
Vectren Corporation

COST

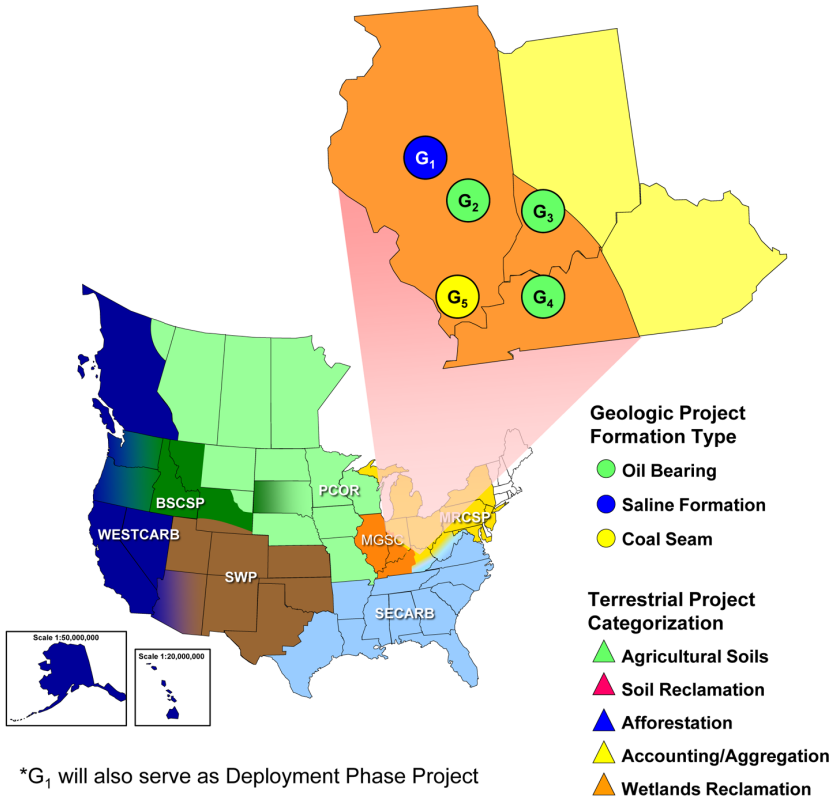
Total Project Value
$28,948,987

DOE/Non-DOE Share
$22,808,745 / $6,140,242

Description

The Midwest Geological Sequestration Consortium (MGSC) is led by the Illinois State Geological Survey, in collaboration with the Indiana and Kentucky Geological Surveys, and focuses on geologic storage potential in the Illinois Basin, a 60,000-mi^2 geologic structure underlying Illinois, southwest Indiana, and western Kentucky. The partnership was established to assess the safety and potential of geologic carbon storage options, in deep coal seams, mature or depleted oil fields, and deep saline formations. The Validation Phase effort was designed to determine the Illinois Basin's potential contribution toward achieving the national and international goals to reduce carbon emissions, with particular emphasis on the development of technologies and best practices.

Over the last six years the MGSC has been testing the storage resource potential of these storage reservoirs for the 291 million metric tons of annual CO_2 emissions from fixed sources in the Illinois Basin. Four of the five planned small-scale CO_2 injection tests were completed during the Validation Phase, which for MGSC ended on January 31, 2012. One of the tests was conducted in a deep coal seam in southern Illinois and the other three were performed in different oil bearing reservoirs in Illinois, Indiana, and Kentucky (G2-G5 on map below). Plans for the fifth small-scale deep saline reservoir test were merged with the MGSC Development Phase (2008-2018+) large-scale injection demonstration project now underway at the Archer Daniels Midland Company (ADM) corn processing complex in Decatur, Illinois. Each of the MGSC Validation Phase tests had an extensive monitoring, verification, and accounting (MVA) program. In addition to assessing the CO_2 storage potential, the ability of the injected CO_2 to improve hydrocarbon recovery was also evaluated to gauge the potential economic benefits for storing CO_2 in hydrocarbon-bearing reservoirs. In the Illinois Basin, up to 10 billion barrels of oil and 11 trillion cubic feet of coalbed methane are estimated to remain in place.



*G_1 will also serve as Deployment Phase Project

Primary Project Goal

MGSC is investigating the Illinois Basin for geologic CO_2 storage options in deep, non-economic coal resources, mature oil fields, and deep saline formations with potential to store CO_2. MGSC's objective is to determine the technical and economic feasibility of using these geologic formations for long-term storage.

Objectives

The primary objective of the MGSC's Validation Phase was to assess the potential for deploying CCUS in the Illinois Basin region, as well as contribute to a general understanding of carbon storage resources and CO_2 storage permanence in depleted oil reservoirs, deep coal seams, and deep saline reservoirs by:

- Assessing and validating aspects of geological CO_2 storage in the Illinois Basin.
- Continuing investigations into the methods and economics of CO_2 capture at facilities, such as coal-fired power plants.
- Examining the costs of transporting large quantities of CO_2 via pipeline.
- Developing MVA protocols to ensure safe and effective storage operations.
- Conducting carbon storage assessments for each of the three geological storage types: depleted oil fields, deep coal seam, and deep saline reservoirs.
- Linking options for capture, transportation, and geological storage within the environmental and regulatory framework.

Geologic Storage Opportunities

Data gathered during the Characterization Phase (2003-2005) indicates that the geology of the Illinois Basin includes stacked porous formations interspersed between or overlain by multiple impermeable rock layers. The porous formations of the Illinois Basin, which include both deep saline and hydrocarbon-bearing reservoirs, were found to be favorable for CO_2 storage, and the multiple impermeable rock layers acting as seals would serve to maintain storage permanence. Based on the MGSC Characterization and Validation Phase data, depleted oil and gas fields are estimated to have up to 0.440 billion metric tons of potential storage, deep coal seams up to 3.2 billion metric tons, and saline formations up to 161 billion metric tons.

Field Projects

Saline Formation Test (G1)

The saline formation test originally planned for the Validation Phase was merged with the Development Phase project (also known as the Illinois Basin – Decatur Project, or IBDP) in collaboration with ADM and Schlumberger Carbon Services. In November 2011, the IBDP began operational injection of supercritical CO_2 at a nominal rate of 1,000 metric tons per day into the lower Mt. Simon Sandstone, a saline reservoir, at a depth of about 7,000 feet. The project goal is to inject one million metric tons over a three year period. At the injection site the Mt. Simon is 1,600 feet thick and exhibits high porosity (up to 25%) and permeability (100's of millidarcies) in the lower portion. The Mt. Simon is overlain by a 300-foot thick, impermeable shale formation, the Eau Claire Shale, which acts as the primary seal for the injected CO_2. The CO_2 is being supplied from the ADM ethanol production facility in Decatur, Illinois. For more information on the IBDP project see NETL's MGSC Development Phase fact sheet or the IBDP website at www.sequestration.org.

Accomplishment Highlights under the Validation Phase:

- Two-dimensional seismic completed in spring 2008.
- Injection well drilled and cased to a depth of 7,200 feet in May 2009.
- Installation of the injection tubing and monitoring sensors in the injection well was completed in November 2009.
- A dedicated geophysical well, permanently fitted with an array of geophones for conducting repeat vertical seismic profiles, was completed in November 2009.

Loudon Oil Field Huff 'n Puff Test (G2)

At the Loudon Oil Field in Fayette County, Illinois the MGSC carried out a small-scale "Huff 'n Puff" test on an oil production well to evaluate the potential for geological storage of CO_2 in mature Illinois Basin oil reservoirs, and to develop MVA protocols for subsequent Validation Phase tests. For this small test, CO_2 gas was injected into the production well (the "Huff" phase), which was then shut in to allow mixing with the oil in place. Following a five-day soaking period the well was placed back in production (the "Puff" phase) to evaluate the portion of CO_2 stored in the reservoir and the incremental increase in oil production. A total of 39 metric tons of CO_2 were injected into the Mississippian Weiler Sandstone at a depth of approximately 1,550 feet.

Accomplishment Highlights:

- After 13 weeks of production following the shut-in period 27% of the injected CO_2 remained in the oil reservoir.
- ~2 incremental barrels of oil were produced per metric ton CO_2 injected.
- CO_2 remained within the storage formation.
- Final report submitted December 2009

Mumford Hills Oil Field Test (G3)

At the Mumford Hills Oil Field in Posey County, Indiana the MGSC carried out a small-scale CO_2 injection test in a sandstone within the Clore Formation in order to gauge the large-scale CO_2 storage that might be realized from enhanced oil recovery (EOR) of mature Illinois Basin oil fields via miscible liquid CO_2 flooding. The small injection Pilot test was conducted at the Bald Unit site within the Mumford Hills Field in Posey County, southwestern Indiana, which was chosen for the project on the basis of site infrastructure and reservoir conditions. The test was conducted using an inverted 5-spot pattern consisting of one central CO_2 injection well surrounded by four production wells. The target reservoir was a 30 foot thick elongated body of sandstone at a depth of approximately 1,900 feet. Geologic data on the target formation were extensive. Core analyses, porosity and permeability data, and geophysical logs from 40 wells were used to construct cross sections and structure contour and isopach maps in order to characterize and define the reservoir architecture of the target formation. A geocellular model of the reservoir was constructed to improve understanding of CO_2 behavior in the subsurface. A MVA program was designed to determine the fate of injected CO_2. Extensive periodic sampling and analysis of brine, groundwater, and produced gases began before CO_2 injection and continued through the monitored waterflood periods. Samples were gathered from production wells and three newly installed groundwater monitoring wells. Samples underwent geochemical and isotopic analyses to reveal any CO_2-related changes. Groundwater and kinetic modeling and mineralogical analysis were also employed to better understand the long-term dynamics of CO_2 in the reservoir. No CO_2 leakage into groundwater was detected, and analysis of brine and gas chemistry made it possible to track the path of plume migration and infer geochemical reactions and trapping of CO_2. Cased-hole logging did not detect any CO_2 in the near-wellbore region.

Accomplishment Highlights:

- Initiated injection of CO_2 in September 2009.
- Completed injection of 6,300 metric tons in July 2010.
- 99.5% of the injected CO_2 was stored after nine months of post-CO_2 injection monitoring
- Model projections based on test results indicated that full-field CO2 injection for 20 years could have 12% oil recovery.
- Final report submitted March 2012.

Injection pump skid with CO_2 supply tanker in the background, Mumford Hills Test site

Sugar Creek Oil Field Test (G4)

At the Sugar Creek Oil Field in Hopkins County, Kentucky the MGSC carried out a pilot project to test storage of CO_2 in the Jackson Sandstone in order to gauge the large-scale CO_2 storage that might be realized from EOR of mature Illinois Basin oil fields via immiscible liquid CO_2 flooding. The target reservoir was within the Big Clifty Sandstone Member at a depth of approximately 1,900 feet. Geologic data on the target formation were limited, but core analysis reports permitted the estimation of porosity and permeability, and geophysical logs were used to define the structure and architecture of the target formation. A geocellular model of the reservoir was constructed to improve understanding of CO_2 behavior in the subsurface. Pressure changes and elevated CO_2 levels in response to injection (breakthrough) occurred at five production wells during the one-year injection period, all within the first five months. The first breakthrough occurred one week after commencement of CO_2 injection, which was sooner than expected based on modeling; this difference was attributed to a previously undetected fracture network. With technical support from the Kentucky Geological Survey a MVA program was set up to document the fate of injected CO_2. Extensive sampling of brine, groundwater, and wellhead gas was carried out, beginning before CO_2 injection and continuing through the waterflooding period. Samples were gathered from production and observation wells, newly constructed groundwater monitoring wells, and nearby domestic and agricultural wells. Samples underwent geochemical and isotopic analysis to reveal any CO_2-related changes. Groundwater and kinetic modeling and mineralogical analysis were also employed to better understand long-term dynamics of CO_2 in the reservoir. No CO_2 leakage into groundwater was detected, and analysis of brine and gas chemistry made it possible to track the path of plume migration and infer geochemical reactions and trapping of CO_2. Cased-hole logging at several wells did not detect any CO_2 in the near-wellbore region.

Accomplishment Highlights:

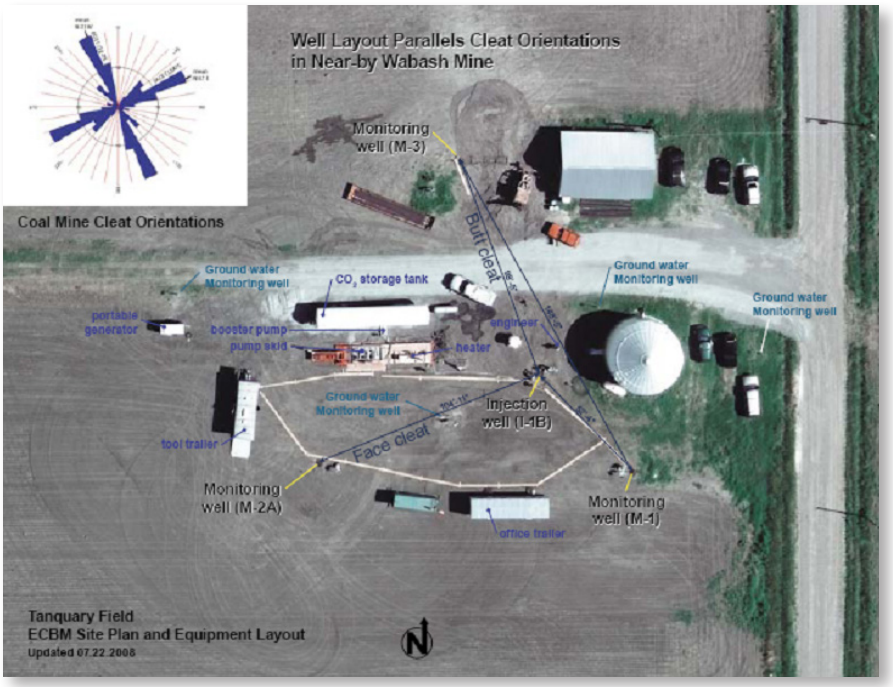
- Initiated injection of CO_2 in April 2009.
- Completed injection of approximately 6,600 metric tons of CO_2 in May 2010.
- Test results indicate 84% of the injected CO_2 was stored at the Sugar Creek field after one year of post-CO_2 injection monitoring.
- Oil recovery rate increased despite early CO_2 breakthrough at one production well.
- Model projections based on test results indicated that full field CO_2 injection for 20 years could have 5.5% incremental oil recovery.
- Final report submitted March 2012.

CO_2 Storage Summary for Oil Field Tests

Project Name	CO_2 Injected, metric tons	CO_2 produced metric tons & % of injected)	CO_2 stored metric tons & % of injected	Comment
Loudon (IL)	39.0	28.3 72.5%	10.7 27.5%	After 13 weeks of production following the shut-in period after injection
Mumford Hills (IN)	6,300	315 <5%	5,985 >95%	After two years of monitoring during and after CO_2 injection
Sugar Creek (KY)	6,560	1,030 15.7%	5,530 84.3%	After two years of monitoring during and after CO_2 injection

Coal Test (G5)

At the Tanquary Farms site in Wabash County, southeastern Illinois, the MGSC carried out a pilot project to test storage of CO_2 in the Springfield Coal Member of the Carbondale Formation in order to gauge the potential for CO_2 storage and/or enhanced coal bed methane recovery from Illinois Basin coal beds. The target formation was the Pennsylvanian Carbondale at a depth of 900 feet in a 7-foot thick Springfield coal seam. The pilot was conducted using a four-well design consisting of an injection well and three monitoring wells. The test was developed and implemented based on numerical modeling and permeability estimates from literature and field data. Coal cores were taken during the drilling process and were characterized in detail in the laboratory. Adsorption isotherms indicated that at least three molecules of CO_2 can be stored for each displaced methane (CH_4) molecule. Microporosity contributes significantly to total porosity. Coal characteristics that affect carbon storage potential vary laterally between wells at the site and vertically within a given seam, highlighting the importance of thorough characterization of injection site coals to best predict CO_2 storage resources. Approximately 92.3 metric tons of CO_2 were injected over the duration of the project, at an average rate of 0.93 metric tons per day. A MVA program was set up to detect CO_2 leakage. Atmospheric CO_2 levels were monitored as were indirect indicators of CO_2 leakage such as plant stress, changes in gas composition at wellheads, and changes in several shallow groundwater characteristics (e.g., alkalinity, pH, oxygen content, dissolved solids, mineral saturation indices, and isotopic distribution). Results showed that there was no CO_2 leakage into groundwater or CO_2 escape at the surface. Numerical and analytical modeling achieved a relatively good match with observed field data. Based on the model results the plume was estimated to extend 500 ft in the face cleat direction and 180 ft in the butt cleat direction.



Test Site in Wabash County, Illinois

Injection Equipment and Wellhead for MGSC CoalTest

Accomplishment Highlights:

- Pre-injection site MVA began in February 2007. Formation permeability and identified and pressure/injection tests conducted.
- Drilled and completed four total wells (three monitoring and one injection) by May 2008.
- CO_2 injection began in the summer of 2008. A total of 91 metric tons were stored.
- Model projections based on test results indicate potential CH_4 recovery of up to 70%.
- Post-injection MVA indicated no CO_2 detected in surrounding groundwater sources.

Benefits

Because of their ability to contain, trap or pool hydrocarbons, mature oil fields and deep coal seams are viewed as excellent candidates for CO_2 storage. Moreover, the economic benefit from the associated incremental hydrocarbon recovery could help facilitate commercial deployment of CCUS. The MGSC Validation Phase has made a major contribution toward validating the CO_2 storage potential (in terms of capacity and permenance) of the Illinois Basin region and the associated economic potential of enhanced hydrocarbon recovery as a driver to move forward. The success of these projects also demonstrates the ability of the government to partner with commercial and industrial stakeholders through collaborations such as the MGSC.

NT42588-P2, December 2012