the ENERGY lab

PROJECT FACTS

Carbon Storage – RCSP

Southwest Regional Partnership for Carbon Sequestration—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).

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U.S. DEPARTMENT OF ENERGY

PARTNERS (2003 TO PRESENT)

(AIST) National Institute of Advanced Industrial Science & Technology
Advanced Resources International (ARI)
Arizona Geological Survey
Arizona State University
Blue Source, LLC
Bureau of Land Management (BLM)
Center for Energy & Economic Development (CEED)
Chevron
Colorado Geological Survey
Colorado School of Mines
Colorado State University
ConocoPhillips
Dine College
Electric Power Research Institute (EPRI)
En Tech Strategies
Gas Technology Institute (GTI)
Idaho National Laboratory
Intermountain Power Agency
Interstate Oil and Gas Compact Commission (IOGCC)
Kansas Geological Survey
Kinder Morgan CO2, Company, L.P.
Los Alamos National Laboratory
Navajo Nation
Navajo Nation Oil & Gas Company
New Mexico Bureau of Geology
New Mexico Environmental Department
New Mexico Institute of Mining and Technology
New Mexico Oil and Gas Association (NMOGA)
New Mexico Oil Conservation Division
New Mexico State University
NM Petroleum Recovery Research Center (PRRC)
Occidental Permian Ltd.
Oklahoma Gas and Electric
Oklahoma Geological Survey
PacifiCorp
Public Service Company of New Mexico (PNM)
Questar Gas
Resolute Natural Resources Company
Rocky Mountain Power
Sandia National Laboratories
Schlumberger
Shell
Southern Cal Edison Electric Service
Texas A&M University
Texas Bureau of Economic Geology

Description

The Southwest Regional Partnership for Carbon Sequestration (SWP) is led by the New Mexico Institute of Mining and Technology in Socorro, New Mexico and includes the states of Colorado, Oklahoma, New Mexico, Utah, and portions of Arizona, Kansas, Texas, and Wyoming. Over 70 organizations are represented in the SWP, including electric utilities, oil and gas companies, State governments, universities, non-governmental organizations, and tribal nations. For the Validation phase, the SWP conducted five field tests—three geologic and two terrestrial—all of which concluded in 2009. Each test was designed to validate the most promising carbon storage technologies and infrastructure concepts. These field tests represent several carbon storage options, including enhanced oil recovery (EOR) with carbon storage, enhanced coal-bed methane (ECBM) production with carbon storage, and the option of combining geologic storage with terrestrial sequestration. Results, data and "lessons learned" experience of the SWP field tests will aid the development of technologies vital for efficacy and safety of capture, utilization, and storage of CO_2 from the region's power plants and industrial sources. In the Southwest region, over 95 percent of anthropogenic CO_2 emissions result from fossil fuel combustion, with about half of these emissions from power plants. Geologic storage options include coal seams (approximately 790 million metric tons of minimum storage potential), natural gas and depleted and marginal oil fields (65 billion metric tons minimum storage potential), and deep saline formations (90 billion metric tons of minimum storage potential). One option the SWP is exploring is the viability of supplanting the CO_2 currently produced from natural CO_2 reservoirs, used for enhanced oil and natural gas recovery, with anthropogenic CO_2 from power plants. A significant network of CO_2 pipelines bridge CO_2 sources and potential CO_2 storage units significantly improves the viability of this option. Finally, although terrestrial CO_2 storage appears to be a viable alternative in several parts of the Southwest region, low rainfall in some areas decreases the relative terrestrial storage capacity, limiting the applications of this option. Geologic storage of CO_2 is the most promising approach for the southwestern region of the U.S.

Primary Project Goal

The SWP's primary project goal is to develop an optimum storage strategy for the southwestern United States by conducting field tests and identifying the most promising carbon storage technologies, especially monitoring technologies, and infrastructure concepts available for the region. Specifically, the SWP is evaluating the most practical, economic and effective methods for storing CO_2 in the southwestern U.S.

Objectives

The SWP's key focus is to recognize the constraints unique to the region (such as water availability), identify the available technologies on which to base the strategy, determine technology gaps, and perform field tests of storage options to help ensure storage permanence and estimate storage capacity. This focus was investigated through the following core objectives:

- Conduct multiple field pilot tests to validate the most promising storage technologies and infrastructure concepts in different parts of the region, including three geologic pilot tests and two terrestrial pilot programs.

PARTNERS (CONT.)

Thunderbird Energy Corp
Tucson Electric Power Company
U. S. Department of Agriculture
U. S. Environmental Protection Agency
University of Idaho
University of Missouri
University of Oklahoma
University of Utah
Utah Automated Geographic Reference Center (AGRC)
Utah Division of Air Quality
Utah Division of Oil, Gas & Mining
Utah Energy Office
Utah Geological Survey
Utah State University
Western Governors' Association
Wyoming State Geologic Survey
Xcel Energy
Yates Petroleum Corporation
Wisconsin Department of Agriculture, Trade, and Consumer Protection
Wyoming Office of State Lands and Investments
Xcel Energy
Yates Petroleum Corporation

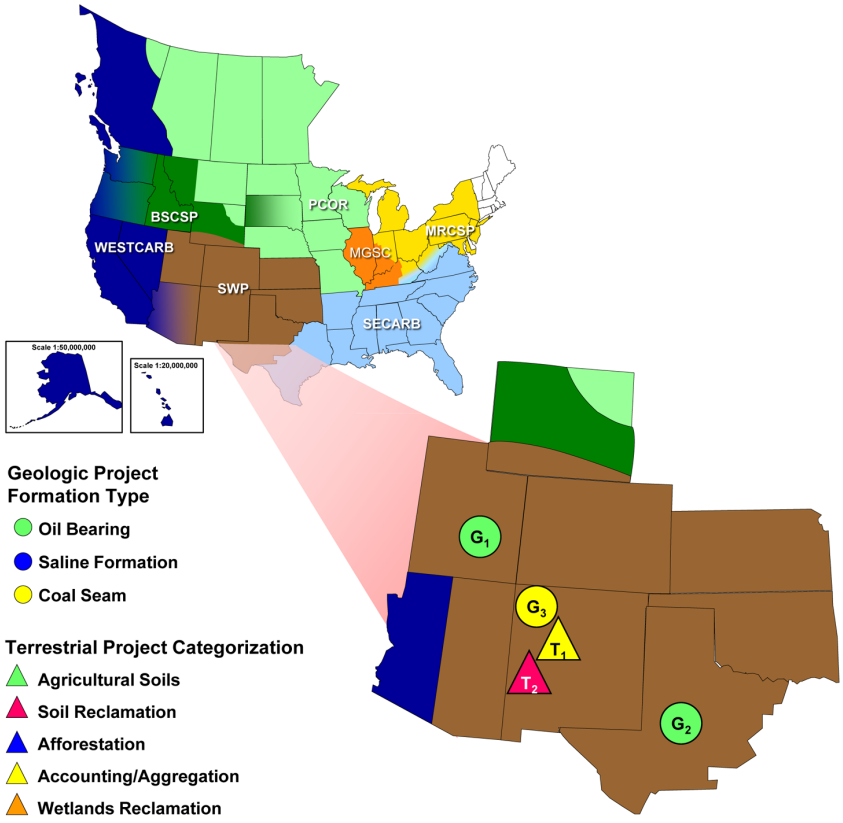
COST

Total Project Value
$22,076,329

DOE/Non-DOE Share
$17,075,412 / 5,000,917

- Develop risk mitigation procedures for the storage tests.
- Optimize monitoring, validation, and accounting (MVA) protocols for each test.
- Conduct effective outreach and communication to stakeholders and the general public.

Field Projects



Geologic Storage Opportunities

The Southwest region is rich in geologic storage options, including depleted oil and natural gas fields, deep saline formations, and un-mineable coal beds. EOR using CO_2 has been a staple technology in the region for almost 40 years. Over a thousand miles of primary CO_2 pipeline, in addition to over a thousand miles of secondary CO_2 pipelines throughout the region, provide CO_2 transportation options near many candidate project sites. The SWP pilot-scale injection tests were deployed in two types of geologic storage and utilization options, including enhanced oil recovery with CO_2 storage and enchanced coalbed methane recovery with CO_2 storage, and the project team coordinated efforts with commercial field operators.

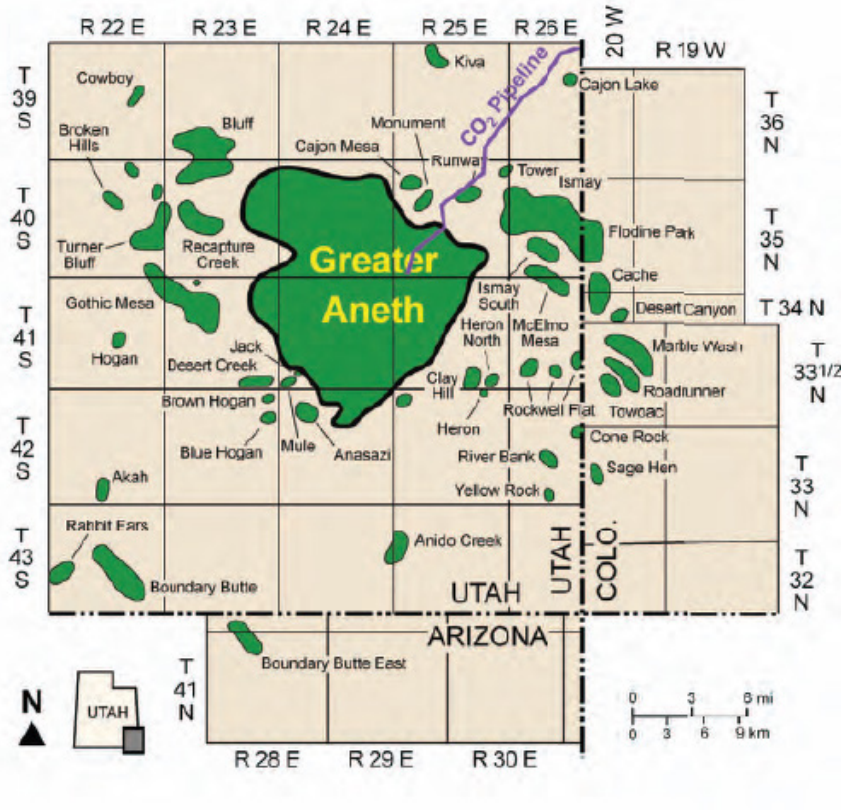
Paradox Basin, Utah: Aneth EOR-Storage Test (G1)

Since August 2007 the SWP has been actively testing EOR combined with CO_2 storage at the Aneth Oil Field in San Juan County near Bluff, Utah. The project has injected a minimum of 127,000 metric tons of CO_2 per year into the Desert Creek and Ismay producing zones, approximately 5,600 - 5,800 feet

deep The injected CO_2 is sourced and delivered by pipeline from the McElmo Dome (a natural or non-anthropogenic CO_2 reservoir) located in southwestern Colorado. Injection was continuous during the SWP Phase II monitoring period. The EOR activities continue, though SWP monitoring ceased in summer of 2010.

Accomplishment Highlights:

- Injected CO_2 the Aneth Field area from August 2007 until September, 2009, at an approximate rate of 127,000 metric tons of CO_2 per year. Upon project conclusion, a total of approximately 254,000 metric tons of CO_2 was injected during the Aneth EOR-Storage Test under the RCSP Validation Phase.
- Measured baseline and multiple-repeat surface fluxes. No evidence of CO_2 above natural fluxes was detected.
- Simulated three-dimensional (3-D) reservoir models of the site, providing short- and long-term CO_2 migration forecasts.
- Refined surface and subsurface geological maps and cross-sections through new mapping.
- Conducted reservoir water tracer testing in July 2007 and gas tracers in July 2009. Results show alcohol tracers perform similar to perfluoro-hydrocarbon tracers and at a significant cost savings. The tracer tests were effective and did indicate specific flow directions.
- Conducted baseline and two repeat vertical seismic profiles. The injected CO_2 plume was indicated, with results slightly less conclusive than the vertical seismic profiles (VSP) performed in the SACROC tests (see G2). Based on this result, we suggest that VSP surveys may be more effective for storage operations, in many cases.
- Electrical self-potential monitoring surveys conducted between November 2007 and September, 2009. Data analysis indicated the tests were inconclusive, suggesting that more research is required for such potential surveys to be effective.



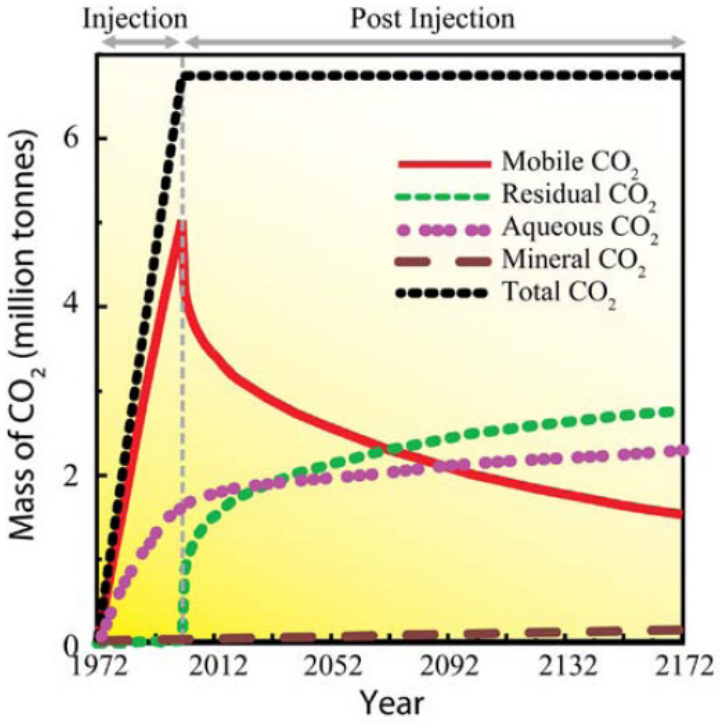
Location of the Greater Aneth and surrounding oil fields in the Paradox Basin

Permian Basin, Texas: SACROC EOR Storage Test (G2)

This test included a post-audit modeling analysis of 40 years of CO_2 injected for EOR at the SACROC Unit in the Permian Basin of Texas, in addition to intensive MVA analyses of CO_2 injection at SACROC. Results were used by Kinder Morgan to forecast an optimized commercial approach to EOR with storage in the Claytonville Oil Field, a nearby field with similar geology not yet been subjected to CO_2 injection. Kinder Morgan retains the option for future CO_2 injection at Claytonville, an option predicated on future economics. The SACROC pilot represents a significant storage analysis— the total injection rate in the SACROC field exceeds 1,000,000 metric tons of CO_2 per year. However, the SWP focused on a small area of the field, and its Validation Phase test included focused, comprehensive monitoring and analysis of a small-scale (4 km2) area, to maximize efficacy of measurement technologies. Approximately 78,000 metric tons of CO_2 was injected and intensively monitored during the 2009 year, and injection continued into 2010. Injection targets are the Pennsylvanian-aged, carbonate-rich Cisco and Canyon groups at approximately 6,300 to 7,100 feet below the ground surface, and these formations continue to be a major EOR target for western Texas.

Accomplishment Highlights:

- Over 200,000 metric tons of CO_2 has been injected during the SACROC EOR-Storage Test under the RCSP Validation Phase effort, and over 800,000 metric tons of CO_2 into broader monitored areas throughout the SACROC field. Cumulatively, the SACROC Unit was subjected to well over 100,000,000 metric tons of CO_2 during the last 40 years, with estimated net storage of CO_2 exceeding 55 million metric tons. Most of this CO_2 was natural, sourced from McElmo Dome in southern Colorado, but significant volumes of anthropogenic CO_2 were piped from natural gas processing plants in Texas.
- Measured baseline and multiple repeat surface fluxes at all stages of the project. These were performed repeatedly at the pilot site, a location where CO_2 had been injected for almost 40 years, and an area remote from any CO_2 injection. As of project conclusion, the SWP observed no significant fluxes above natural flux levels.
- Assessed baseline and multiple repeat reservoir and groundwater (brine) compositions. No indication of USDW contamination from CO_2 injection activities.
- Simulated 3-D reservoir models of the SACROC site, including short-term (annual) and long-range (century) forecasts of CO_2 trapping mechanisms at the site. These 3-D reservoir simulations were fully-parameterized with multiphase flow of oil, CO_2, brine, and reactive chemistry.



Using known CO_2 injection history from the SACROC field, long-term CO_2 trapping mechanisms were estimated.

- Completed baseline 3-D reflection seismic survey in 2007 and conducted a 2-D walkaway vertical seismic profile (VSP). VSP and 3-D surface seismic monitoring data successfully indicated the extent of the injected CO_2, including migration rates.

San Juan Basin, New Mexico: Enhanced Coalbed Methane (ECBM) Storage Test (G3)

The purpose of the San Juan Basin pilot test, located within the San Juan Basin Coal Fairway, near Navajo City, New Mexico, was to examine ECBM efficacy and to estimate the maximum amount of CO_2 storage possible for a typical ECBM operation. The SWP injected 18,400 metric tons of CO_2, though reduced injectivity associated with coal-bed swelling (a common side-effect for coalbeds) was limited from the total proposed injection amount. The CO_2 was sourced from the McElmo Dome in Colorado and was injected into coals of the Upper Cretaceous Fruitland formation. This test was also unique because it was synergistically

combined with terrestrial sequestration. Specifically, produced water from the Fruitland formation was desalinated and applied to rangeland near the injection site, forming a combined ECBM – terrestrial storage project.

Accomplishment Highlights:

- Began CO_2 injection operations during July 2008 and ended in July 2009. A total of approximately 18,400 metric tons of CO_2 was injected. This amount was much less than the original proposed amount of 68,000 metric tons, but significant injectivity was lost during the test; simulation results suggest injectivity loss to be due to coal-swelling. The injection well has since been plugged and abandoned.
- Measured baseline surface fluxes with follow-up a number of repeat surveys and assessed baseline reservoir groundwater (brine) compositions prior to CO_2 injection.
- Simulated 3-D reservoir models of the site, to forecast injectivity changes and CO_2 migration. Simulations were also performed to develop porosity maps of the site and predict bottom-hole pressure as a function of time.
- Acquired desalination testing permits. Water was used for a terrestrial test (see T2 field test).
- Completed baseline vertical seismic profile (VSP) and well logs. Completed post-injection VSP in September 2009. VSP resolution was not high enough to detect the CO_2 plume; simulations suggest that that higher-fold surveys would be required for effective detection. The CO_2 displaced reservoir gas, both at relatively low pressures (>200psi). SWP personnel hoped that absorbed CO_2 would change coal properties sufficient for seismic surveys to detect changes in reservoir properties, but these changes could not be detected.
- Conducted a multi-scale investigation of sealing behavior of the seal formation overlying the Fruitland coals, the Kirtland shale. Results of this analysis were indicative of a good reservoir seal, consistent with observations of the pilot test.

Terrestrial Storage Opportunities

Terrestrial carbon capacity in the Southwest region is limited by low average annual precipitation and yearly variability in precipitation. Even in systems managed for carbon storage, wet years followed by a series of dry years may result in a net carbon flux out of the system. There is limited opportunity to increase carbon storage on rangelands because most areas are at a relatively stable equilibrium given land use history and management. Much of the desert grassland and shrub land areas with less than 12 inches of annual precipitation are subject to loss of cover and exposure to wind and water erosion. Retaining soil carbon levels in these ecosystems requires active restoration practices that are challenging, given current technologies. The SWP conducted two terrestrial storage demonstration projects.

Southwest Regional Terrestrial Pilot Analysis (T1)

The SWP terrestrial pilot analysis has resulted in a carbon reporting and monitoring system that functions consistently across hierarchical scales and is compatible with the existing technology underlying the DOE's Energy Information Administration Voluntary Reporting of Greenhouse Gases (1605b) Program. Within this system, the project goals were the following: (1) develop improved technologies and systems for direct measurement of soil and vegetation carbon at reference sites selected within the region; (2) develop remote sensing and classification protocols to improve mesoscale (km2) soil and vegetation carbon estimates; (3) integration of available information at a sub-Major Land Resource Regional scale into a regional inventory system. The regional inventory can be used to estimate carbon changes at small scales using existing models and can also be used to make program and policy decisions.

Accomplishment Highlights:

- Developed and implemented calibration equations allowing the use of direct measurement technologies (laser induced breakdown spectroscopy and near infrared spectroscopy) as a more cost effective alternative to standard laboratory analyses.
- Included results of field trials in model calibration to increase the validity of model estimates of carbon change in response to management.
- Improved the utility of a USDA computer based model (COMET-VR) for estimating changes in rangeland soil carbon storage.
- Worked to develop the Sustainable Rangeland Management Soil Carbon Offset Project Protocols based on the results of this project.

- Demonstrated the use of remote sensing based protocols for estimating the status (ecological state) of rangeland soil/vegetation combinations that affect carbon fluxes across multiple years.
- Developed an application of Normalized Differential Vegetation Index remote sensing methodology to determine the carbon inputs on a seasonal basis. The application of this technology is the basis for a verification protocol that will allow private sector market offset projects to be verified for less than $1/ha/year.

Local Terrestrial Arid-Land Rehabilitation and Concomitant Storage Project (T2)

In this local-scale terrestrial storage pilot, the SWP used desalinated produced water from wells near the San Juan Basin ECBM pilot test for irrigating rangeland, forming a combined ECBM/terrestrial storage project. This project examined the decadal changes in land use and management in LaManga Canyon, located within the San Juan Basin Coal Fairway near Navajo City, New Mexico, as a means to estimate carbon fluxes and to determine the potential for increases in carbon storage via ecological restoration. The project also evaluated the use of filtration technology to provide produced water for small-scale site restoration.

Accomplishment Highlights:

- Constructed a 50+ year history of the dynamics of the extent and distribution of the road and well pad network.
- Quantified the local, small-scale impact of the construction of roads on soil and vegetation attributes.
- Estimated watershed scale carbon dynamics in response to land degradation (riparian zone loss, shrub increase, cheatgrass invasion).
- Applied desalinated produced water treated to nearby rangeland soils, to determine the impact of such irrigation on soil and vegetation. The test plot showed marked improvement in vegetation and associated carbon uptake, suggesting positive potential for this combined geologic-terrestrial sequestration approach.
- SWP integrated the soil, vegetation and road/well-pad spatiotemporal information into a watershed scale model (WinAPEX) to determine the criteria for evaluating the efficacy of applying produced water to restore hydrologic function within the landscape.

Benefits

This project benefits the United States by providing a comprehensive assessment of the sources and potential storage options and capacities for CO_2 in the Southwest region. These data can be integrated with the data from other partnerships to provide a database covering the entire nation. The data generated by the field tests provides information to evaluate potential commercial-scale storage projects in the Southwest. Reports detailing the operations, resulting data, and analysis have been published for each of the five pilot field sites. A final report summarizing all Phase II tasks was completed in 2011 and is now available.

Some value-added benefits of the project include enhanced recovery of oil and coalbed methane. Methane is adsorbed in coals, and CO_2 can replace the methane and release it for recovery. Part of the value-added benefits for oil, natural gas, and methane recovery is that some of the cost of CO_2 storage is mitigated by the revenue from the sale of the recovered hydrocarbons. Currently, over 80% of the enhanced oil recovery operations in North America (95% in the southwest) use CO_2 drawn from natural CO_2 reservoirs. If all enhanced recovery operations in the southwestern United States were to use power plant generated CO_2 rather than natural CO_2, the SWP estimates that 30 million metric tons of CO_2 could be stored annually, and storage could achieve a significant reduction in GHG intensity.

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