Experience from Geologic CO₂ Storage Field Projects
Supported by DOE’s Sequestration Program

**Background:** The U.S. DOE’s Sequestration Program began with a small appropriation of $1M in 1997 and has grown to be the largest most comprehensive CCS R&D program in the world. The U.S. DOE’s sequestration program has supported a number of projects implementing CO₂ injection in the United States and other countries including, Canada, Algeria, Norway, Australia, and Germany. The program has also been supporting a number of complementary R&D projects investigating the science of storage, simulation, risk assessment, and monitoring the fate of the injected CO₂ in the subsurface.

The program supports a number of field activities in the United States which would be considered small scale <1,000,000 tons of CO₂ injected during the life of the projects (typically 1-4 years). Environmental Assessments have been prepared one of the first small scale injection projects and large scale injection projects injecting more than 1,000,000 tons of CO₂. Most of the small scale projects underwent NEPA review and were granted categorical exclusions (CX). All of these projects were required to receive and operate their facilities according to the U.S. EPA’s Underground Injection Control (UIC) permit requirements to protect underground sources of drinking water (USDW). In addition, several of the projects located on state lands in the western United States received a CX only after satisfying the state agencies’ requirements to perform historical studies or biological impact assessments before being granted approval to perform surface operations.

Much of the information on these other projects is located in the [2010 Sequestration Project Portfolio](http://www.netl.doe.gov/publications/others/nepa/ea.html). Additional scientific reports from the projects are available through the OSTI website.

**Frio Brine Field Test:**

The Frio Brine Sequestration Project was the first field project in the United States to inject CO₂ into a saline formation for the sole purpose of CO₂ storage. The project injected approximately 5,000 tonnes of CO₂ over two separate time periods (~2 weeks each) into the deep saline Frio formation in Texas. Crosswell seismic and tracers with U-tube fluid sampling were the primary methods used to measure, monitor, and validate the research team’s predictions of the fate of the injected CO₂. The results of this project also showed that the CO₂ would remain in the target formation and would be contained by the cap rock. The project was permitted under the Underground Injection Control (UIC) Program, with a Class I non-hazardous injection well permit. An Environmental Assessment was prepared and FONSI issued for this project prior to field operations. Additional information on the Frio project is available at: [http://www.netl.doe.gov/publications/others/nepa/ea.html](http://www.netl.doe.gov/publications/others/nepa/ea.html)
Small Scale Field Tests - Regional Carbon Sequestration Partnerships Phase II:

The U.S. DOE has been supporting the implementation of 20 small scale projects (<700,000 tones) through the Regional Carbon Sequestration Partnerships (RCSP) Initiative. These projects began in 2005 and are focused on understanding the science behind CCS in different regions of the country, geologic settings (injection zones, caprocks, fluids, and diagenetic processes), and determining the fate of the injected CO2 in the subsurface. The projects include storage in (tons injected at each site):

- 5 unmineable coal seams (from 100 to 18,000 tons)
- 8 depleted oil fields (from 40 to 637,000 tons), and
- 7 saline formations (from 55 to 60,000 tons).

DOE’s involvement in each of these projects depends on the extent of existing CO2 injection operations at the sites. DOE was providing the various projects with support for well field development, drilling operations, workover of existing wells, simulation modeling, injection operations, monitoring of injected CO2, injection operations, and closure of the sites. At some of the oil field enhanced recovery sites, the DOE was only providing support for measurement and monitoring efforts. The projects deployed a portfolio of technologies to measure, monitor and verify the fate of the CO2 in these formations. In all cases, the CO2 remained in the subsurface with no measurable impacts to the surface water or underground sources of groundwater. Limited disturbance at the surface is necessary to drill new wells, build short spur pipelines, and conduct seismic and other monitoring surveys.

Fifteen (15) of the small scale projects have completed their injection operations in the past four years, two are currently injecting, and one is planning to begin injection operations in November 2010. Similar to the Frio Brine project, these tests have deployed a number of measurement tools, simulation packages, and monitoring protocols to validate that CO2 remains in the formations developed for storage. A summary of the partnerships’ best practices with Monitoring, Verification and Accounting (MVA) is available at: [DOE MVA Best Practices Manual](#)

A summary of the Phase II projects and their accomplishments is provided in [Attachment 1 (PhaseIIProjects.xls)](#). Project details for each site are also located in [2010 Sequestration Project Portfolio](#) and through OSTI website.

The partnerships are required to present to DOE the results of their injection projects at an annual review meeting. Each project is required to develop a summary of project activities and to present project findings during the meeting. From these reviews, it is evident that the projects have been successful in being able to validate that the CO2 is safely injected and stored in these deep geologic formations. Presentations and factsheets from each review can be viewed by clicking on each of the following years: [2006](#), [2007](#), [2008](#), [2009](#).
Large-Scale Field Tests - Regional Carbon Sequestration Partnerships Phase III:

Nine large-scale (>1,000,000 tones) CO₂ injection projects through the Regional Carbon Sequestration Partnerships are in various stages of development and environmental review. Eight projects are injecting CO₂ in deep saline formations and one will be conducting extensive MVA activities at a depleted oil field to determine the fate of the injected CO₂. Field activities for these projects are very similar to the small-scale field projects, but at a larger scale. Two of the large-scale projects have completed Environmental Assessments, which resulted in FONSIs, and one of these projects has currently injected more than 1 million tones of CO₂ in a saline formation. A summary of the Phase III projects and their accomplishments is provided in Attachment 2 (PhaseIIIProjects.xls). Project details for each site are also located in the 2010 Sequestration Project Portfolio and at the 2009 RCSP review meeting proceedings.

International Field Tests:

DOE also supports several activities through National Laboratories and other research institutions that are providing support to monitoring and simulation activities for several international carbon sequestration projects. These projects are all considered near commercial-scale integrated CCS Operations, which are injecting at least 1MMT of CO₂ each year for either enhanced oil recovery or storage in saline formations. The Sleipner and Weyburn projects have both been operating for more than 10 years without incident. Over 30 million tons of CO₂ have been stored at these projects sites combined. Our collaborative efforts with these and other international projects (e.g., Snohvit, In-Salah, and Otway) have provided decades of cumulative operational experience to show that CCS is a safe and effective technology to reduce CO₂ emissions to the atmosphere.
<table>
<thead>
<tr>
<th>Test Number</th>
<th>Test Name</th>
<th>Project Goals</th>
<th>Vendors/Utilities/Other Formations/Geologic Setting</th>
<th>Test Site</th>
<th>Source of CO₂</th>
<th>Geologic Province</th>
<th>Geologic Setting</th>
<th>EPA UIC Permit</th>
<th>Outcome of Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Big Boy</td>
<td>1. baseline formation and adjacent formation response in clay;</td>
<td>Flatland Exploration Company</td>
<td>Flatland County, WA</td>
<td>Commercial Source</td>
<td>Claystone, 30 m thick</td>
<td>3,500</td>
<td>yes</td>
<td>Successful. 3,500 tons of CO₂ permanently sequestered.  Drilling began July 2003; injection started September 18, 2003.  CO₂ injection continued until February 2004.  Post-injection monitoring activities are ongoing.</td>
</tr>
</tbody>
</table>

**Outcome of Project:**
- Successful completion of 1,000 tons of CO₂ at depths between 3,200 and 3,600.
- Post-injection monitoring activities are ongoing.
<table>
<thead>
<tr>
<th>Test Number</th>
<th>RP</th>
<th>Test Name</th>
<th>Vendors/Utilities/Other</th>
<th>Formation Type</th>
<th>Test Site</th>
<th>Source of CO₂</th>
<th>Geologic Province</th>
<th>Geologic Setting</th>
<th>Amt Scheduled for Injection metric tonnes (short tons)</th>
<th>Amt Injection metric tonnes (short tons)</th>
<th>Injection Scheduled Begin (Month/Yr)</th>
<th>Injection Completed (Month/Yr)</th>
<th>NEPA</th>
</tr>
</thead>
</table>
| 1          | Big Sky | Large-Volume CO2 Injection on Kevin Dome | - Montana State University  
- University of Wyoming  
- Schlumberger  
- Los Alamos National Laboratory  
- Lawrence Livermore National Lab | Saline | Northern Montana | Kevin Dome - Natural Source | Madison Formation | Kevin Dome | 2,000,000 (2,200,000 tons) | 0 | 2012 - Q4 | 2015 - Q4 | EA Pending |
| 2          | MRCSP | Large Scale Geologic Injection Test | - Core Energy | Saline | Otsego County, Michigan | Natural Gas Processing Facility | Michigan Basin | St. Peter Sandstone | Base Islands Delta | 1,000,000 (1,100,000 tons) | 0 | 2011 - Q4 | 2015 - Q4 | EA Initiated |
| 3          | MGSC | Demonstrating CO2 Storage in the Mount Simon Sandstone of the Illinois Basin | - Archer Daniels Midland | Saline | Decatur, IL | ADM’s Ethanol Production Facility | Illinois Basin | Mt. Simon Sandstone | 1,000,000 (1,100,000 tons) | 0 | 2011 - Q1 | 2014 - Q1 | EA Complete - FONSI issued |
- Natural Resources Canada  
- Spectra Energy | Saline | British Columbia, Canada | Spectra Energy’s Fort Nelson Natural Gas Processing Facility | Alberta Basin | Elk Point Formation | 6,500,000 (7,100,000 tons) | 0 | 2012 - Q3 | 2017 - Q4 | EA (monitoring activities only) |
| 5          | PCOR | Bell Creek Demonstration - southeastern Montana | - Denbury Resources | Oil Bearing | Bell Creek Oil Field | Natural Gas Processing Facility | Powder River Basin - Montana | Cretaceous Muddy Formation | 1,500,000 (1,650,000 tons) | 0 | 2013 - Q1 | 2017 - Q4 | NEPA Determination Pending |
| 6          | SECARB | Early Test | - Advanced Resources International  
- EPRI  
- Denbury Resources, Inc.  
- Southern Company  
- Gulf Coast Carbon Center (SECG)  
- Mississippi State University  
- Lawrence Berkeley National Lab  
- Schlumberger Carbon Services  
- Lawrence Livermore National Lab  
- Southern Company  
- QEA  
- University of Mississippi  
- U.S. Geological Survey | Saline | Cranfield, MS | Jackson Dome (natural source) | Lower Tuscaloosa | Cranfield Unit | 1,500,000 (1,650,000 tons) | ~1.4 million tons  
< Amount injected as of end of August 2010 based on injection initiated 4/1/09> | 2009 - Q2 | 2011 - Q3 | EA Complete - FONSI issued |
| 7          | SECARB | Anthropogenic Test | - Advanced Resources International  
- EPRI  
- Denbury Resources, Inc.  
- Southern Company  
- Gulf Coast Carbon Center (SECG)  
- Mississippi State University  
- Lawrence Berkeley National Lab  
- Schlumberger Carbon Services  
- Lawrence Livermore National Lab  
- Southern Company  
- QEA  
- University of Mississippi  
- U.S. Geological Survey | Saline | Citronelle, AL | Southern Company’s Plant Barry Coal-Fired Power Plant (Bucks, AL) | Paluxy Formation | Citronelle Field | 300,000 (300,000 tons) | 0 | 2011 | 2014 | EA Draft in development |
| 8          | SWP | Demonstration of Storage in Deep Jurassic/Triassic Formations of the Western U.S. | - Thunderbird Energy Corp.  
- PacifiCorp  
- Rocky Mountain Power  
- Southern California Edison  
- Schlumberger  
- Baker Hughes | Saline Aquifer | Gordon Creek Field, Edge of Uinta Basin; ~20 miles West of Price, UT; ~100 miles southeast of Salt Lake City; UT | Natural CO2 | Colorado Plateau | Intermontane Sedimentary Basin | 2,600,000 (2,900,000 tons) | 0 | 2012 - Q1 | 2016 - Q1 | |
| 9          | WESTCARB | California Development Phase Test | - California Energy Commission  
- CS Resources, LLC  
- Shell Martin Refinery  
- Schlumberger Carbon Services  
- Northern California Reservoirs  | Saline | California | Northern California or Central Valley, CA (Currently downsizing site) | TBD | TBD | TBD | 0 | 2015 | TBD | |