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Abstract

The Southwest Partnership on Carbon Sequestration completed several more tasks during the period of October 1, 2004–March 31, 2005. The main objective of the Southwest Partnership project is to achieve an 18% reduction in carbon intensity by 2012. Action plans for possible Phase 2 carbon sequestration pilot tests in the region are completed, and a proposal was developed and submitted describing how the Partnership may develop and carry out appropriate pilot tests. The content of this report focuses on Phase 1 objectives completed during this reporting period.

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Executive Summary

The primary progress achieved during October 2004 through March 2005 was to finish evaluation of the top prospects for carbon sequestration field validation testing. The Partnership proposes to carry out five field pilot tests to validate the most promising sequestration technologies and infrastructure concepts, including three geologic pilot tests and two terrestrial pilot programs. This field testing will demonstrate the efficacy of proposed sequestration technologies to reduce or offset greenhouse gas emissions in the region. Risk mitigation, optimization of MMV protocols, and effective outreach and communication are additional critical goals of these field validation tests. The southwest region possesses an extensive CO_2 pipeline network that transports over 30 Mt of naturally-sourced CO_2 per year from the central Rockies to the Permian Basin for EOR operations. In the Southwest Partnership's Phase I project, we concluded that the most convenient and practical "first opportunities" for sequestration would be to supplant the natural CO_2 in these pipelines with power-plant-sourced CO_2. With such an approach the region would meet, at the least, minimum GHG intensity reduction targets for the region. We maintain this idea and suggest that "first options" for the nation may lie along existing pipelines. Furthermore, the Southwest Partnership's Phase I ranking of sequestration opportunities considered proximity to sources and/or pipeline infrastructure in addition to economic, safety, risk mitigation potential, and other factors. The result of the Phase I ranking process resulted in a proposal for a Phase II program, consisting of three proposed geologic pilot tests located on the region's existing CO_2 pipelines and two terrestrial pilot tests.

Results of the Phase I analysis suggest a truly regional approach for a technology validation program, including geologic pilot tests located in Utah, New Mexico, Texas, and a region-wide terrestrial analysis. Each geologic sequestration test would include injection of a minimum of ~75,000 tons/year CO_2, with a minimum injection duration of one year. These proposed pilots represent medium-scale validation tests in sinks that may host capacity for possible larger-scale sequestration operations in the future. These proposed validation tests also demonstrate a broad variety of carbon sink targets and multiple value-added benefits, including testing of deep saline sequestration, enhanced oil recovery and sequestration, enhanced coalbed methane production and a geologic sequestration test combined with a local terrestrial sequestration pilot. The local terrestrial pilot involves restoration of riparian lands for sequestration purposes, using desalinated waters produced from our proposed enhanced coalbed methane/CO_2 sequestration pilot project. The Partnership also proposes a regional terrestrial sequestration pilot program focusing on improved terrestrial MMV methods and reporting approaches specific for the Southwest region. In sum, the Southwest Partnership's proposed field validation testing program seeks to maximize specific performance, economic, and environmental goals of the DOE Carbon Sequestration Roadmap.

The Southwest Regional Partnership on Carbon Sequestration comprises a diverse group of expert organizations specializing in carbon sequestration science and engineering, as well as economics, public policy and outreach. These partner organizations are drawn from: 1) industry, 2) State governmental agencies and universities, 3) U.S. Federal government entities, and 4) other specialized partners, including the Western Governors Association. The Southwest Partnership continues a close alliance with the other Regional Partnerships, and the Western Governors' Association has facilitated communication and collaboration. For Phase II, the Southwest Partnership intends to collaborate with Big Sky Partnership and WESTCARB on two different pilot tests in the region.

Experimental

No special experimental methods are being employed in this project. Materials and equipment used include only standard communication means and data management tools, including computerized databases, internet websites, etc.

Results and Discussion

The October 2004–March 2005 results of this project are described in this section. Specific aspects detailed here include: (1) Brief Discussion of Southwest Terrestrial Carbon Capacity, (2) Brief Description of Regulatory Requirements for Sequestration in the Southwest, (3) Summary of Most Viable MMV Options, (4) Summary of Phase II Options.

(1) Brief Discussion of Southwest Terrestrial Carbon Capacity

The removal of carbon from the atmosphere and its storage in the soil and vegetation (sequestration) is a contribution that agriculture and forestry can make to mitigate the greenhouse effect. Although the process of sequestration is relatively well understood by scientists and land managers, a systematic approach to prioritizing carbon sequestration activities is lacking, especially in the arid and semi-arid west. A regional characterization of carbon sequestration potential is needed so that government incentive programs can be targeted where impacts would be greatest. As part of the Southwest Regional Partnership, we identified target areas based on spatially explicit climate, soils and land tenure information organized in GIS format. Once target areas were identified, we assessed baseline carbon for individual soils using COMET-VR, a CENTURY model-based interface to estimate change in soil carbon in response to management practices. COMET-VR was parameterized to predict carbon change under practices consistent with existing federal conservation programs. Results indicated significant potential to increase carbon storage through changes in land use and management. Achieving that potential, however, is constrained by low rainfall and soil fertility. Broad, landscape-scale analysis indicated much of the region would accumulate soil carbon at <0.1 t/ha/y unless changes in land use occur, primarily conversion of cropland to perennial cover. Land use conversion can result in accumulation rates of up to 1.0 t/ha/y in a limited portion of the region. Increasing soil carbon in the southwest will require policy and program decisions that motivate land managers to implement conservation practices on a broad scale.

(2) Brief Description of Regulatory Requirements for Sequestration in the Southwest

The objective of Phase I regulatory activities was to determine the regulatory framework of each state, specifically as they relate to carbon sequestration. This information serves both as a tool for future sequestration projects, such as pilot tests for Phase II, and to identify regulatory gaps that may prove a hurdle to such projects. The Southwest Partnership began developing regulatory and permitting action plans during Phase I for possible pilot tests, and this effort will integrate seamlessly with any Phase II activities the partnership engages in.

Researchers in Arizona, Colorado, New Mexico, Oklahoma, Texas, and Utah reviewed the relevant State statutes and rules, and consulted with respective State regulators to assess current regulatory framework for carbon sequestration. The general consensus is that because most of the partnership States have oil production, often handling CO_2 injection for enhanced oil recovery (EOR), the existing regulatory framework is sufficient to handle the pilot test-scale projects. As discussed below, however, it is possible that these test projects will reveal gaps that must be closed through regulatory action.

A significant start in assessing the current regulatory framework has been made by the IOGCC Geological Sequestration Task Force, who during the time period of Phase 1 assembled a regulatory framework for carbon capture and geological storage at the request of the Department of Energy. Its report summarizes the current regulatory regime for CO_2 on a state-by-state basis. One of our partnership researchers also participated in the Interstate Oil and Gas Compact Commission (IOGCC) Geological Sequestration Task Force (detailed below), assisting by providing information and guidance.

Our expectation is that as carbon sequestration activities intensify, the current regulatory environment will shift to accommodate emerging technologies and realities. An area where this is particularly important is the realm of measurement, monitoring, and verification (MMV). The development of MMV protocols is an evolutionary process, and activities in Phase II could set new regulatory requirements. During Phase I we have been able to develop close working relationships with several State regulators, keeping them informed of our progress and new developments. These relationships should enable effective technology transfer.

A product of the Phase I project is the identification of three geological and one terrestrial sequestration Pilot Test projects: (1) Aneth Field, Paradox basin; (2) San Juan Basin Coal fairway; (3) SACROC-Claytonville fields, Permian basin; (4) San Juan Basin terrestrial project. Fortunately, Utah, New Mexico, and Texas already have existing regulatory regimes handling CO_2 injection for EOR projects, which should streamline the permitting process for the geological sequestration projects. The terrestrial project would be permitted in accordance with USDA regulations.

Aneth Field, Paradox basin – In Utah, wells that are used for the enhanced recovery of oil and gas are considered Class II wells under the Underground Injection Control (UIC) program, and normally regulated by the Utah Division of Oil, Gas, and Mining of the State's Department of Natural Resources. However, the regulation of Class II injection on Native American tribal lands is retained by the federal government through the U.S. Environmental Protection Agency, specifically the Region 8 Office in Denver. The proposed Aneth Field project is in the Navajo Nation, and therefore falls under EPA jurisdiction.

San Juan Basin Coal fairway – New Mexico already has an existing regulatory construct for CO_2 injection, and classifies EOR and EGR injection activity as Class II under UIC. The State has also adopted specific rules and regulations governing long-term CO_2 storage through the Oil Conservation Division. Thus, the enhanced coalbed methane project in the San Juan Basin will be permitted under rules and regulations developed and administered by the New Mexico Oil Conservation Division.

SACROC-Claytonville fields, Permian Basin – In Texas CO_2 is currently being injected for EOR, and such activity is classified as Class II injection under UIC. Furthermore, the industry partner for this project, Kinder Morgan, has extensive experience transporting and injecting CO_2, and is familiar with the permitting requirements.

(3) Summary of Most Viable MMV Options

MMV deployment and associated modeling are the primary vehicles for determining how well the southwest region may meet or exceed performance targets of the Carbon Sequestration Roadmap, including prediction of storage capacity to +/- 30% accuracy, verification of indirect sequestration and associated costs, and verification of MMV technology efficacy. MMV is also central to our risk assessment and risk mitigation approaches. All MMV protocols are designed to meet the performance goals of the DOE Roadmap and the DOE EIA 1605B "Voluntary Guidelines for Greenhouse Gas Reporting," where possible, to meet the needs of evolving voluntary carbon markets in the U.S.

MMV plans for the southwest region should be designed to track the movement and fate of CO_2 injected into deep saline aquifers and coal beds, and oil and gas reservoirs. Additional MMV goals are to monitor CO_2 well injectivity, verify abandoned well veracity, and to assist with risk assessment and mitigation. Baseline MMV activities will elucidate the geologic, hydrogeochemical, isotopic and other physical conditions prior to injection. During pilot tests and possible long-term sequestration operations, baseline data will be compared to results of repeat and continuous MMV surveys conducted after injection to forecast ultimate fate of CO_2 in the subsurface for different conditions.

The Partnership's MMV programs proposed for each of the top-ranked pilot sites are detailed below. The suggested individual site plans are tailored for the unique setting of each site and for maximizing comparisons to approaches deployed at the other sites.

MMV Options for Aneth Field, Utah

For geologic sequestration at Aneth in the Paradox basin of Utah, a primary contrast with other recommended pilot sites is the application and testing of 2-D seismic lines. Results of the Weyburn project suggest that even the most sophisticated 4-D seismic approaches have limited efficacy for CO_2 sequestration monitoring; seismic methods are very effective for detecting the "front" of a CO_2 plume, but are not very effective for determining volumes or amounts of CO_2 behind the plume front. Thus, we recommend to investigate how to optimize 2-D seismic lines for detection and monitoring purposes, because 2-D lines are two to four times less expensive than 3-D. We recommend optimization of 2-D seismic efficacy by combining surveys with crosswell, VSP, and ASTLI. We will also recommend comparison of the efficacy and approaches for 2-D surveys to planned 3-D surveys at other sites in the region. Additionally, passive seismic monitoring promises to be particularly effective at the Aneth site, because a brine injection facility (Allis, Utah GS, personal communication) near the Colorado–Utah border provides an abundance of passive seismic energy.

MMV Options for San Juan Basin, New Mexico

For this recommended pilot test, the primary contrast with other potential test sites concerns coal and CH_4. Specifically, we recommend testing techniques to help track the movement of CO_2 within the coalbeds, a potentially difficult task given that the coals are already saturated with CH_4. Thus, we recommend several special MMV applications. As CO_2 is injected, swelling of the coals will occur, permeability will reduce, and fluid pressures will increase dramatically. Swelling may be significant and detectable by tiltmeters. For example, an array of 30 or more surface tiltmeters could be deployed throughout a pattern area, calibrated by fixed GPS stations, and could serve as one of the primary monitoring methods of CO_2 movement in coals. In any interwell areas, continuous monitoring of tiltmeter arrays may effectively monitor surface deformation related to coal swelling with CO_2 injection. In the event the CO_2 plume extends beyond the pattern, interferometric synthetic aperture radar (In SAR) data may be obtained periodically (~monthly) to monitor surface deformation over a larger area. Additionally, spinner surveys near injection wells may be used to determine vertical injection conformance among the individual coal seams that exist at specific sites. Finally, we recommend focusing on both 2-D and 1-D seismic methods, to evaluate CO_2 movement out of the top and bottom of the coal beds. If coals are already saturated with CH_4, MMV plans must account for seismic properties of CH_4 and CO_2 being nearly identical, and thus resolving the CO_2 front (laterally) will likely be impossible, and 3-D surveys may be excessive (e.g., "overkill"). Thus, the SWP recommends focusing on evaluating the vertical change in seismic reflectors as a means of tracking the CO_2 front; 1-D and 2-D seismic methods (single source reflection; borehole methods such as VSP, etc.) will likely be effective for resolving changes in vertical reflectors at the coal boundaries. Combining and co-interpreting seismic and borehole geophysical methods with tiltmeters is a promising "coupled" approach for monitoring CO_2 and its effects on injectivity, CH_4 production, and efficacy of CO_2 storage in the coals.

MMV Options for Permian Basin, Texas

For possible Texas pilot tests, we recommend application and testing of 3-D seismic lines. We recommend using repeat 3-D (i.e., 4-D) surveys, and we suggest coupling interpretation and modeling of 4-D results with borehole geophysical results (VSP, ASTLI, crosswell)—i.e., we suggest optimization of 4-D seismic efficacy by combining surveys with crosswell, VSP, and

ASTLI results. We will also recommend comparison of efficacy and approaches for these 4-D surveys to planned repeat 2-D surveys in other potential pilot test sites in the region.

Establishing and communicating the consequences and tradeoffs between alternate sequestration sites and strategies to store GHG is the necessary first step in formulating an effective and publicly acceptable sequestration program, and in addressing the 2007 and 2012 metrics for success of the DOE Carbon Sequestration Technology Roadmap. In the planned field pilot operations, MMV protocols and associated modeling are the primary vehicles for determining how well the SWP meets or exceeds performance targets of the CST Roadmap, including prediction of storage capacity to +/- 30% accuracy, verification of indirect sequestration and associated costs, and verification of MMV technology efficacy.

The following sections summarize all components of our recommended MMV program.

Direct MMV Technologies Recommended for the Southwest Region

<u>INJECTION WELL MONITORING:</u> At the injection well, continuous measurements of injection rate, pressure and temperature should be monitored.

<u>IN-SITU FIBER OPTIC P/T SENSORS</u>: The Partnership recommends deployment of optical fiber-based in-situ physical sensors that have been demonstrated successfully in field trials for downhole oil recovery and geothermal applications. Such sensors, less than 1 mm in size, operate on the remote interrogation using Faby-Perot interferometer (EFPI). Test data show that the sensor is capable of measuring temperature up to 600°C and hydraulic pressure up to 8000 psi at temperatures up to 220°C.

<u>SPINNER FLOWMETER SURVEYS:</u> At an injection well, spinner surveys are recommended to determine vertical injection conformance.

<u>PRODUCTION WELL IN-SITU LI-COR</u>©: In addition to continuous monitoring of gas and water production rates and pressures, continuous monitoring of produced gas CO_2 content may be made using LI-COR© IRGA devices at selected production wells.

<u>ABANDONED WELL LI-COR</u>©: At selected abandoned wells nearby, LI-COR© IRGA devices may also be installed in situ, to monitor potential flow of CO_2 from units below (e.g., degraded well-casings).

GAS PIEZOMETERS USING LI-COR©: We suggest drilling a number of shallow wells, less than 800 ft deep, for cross-well seismic, ASTLI, and/or VSP, described below. These wells may be outfitted with in situ LI-COR© IRGA devices with dataloggers and wireless data transmission, for constant monitoring. In concept, these are like water-well piezometers, but instead of measuring hydraulic head, they will record CO_2 flux from depth.

ISOTOPIC AND COMPOSITION MEASUREMENTS: Periodic gas sampling and measurements of produced CO_2 isotopic signatures will also be made to distinguish between naturally produced CO_2 (CO_2 content of the produced gas is currently –25 ‰ to –27 ‰ range for $\delta^{13}C$) and the $\delta^{13}C$ of the injected CO_2 (either –1 ‰ to –2 ‰ from magmatic sources of CO_2 or –38 ‰ to –43 ‰ from industrial sources of CO_2) (~monthly).

TILTMETERS [For the SJB ECBM pilot only] Potential coal swelling will likely cause a significant geodetic response. Specifically, actual laboratory strain measurements on San Juan basin coal, when methane is replaced with CO_2 at pressures of around 100 psi, show a volumetric strain on the order of 0.5–1.0%, which occurs due to coal swelling.

Indirect MMV Technologies (Seismic) Recommended for the Southwest Region

2-D and 3-D SEISMIC SURVEYS: 2-D or 3-D seismic surveys, coupled with borehole seismic data, will be used to monitor the injection process at the pilot sites.

VERTICAL SEISMIC PROFILES (VSP) AND CROSSWELL SEISMIC: Boreholes will be used to collect VSP data, which will have significantly higher frequencies than surface data and hence be more sensitive to small-scale changes in reservoir properties. VSP and crosswell data may be interpreted to infer changes in reflection character due to the presence of CO_2. We will also employ Active-Source Time-Lapse Intercomparison, or ASTLI: small changes in the phases of the individual wave packets measured before, during, and after the injection can be measured using an interferometric approach to determine very small changes in seismic velocity within the reservoir.

PASSIVE SEISMIC**:** Passive seismic monitoring using instruments placed in boreholes may be used to detect induced seismicity caused by the CO_2 injection.

SEISMIC MODELING: Appropriate modeling will determine the optimum data acquisition geometry for both surface and borehole, and active/passive seismic data.

(4) Summary of Phase II Options

Outcomes of the Phase I project include action plans and a proposal for the Partnership to conduct a series of validation tests of the most promising sequestration technologies for the region, including three major geologic pilot tests and two terrestrial pilot test programs. Phase I results suggest a possible theme of the Partnership to be "First Options for Carbon Sequestration." The Regional Partnerships are collectively evaluating sequestration options and will begin testing options soon. If carbon sequestration becomes a practical carbon management approach, the "first options" of sequestration will likely be those that fall along existing CO_2 transportation infrastructure. Our Phase I ranking of sequestration opportunities factored proximity to sources and/or pipeline infrastructure in addition to economic, safety, risk mitigation potential, and other factors. The result of the Phase I ranking process resulted in a proposal of three geologic pilot tests that are located on the CO_2 pipeline infrastructure. Each geologic sequestration test will include injection of a minimum of ~75,000 tons/year to ~150,000 tons/year, with a minimum injection duration of one year. The recommended pilot test portfolio is summarized in Table 1.

Table 1. Recommended Pilot Test Portfolio

Pilot Test Location	**Type of Pilot(s)**	**Amount/Duration of CO_2 Injection**	**Key Industry / Govt. Partner(s)**
Aneth Field, Paradox basin, near Bluff, UT	Deep Saline Aquifer and EOR with Sequestration	Up to 150,000 tons per year for 3.5 years	Navajo Nation Oil and Gas Co. Resolute Natural Resources Co.
San Juan basin Coal Fairway, near Navajo City, NM	ECBM and Sequestration, with Produced Water Desalination, and Terrestrial Riparian Restoration Sequestration	Est. 75,000 tons per year for 1 year	Burlington Resources, BLM, USDA
SACROC-Claytonville Fields, Permian basin, near Snyder, TX	EOR with Sequestration	Over 150,000 tons per year for 2 years	Kinder Morgan CO_2 Company, L.P. (KinderMorgan)
Entire Southwest Region	Regional Terrestrial Analysis	N/A	USDA

Conclusions

The most significant work completed during the period October 1, 2004–March 31 included action plans for possible Phase II carbon sequestration pilot tests in the region. During this period, the Partnership developed and submitted a proposal describing how the Partnership would develop and carry out appropriate pilot tests. This report provides a brief summary of significant tasks completed during this period, including a brief description of the recommended and proposed technology validation tests for the region. At this time, the Partnership is making preparations for deployment of the recommended pilot tests, which will commence in November 2005.