the ENERGY lab

PROJECT FACTS

Carbon Storage - RCSP

Southwest Regional Partnership Farnsworth Unit EOR Field Project – Development 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 regional 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 storage. The partnerships include more than 400 distinct organizations, spanning 44 states and four Canadian provinces, and are developing the framework needed to validate geologic carbon storage technologies. The RCSPs are unique in that each one is determining which of the numerous geologic carbon storage approaches are best suited for their specific regions 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 (2003–2005) began with the seven partnerships characterizing geologic and terrestrial opportunities for carbon storage and identifying CO_2 stationary sources within the territories of the individual RCSPs. The Validation Phase (2005–2013) focused on evaluating promising CO_2 storage opportunities through a series of small-scale field projects. Finally, the Development Phase (2008-2018+) 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 field projects 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 Southwest Regional Partnership on Carbon Sequestration (SWP) is led by the New Mexico Institute of Mining and Technology and represents a coalition comprising a diverse group of experts in geology, engineering, economics, public policy, and outreach. Stakeholders in SWP projects include private industry, non-governmental organizations, government entities, and most importantly, the general public. The SWP region encompasses Arizona, Colorado, Oklahoma, New Mexico, Utah, Kansas, Nevada, Texas, and Wyoming and contains plentiful supplies of oil, natural gas, and coal. Combustion of these fuels for electricity, transportation, and other industrial processes, produces CO_2.

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Schlumberger Carbon Services

PROJECT DURATION

Start Date	End Date
10/01/2007	07/31/2022

COST

Total Project Value
$78,910,800

DOE/Non-DOE Share
$53,017,771 / $25,225,261

PROJECT NUMBER

FC26-05NT42591

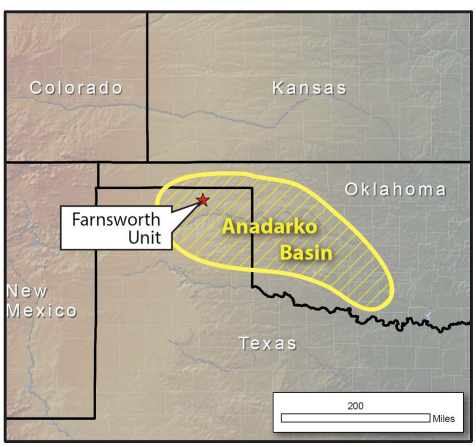

Figure 1. Map depicting the location of the Farnsworth Unit (red star) within the Anadarko Basin. Potential CO_2 storage resources for the Morrow within the FWU exceed 10 million metric tons based on rough estimates of formation volume and porosity.

The sum of the emissions from the region's coal-fired power plants make them the largest stationary emitters of CO_2 in the SWP region. Other sources that contribute significantly to emitted CO_2 include natural gas processing plants, refineries, ammonia/fertilizer plants, ethylene and ethanol plants, and cement plants. The SWP selected a site that was using CO_2 captured from a fertilizer and an ethanol plant to supply CO_2 needed for their enhanced oil recovery (EOR) operations. The SWP is studying the site's ability to safely store CO_2 as part of an EOR operation.

Project Description

As part of its Development Phase efforts, the SWP is characterizing, modeling, monitoring, and tracking at least 1 million metric tons of CO_2 at an active CO_2-EOR operation in Ochiltree County, northern Texas. The primary target reservoir is the Pennsylvanian-age Morrow Sandstone Formation within the Farnsworth Unit (FWU) of the Anadarko Basin (Figure 1). A particularly important research focus for this project is to develop portability or transferability of site-specific results to other sites, specifically within the southwestern United States. The project is being performed in two phases: (1) Characterization and Active Monitoring, Verification, Accounting, (MVA) and Assessment; and (2) Post-injection Monitoring, Verification, Accounting, and Assessment.

The project includes several key aspects that are being emphasized as necessary components for wide deployment of carbon capture and storage (CCS). These include (1) meaningful public outreach and education, (2) effective storage site selection and characterization protocols; (3) optimization of storage engineering; (3) quantitative monitoring, simulation, and risk assessment of injected and stored CO_2; (4) a project assessment for storage efficacy and management, and (5) accounting protocols for both CO_2 sources and storage sites.

The first phase of the project includes efforts focusing on tracking subsurface CO_2 during the active injection and monitoring period of the FWU. The FWU, an active CO_2 injection petroleum recovery site, is managed by Chaparral Energy, L.L.C. (CELLC). SWP efforts include (1) performing baseline surface and subsurface characterization using both existing and new data, (2) evaluating and quantifying potential risks associated with injection operations; (3) developing and updating site models, injection simulations, and risk assessment evaluations; (4) assessing and drilling characterization wells and monitoring/observation wells; (5) designing, developing, and implementing MVA plans to monitor and track injected CO_2; and (6) continuing to refine storage estimates.

The second phase includes all aspects related to post-injection monitoring that will be required once active CO_2 injection monitoring operations cease. The post-operation period for the SWP FWU project will commence after at least 1 million metric tons of CO_2 are confirmed as stored. During this period SWP will continue to (1) perform MVA activities and track CO_2 plume movement using in-place facilities and wells, (2) conduct simulation analysis and risk assessment activities, and (3) make improvements to area and regional models, as well as CO_2 storage estimates.

Description of Geology

The Anadarko Basin is approximately 50,000 square miles in size and primarily located in the northern Texas panhandle and western Oklahoma, extending into eastern Colorado and western Kansas. The basin is known to contain significant reserves of oil and gas and has been extensively developed for the recovery of hydrocarbons. The target formation for the CO_2 storage study is the oil bearing upper Morrow sandstone that is part of the rock sequence comprising the Farnsworth Unit (Figure 2).

The Morrow Formation is undergoing active EOR operations that began in December 2010. The depositional environment for the Morrow Formation is an incised valley filled with coarse sandstone that has produced more than 19 million barrels of oil and 44 billion cubic feet of gas. The formation lies at an average depth of 7,750 feet and contains rock with permeabilities ranging from 10 to 500 millidarcies (mD) (average ~54mD), which is within the range for CO_2 injection and storage. Preliminary estimates of CO_2 storage capacity of the Morrow within the Farnsworth Unit of the basin exceeds 25 million metric tons. The field is divided into patterns based on injection and recovery wells in place. Additional patterns are added as tertiary injection expands across the field. As the SWP acquires production and other reservoir data, more refined storage capacity estimates can be made.

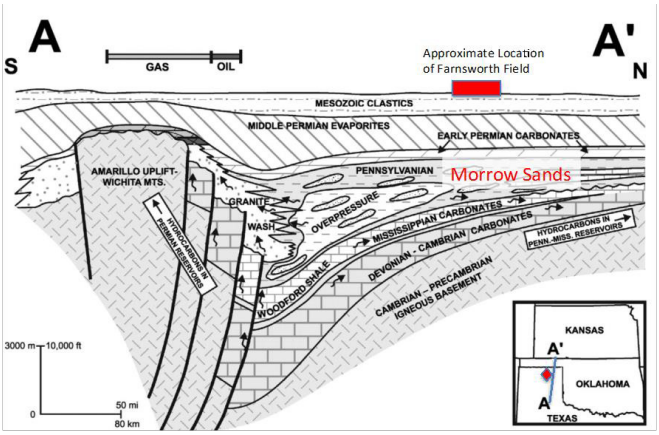

Figure 2. Cross section schematic of the Anadarko Basin depicting the FWU and underlying Morrow Sands (in red)

Sources of CO_2

The project includes modeling, monitoring, and tracking the injection of over 0.2 million metric tons of CO_2 per year over multiple years. The CO_2 is obtained from two anthropogenic sources: (1) the Arkalon Ethanol Plant in Liberal, Kansas and (2) the Agrium Fertilizer Plant in Borger, Texas. The CO_2 is transported by pipeline from the sources, which are located less than 100 miles from the site.

Injection Monitoring Operations

The site is located within an active oilfield where CO_2 injection has been ongoing prior to this project's involvement with CO_2 monitoring and tracking efforts. Injection is being performed by CELLC in five-spot injection patterns where four oil recovery wells surround a central injection well. Injection operations expand to adjacent five-spot patterns as operations continue. The SWP is monitoring and tracking activities on active five-spot patterns and monitors additional patterns as they come online.

The injection process being used by CELLC is referred to as a hybrid water alternating with CO_2 gas injection (WAG). An initial 'dry slug' (CO_2 only) is injected during the process followed by a 'wetter' combination of an increasing ratio of water to CO_2 as the process matures. The slug size may vary depending on breakthrough time and gas production. The water and gas ratio and injection rates are controlled by CELLC and determined by reservoir response (such as oil and gas production) and available CO_2.

The SWP designed a rigorous direct monitoring strategy to track both the injection operations and the behavior of the CO2 in the subsurface. The MVA program is designed to provide data needed to characterize injected CO_2 and existing reservoir fluids, including volumes of CO_2 injected, produced, and recycled; fluid migration and identification; and quantification of any potential release of CO_2 and/or fluids from the reservoir (Figure 3). Deep monitoring efforts are designed to track the CO_2 plume and detect any potential migration into unintended areas.

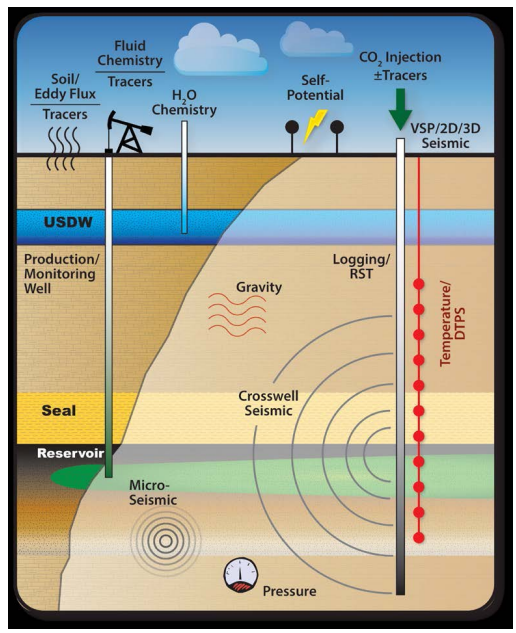

Figure 3. Direct monitoring strategy at the Farnsworth Unit. Several different monitoring components are shown.

The deep MVA efforts are combined with other monitoring activities to facilitate effective simulation results and risk assessment for underground sources of drinking water (USDWs), the shallow subsurface, and atmosphere. Surface and atmospheric CO_2 monitoring includes eddy covariance towers for measuring atmospheric CO_2 and methane fluxes and is used to constantly monitor large areas for increases in gas emissions. Additional surface monitoring activities include on-surface flux, remote and airborne sensors designed to detect CO_2 fluctuations to help identify possible emissions from depth. Shallow subsurface and USDW monitoring activities include groundwater chemistry and tracer analysis, microgravity surveys, and self-potential surveys (detection of minute electrical changes caused by subsurface fluid migration).

Modeling and Simulation

Initial site characterization activities and a review of historical data were used to develop preliminary interpretations of structure, reservoir, and caprock stratigraphy; fluids and facies distributions; and pressure and temperature data. Initial and current characterization activities included 3-D seismic surveys, vertical seismic profiling, cross-well seismic tomography, downhole logging and coring, and geophysical and geochemical analysis. The data from these efforts are the basis for developing and updating a series of models for simulating CO_2 migration and trapping over the duration of the project. An initial stratigraphic model was generated for the reservoir and overlying strata, incorporating information from interpretations of formation lithology that were then used to build a baseline geomodel.

The ultimate goal of the characterization and interpretation of the subsurface is to simulate a 3-D, fully coupled process model of the FWU injection site, based on the detailed geomodel. Simulation models are continuously updated with ongoing collected data from monitoring efforts, including drilling activities, seismic surveys, and sampling of strata and reservoir fluids (both gasses and liquids).

The SWP is applying a suite of numerical simulators to understand the complex coupled subsurface processes associated with injecting CO_2 and water into the Farnsworth Unit for enhanced oil recovery and storage of CO_2. Specifically, these simulations quantify fully coupled multi-fluid hydrologic, heat transport, reactive transport and geomechanics (HTCM) processes, resulting in forecasts of migration and trapping. Simulations are specifically designed to explore different permutations of three-phase relative permeability, mixed wettability capillary pressure-saturation functions, and compositional fluid phase behavior. The comprehensive simulation model approach facilitates risk assessment and evaluation of storage capacity, injectivity, CO_2 fate, CO_2 transport, and trapping mechanisms. Simulations (models) are continuously updated throughout the project as new data are obtained from MVA efforts, injection and production data are logged, and as additional geologic and reservoir data are obtained and studied.

The goal of the combined simulation and monitoring efforts is to create a maximum-resolution reservoir model. Understanding reservoir lithology, heterogeneity, and architecture is critical to building a reservoir model for prediction of fluid flow, sweep efficiency, oil recovery, and storage potential. The forecasts gained from the continuously-updated reservoir model are expected to be applicable to similar basins that may be candidate CO_2 storage sites.

Goals and Objectives

The primary objective of the DOE's Storage Program is to develop technologies to safely and permanently store CO_2 and reduce greenhouse gas emissions without adversely affecting energy use or hindering economic growth. The programmatic goals of storage research are to (1) develop and validate technologies to ensure 99 percent storage permanence; (2) develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness; (3) support industry's ability to predict CO_2 storage capacity in geologic formations to within 30 percent; and (4) develop Best Practices Manuals (BPMs) for monitoring, verification, accounting, and assessment; site screening, selection, and initial characterization; public outreach, well management activities, and risk analysis and simulation.

The primary objective of the SWP development effort is to demonstrate the successful reservoir characterization, modeling, monitoring, and tracking of at least 1 million metric tons of CO_2 used for EOR at a mature and active oil field as part of CCS deployment. This work has two objectives, with the first focusing on geologic and reservoir characterization and the second focusing on accurately predicting and monitoring CO_2 movement and storage within, and recovery from, the reservoir for the duration of the project. Characterization and modeling efforts are creating an improved model of the reservoir and overlying seals. Understanding reservoir lithology, heterogeneity, and architecture is critical for prediction of fluid flow, sweep efficiency, oil recovery, and storage potential for this site and is contributing to our understanding of similar geologic settings within the United States. Monitoring technologies are being compared and contrasted during operational and post-operational monitoring efforts to determine the ultimate fate of injected CO_2. It is anticipated that this work may identify the most effective and least expensive monitoring technologies. Additionally, it may improve our understanding of reactive transport of CO_2 in EOR projects through detailed characterization and modeling, allowing for less expensive monitoring of CO_2 in subsequent EOR projects.

Accomplishments

- Characterization and monitoring efforts have helped acquire baseline data for CO_2 flux, ground water quality, surface seismic, two generations of geomodels, reservoir performance, and risk prior to CO_2 injection. Updates to these items are acquired through monitoring during injection operations. These data and interpretations support the modeling efforts, MVA program, and simulation and risk assessment activities.

- Performed a 3D surface seismic survey to provide a framework for field wide geomodels, two baseline vertical seismic profiles centered on three injection wells, one repeat vertical seismic profile after CO_2 injection had commenced, four baseline and two repeat cross-well seismic surveys, and installed a passive seismic array in a monitor well at the FWU (Figure 4). Resulting interpretations improve geologic understanding and improve MVA, simulation, and risk assessment studies.

- Generated a new risk registry and performed a risk assessment for the site. This effort helps to identify and rank potential risks to the project so that potential solutions to mitigate or reduce those risks can be identified.

- Drilled, cored, sampled, and logged three characterization wells to gather critical data for the static geologic model and simulation efforts. These data are used to support/verify seismic studies as well as provide geologic data such as porosity, permeability, and identify fractures and faults. These features directly affect the CO_2 plume behavior and the ability of the formation to accept and store CO_2.

- Characterized, monitored, and tracked over 1,070,000 metric tons of CO_2 injected as part of the EOR effort in the FWU. Of the volume injected, a total of 318,179 metric tons remain in the formation as stored CO_2 through July of 2015.

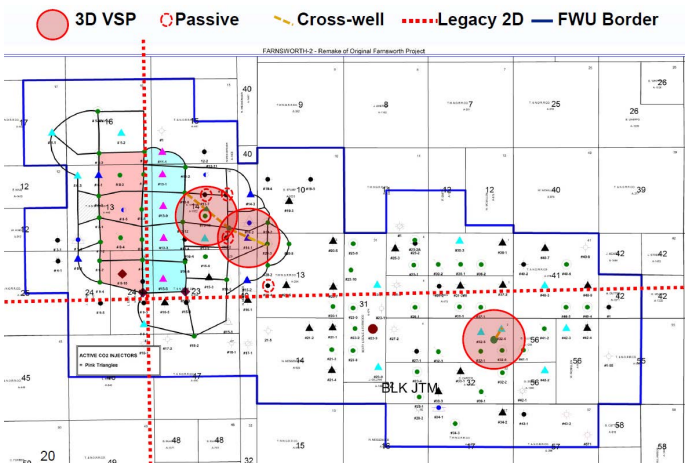

Figure 4. Acquired baseline, and planned repeat seismic acquistions in the FWU.

Benefits

This effort is improving techniques needed for future commercial carbon storage projects in the United States by demonstrating that CO_2 used at active EOR sites can be successfully modeled, monitored, and tracked using techniques refined through large-scale CCS efforts. The effort will contribute to the Storage Division goals of developing technologies for ensuring 99 percent storage permanence and predicting reservoir storage capacity to within 30 percent. This effort is optimizing monitoring design and improving identification and reduction of potential risks associated with CO_2 injection and storage. The knowledge gained will help develop a 'blueprint' for CCS at numerous similar sites with existing infrastructure in the southwestern United States.

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