the ENERGY lab

PROJECT FACTS

Carbon Storage – RCSP

Big Sky Regional Carbon Sequestration Partnership—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.

Description

The Big Sky Regional Carbon Sequestration Partnership is building on the work conducted in the Characterization Phase with a focus on geologic and terrestrial field verification tests that assess the relative efficiency of alternative geologic carbon storage options, prove the environmental efficacy and sustainability of carbon storage, verify regional CO_2 storage capacities, and satisfy field test permitting and regulatory requirements. Data from Validation Phase tests is being integrated into a Geographical

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PARTNERS (CONT.)

EnTech Strategies, LLC/New Directions
Idaho Carbon Sequestration Advisory Committee
Idaho Department of Environmental Quality
Idaho National Laboratory
Idaho Soil Conservation Service
Idaho State University
Inland Northwest Research Alliance
Institute for Energy Technology (Norway)
Intertribal Timber Control
Jackson Hole Center for Global Affairs
Los Alamos National Laboratory
Montana Bureau of Mines and Geology
Montana Department of Administration
Montana Department of Environmental Quality
Montana Farm Bureau Federation
Montana Governor's Office
Montana State University - Bozeman
Montana Tech
National Carbon Offset Coalition
Nez Perce Tribal Council
Oregon State University
PacifiCorp
Portland General Electric (PGE)
Power Procurement Group
PPL Montana
Puget Sound Energy (PSE)
Ramgen Power Systems, Inc.
Sage Resources
Schlumberger
Semiarid Prairie Agricultural Research Centre
Shell
South Dakota School of Mines and Technology
Southern Montana Electric
Summit Energy
The Sampson Group
Unifield Engineering
United Power/Edison Mission Group
United States Department of Energy
University of Idaho
University of Wyoming Enhanced Oil Recovery Institute
University of Wyoming GIS Center
Western Governors' Association
Wyoming Carbon Sequestration Advisory Committee
Wyoming Department of Environmental Quality
Wyoming State Geological Survey
Wyoming State Governor's Office

Information System (GIS) tool that will assist industry and regional planners to optimize energy development strategies. The Big Sky Partnership is conducting extensive public outreach, education, and training opportunities for students and young professionals. The BSCSP estimates that the region annually produces more than 110 million metric tons of CO_2 from stationary sources. While the Big Sky region currently produces only a small fraction of U.S. CO_2 emissions, it is a key area for fossil energy development and has a growing population. Carbon storage is expected to play a paramount role in developing this sustainable future by enabling the region to cleanly utilize its abundant fossil energy resources (nearly 40 percent of total U.S. coal reserves) and carbon storage options to support future energy demand and economic growth. The Big Sky Partnership region has abundant geologic and terrestrial sink opportunities available, including areas of mafic volcanic rocks (flood basalts), reactive carbonate reservoirs (e.g., the Madison formation), and Powder River basin coals.

Primary Project Goal

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). The overarching goal of the partnership is to promote the development of a regional framework and infrastructure required to verify and deploy storage technologies. To achieve this, the Validation Phase focuses on the most promising geologic and terrestrial field tests combined with market assessments, economic analysis, and regulatory and public outreach.

Objectives

In the Validation Phase, the Big Sky Partnership is developing regional solutions for the estimation of CO_2 storage resources and the evaluation of CO_2 storage permanence, in addition to providing insights critical to others involved in greenhouse gas (GHG) management throughout the United States and the world by:

- Conducting field investigations of prominent geological formations that are located throughout the region—mafic rock formations, such as basalts, and sedimentary rock hosted saline-bearing formations.
- Conducting terrestrial field tests to demonstrate the technical and economic feasibility of carbon storage in the major terrestrial carbon sinks, implementing monitoring and verification protocols, and assessing the impacts to existing ecosystems.
- Developing a national mafic rock atlas and assessing the CO_2 storage potential of these rocks through modeling studies, laboratory testing, and insights developed from the basalt pilot project.
- Evaluating the technical and economic potential for and implications of carbon storage in the region.
- Establishing the Big Sky Energy Future Coalition to bring industry, academia, environmental non-governmental organizations, and regulatory and governmental officials together to discuss the role that carbon storage can play in providing a technological solution to the region's energy requirements.

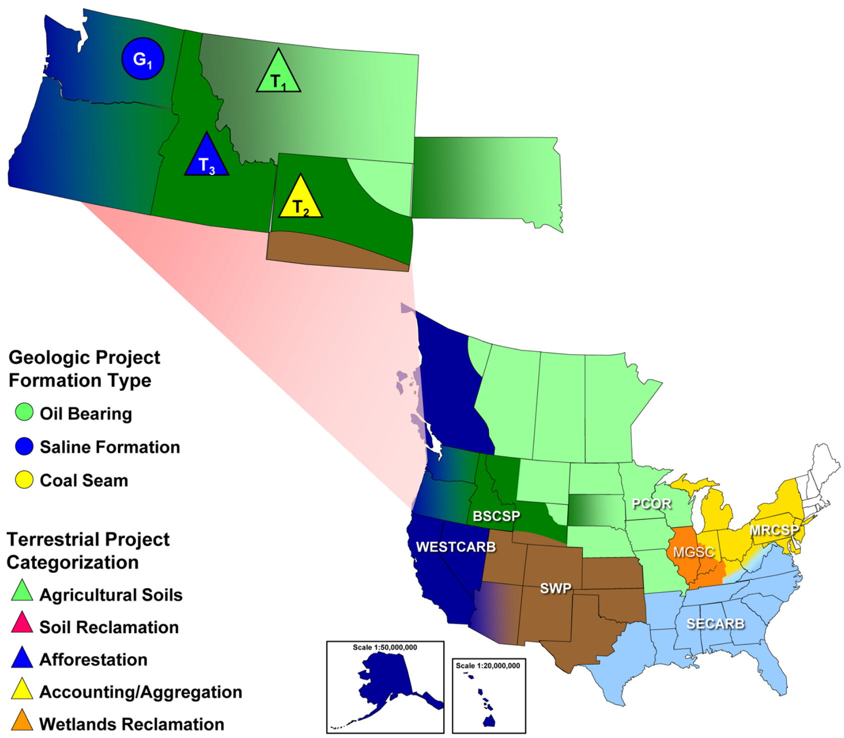
COST

Total Project Value
$29,904,824

DOE/Non-DOE Share
$22,608,636 / $7,296,188

Field Projects

Big Sky is conducting a series of tests investigating both geologic and terrestrial carbon storage options. In addition, the partnership is utilizing other opportunities to understand and research carbon storage potential in the region.



Geologic Storage Opportunities

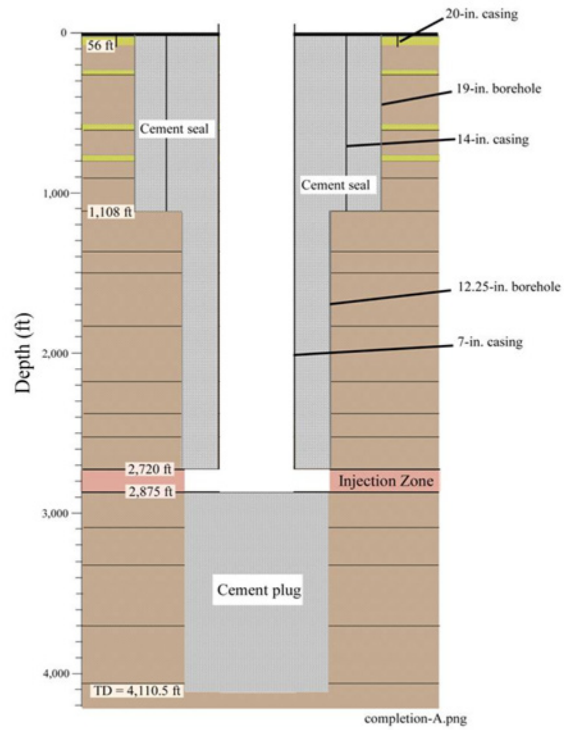
The partnership's primary geologic effort is to demonstrate carbon storage in mafic/basalt rock formations, a geology not yet well- characterized, but with significant long-term storage potential in the region and in other parts of the world. For example, the region's Columbia River Basalt Group covers approximately 164,000 km2 (63,320 square miles), with CO_2 storage capacity estimated at 33 - 134 billion metric tons (36 - 148 billion tons). Although the basalts have inherently low porosity and permeability, it is believed that significant CO_2 injectivity and storage capacity is available within brecciated zones between major basalt flows. Furthermore, preliminary calculations show that rapid conversion of injected CO_2 to carbonate minerals can occur in basalt formations, with complete conversion of fluid phase CO_2 to solid phase carbonate minerals in a few hundred years. If these laboratory-based estimates can be verified in the field, basalt formations may offer a unique geologic medium for long-term, secure carbon storage.

Basalt Field Validation Test (G1)

This field test involves injection of approximately 907 metric tons of supercritical CO_2 into a deep basalt formation (Columbia River Basalt Group – Grand Ronde Formation) near the town of Wallula in eastern Washington State. Boise White Paper, LLC is the host site for the CO_2 injection. The test is assessing the mineral-ogical, geochemical, and hydrologic impact of injected CO_2 within a basalt formation and includes site monitoring and verification activities. Initial injection of CO_2 is currently scheduled for late spring 2013, pending further hydrologic testing to determine the extent and characteristics of a potential high-permeability zone in the vicinity of the targeted injection interval. An extensive comparison of different approaches for modeling CO_2 storage in basalts is also being performed to accompany the field testing.

Accomplishment Highlights:

- Drilling of the characterization/injection well was completed in April 2009; a final hole depth of 4,110 feet was reached. A complete set of wireline geophysical logs and a series of hydrologic tests revealed that a zone between 2,720 and 2,875 feet depth would be most suitable for CO_2 injection (Figure 1).
- Simulations of CO_2 injection for two basalt flows were completed. Results indicate the radial extent of CO_2 from the injection of 907 metric tons over 14 days is approximately 180 feet at one year after injection.
- Two shallow soil gas probes were installed in the vicinity of the injection well. Gas samples have been collected on a monthly basis to detect any anomalous gas composition readings and establish background concentrations for CO_2 and other gases.
- A five line, four-mile long 3D seismic swath survey was acquired in December 2007 that successfully images deep basalt strata at the field site location.
- On October 18, 2010, the Washington State Department of Ecology issued the world's first CO_2 injection permit for a continental flood basalt sequestration project.
- Extensive hydrologic tests were conducted during the winter and spring of 2011 confirm there is no hydraulic communication between the targeted injection zone and overlying formations.



Well design for the basalt field validation test (G1)

Kevin Dome Investigation

The overall objective of this investigation is to assess the viability and capacity of the Duperow Formation on Kevin Dome in northwestern Montana as a deep saline reservoir for large-scale geologic carbon storage. The specific technical objectives are to: (1) characterize the local or larger-scale potential and capacity of the Duperow Formation for injection of supercritical CO_2, both on Kevin Dome and in the surrounding region, and (2) to use the characterization results from Kevin Dome to assess other analogous dome structures in the Big Sky Carbon Sequestration Partnership region. This activity will utilize public-domain information from existing boreholes, raster log images from all wells drilled on Kevin Dome, cuttings or core data from wells on the dome and in the vicinity; and seismic data available for purchase from Seismic Exchange, Inc. The target formation and caprock on the dome will be compared to those of outcrops exposed to the south along the south flank of the Big Belt Mountains, to the west in the Disturbed Belt, and to the northeast in the Sweetgrass Hills.

Kevin Dome has naturally occurring CO_2 in the Duperow Formation but the volume, continuity of the trapped gas, and circumstances of its entrapment are poorly understood. The Duperow Formation is also a saline-bearing formation having very poor water quality (greater than 10,000 ppm total dissolved solids [TDS]). The combination of a natural caprock trap presence, existing formation compatibility with CO_2, the large volume of this static trap, the poor quality of the contained water, the proximity to present and future sources of anthropogenic CO_2, and the similarity of this feature to other large domes in Montana and Wyoming suggest this geologic feature may have great regional significance for understanding carbon storage potential and capacity.

Accomplishment Highlights:

- Available data have been used to construct a preliminary static geologic model of Kevin Dome that could be used for flow simulations of CO_2 and brine fluids, and to draw conclusions regarding the potential of other analogous geologic domes as carbon sequestration sites. The model indicates that the Duperow Formation contains significant quantities of naturally-occurring CO_2 near the crest of the dome, and also possesses additional storage capacity on the flanks of the dome that is not currently occupied by CO_2.

Reactive Carbonate Reservoir Investigation

The Madison Formation, a reactive carbonate reservoir, has regions in southwest Wyoming (on the Moxa Arch) that have been exposed to CO_2 for millions of years in a naturally occurring gas reservoir. The objective of the Phase II investigation was to determine changes in rock properties resulting from CO_2 exposure and conduct a geologic reservoir analysis that could provide the foundation for a future demonstration to evaluate monitoring, verification, and accounting (MVA) performance at commercial-scale.

Accomplishment Highlights:

- The mineralogy of public-domain core samples from the Madison Formation was determined by X-ray diffraction on whole rock and clay separate samples and verified by examination of thin sections prepared from the cores. The results show that the Madison Formation was composed of Dolomite, Quartz and Calcite with minor amounts of Illite, Anhydrite, Analcime, Epsomite and Natronite.
- Work showed that reactions between the primary minerals in the Madison Formation and carbon dioxide can produce the secondary mineral assemblage observed which include minor amounts of elemental sulfur.

Enhanced Coalbed Methane Recovery and CO_2 Storage

This investigation determined the technical and economic issues associated with injecting a pure CO_2 stream into a coal seam versus a non-separated flue gas stream. It is also evaluating the effects of coal swelling on coal-bed permeability and incorporating these effects into a coal bed reservoir simulator.

Accomplishment Highlights:

- Laboratory studies were completed on the swelling potential of coal from two Colorado mines (Colowyo mine and Trapper mine) and two North Dakota mines (Falkirk and Beulah).
- An economic feasibility study showed that separating CO_2 from flue gas and injecting it into the unminable coal zones of the Powder River Basin seam is currently uneconomical, but can effectively store over 78,200 metric tons of CO_2 per acre while recovering methane to offset costs. Breakthroughs in separations technology could aid the economics, but in the Powder River Basin, they cannot achieve the necessary cost reductions for breakeven economics without incentives.

Terrestrial Storage Opportunities

The Big Sky Partnership region provides tremendous potential for GHG offsets through terrestrial carbon storage in forests, rangelands, and agricultural croplands. The partnership currently has the most comprehensive terrestrial storage program in the nation. The Big Sky Partnership has designed cropland, rangeland, and forestland field validation tests to advance the partnership's Characterization Phase market-based carbon storage methods and verification protocols to demonstrate the viability of emerging pilot carbon markets. Furthermore, the partnership is integrating results from the field tests into its economic assessment framework.

Cropland Field Validation Test (T1)

The cropland field test was conducted in north central Montana which consists of over two million hectares of cropland. Small grain agriculture is the most common land-use practice in the region. The objectives of this test were to: (1) quantify and determine cropland management practices that optimize carbon storage in semi-arid Montana; (2) develop MVA protocols to evaluate carbon storage for farms enrolled in carbon trading; and (3) investigate satellite image analysis as an alternative to the on-site verification of National Carbon Offset Coalition carbon contract compliance and as a means to remotely obtain cropland data used in predicting farmland soil carbon storage. Existing field trials at six controlled benchmark sites address the first objective by testing the effects of tillage vs. no-tillage and fallow-wheat vs. lentil-wheat crop rotations. The second objective was addressed through the use of eight enrolled sites to develop and test MVA technologies and protocols. The MVA methods compared to estimate soil carbon content are: (1) lab-based and "on-the-go" visible and near-infrared (VisNIR) spectroscopy; (2) laser-induced breakdown spectroscopy (LIBS); and (3) conventional laboratory methods. The third objective was addressed via a remote sensing study that relies primarily upon analysis of Landsat Thematic Mapper (Landsat 5) satellite imagery.

Accomplishment Highlights:

Controlled Study

- Biomass carbon (C) budgets suggest that increasing cropping intensity (i.e. fewer years of summer fallow) will be key to increasing soil organic C. No-till management showed no increase in measured and estimated biomass C inputs, and so any measured soil C change will be more likely related to an alteration of soil organic matter decomposition.
- Results of proximal soil sensing using "on-the-go" VisNIR show lab-based spectroscopy provided more accurate predictions than "on-the-go" VisNIR. "On-the-go" VisNIR did show potential for mapping soil properties with some potential limitations. Findings suggest that "on-the-go" VisNIR may be best applied to mapping fields or regions with relatively high soil organic content (SOC) and clay content variability.
- Results of initial simulated in situ soil organic carbon measurements showed that LIBS analysis of soil cores is a valuable tool for measuring soil carbon in situ. It is a more rapid approach and more cost effective than standard analyses.

Remote Sensing Study

- Recognition of no-till from conservation tillage management through spectral and textural-based satellite mapping is unlikely with landsat data alone given the current technology and similarities in surface residue coverage. However, the incorporation of Moderate Resolution Imaging Spectroradiometer (MODIS) data is being investigated as a means of improving till vs. no-till accuracy.

Rangeland Storage Potential Assessment (T2)

Completing a study which began in 1982, this field test is focused on determining best management practices for carbon storage on rangelands. The test included soil and biomass sampling at two long-term rangeland sites in eastern Wyoming to establish the storage effects of grazing intensity and seasonality of grazing on native northern mixed-grass prairie. An assessment of storage potential for these rangelands has been performed, including potential benefits to ranchers. Findings from this field test are expected to be relevant to rangelands in Montana and eastern Colorado.

Accomplishment Highlights:

- Completed a literature review and synthesis of findings on carbon storage in rangelands.
- Expanded studies initiated in 1982 on the effect of grazing intensity (320 soil samples analyzed).
- Results indicate that grazing can significantly affect carbon dynamics and plant community composition of rangeland ecosystems, with grazing at proper stocking rates enhancing soil carbon and the potential for soil carbon storage.

Forestry Field Validation Test (T3)

This forestry field test employed remote sensing with field surveys and forest stand growth modeling to predict rates of aboveground carbon storage in forested regions in the Northern Rocky Mountains. This remote sensing complements ground-based, random plot sampling and allometric measurements. The primary objective was to quantify storage potential in forests through understanding the effects of forest management on different carbon pools in forests. The effort included: (1) baseline vegetation sampling; (2) collect and analysis of data from a time-series of airborne LIDAR (light detection and ranging) techniques, (3) calibration of remote sensing data to field data, and (4) develop a process-level forest growth model to extrapolate findings to other forested areas.

Accomplishment Highlights:

- Lidar data were collected in 2003, 2007, and 2009. Preliminary analysis yielded estimates of carbon sequestration rates over a 4-year timespan.
- Forest metrics quantified in the field between 2003 and 2008 indicated that (1) forest growth was quantifiable and (2) data could be used to obtain the annual increase in forest aboveground biomass.
- RapidEye satellite data was examined as a means of estimating carbon storage potential at a forested study area in Idaho. RapidEye satellite data enhances the mapping of carbon storage potential because it provides red-edge band information that is not provided by other major earth observing satellites such as Landsat.

Benefits

The Big Sky Partnership's efforts benefit the United States by providing a comprehensive assessment of the carbon sources and carbon storage resources and effective carbon storage permanence in the Big Sky region, which includes the northern Rockies and western Great Plains, as well as the inland Pacific Northwest area. This information is being integrated with the data from other partnerships to provide a comprehensive database covering the entire nation. This effort provides information to evaluate potential pilot storage projects in the Big Sky region with respect to the effectiveness, efficiency, and permanence of the stored CO_2. The project promotes cooperation among stakeholders and helps ensure public acceptance of CO_2 storage.

Preliminary estimates of CO_2 storage potential of the storage of the mafic/basalt rock formations in the region's Columbia River Basalt group range from 33 - 134 billion metric tons of CO_2, which is enough capacity for over 20 years of storage of all U.S. coal-fired power plant emissions of CO_2. Additional storage potentials exist in the deep saline formations which run along the eastern slopes of the Rocky Mountains from Canada into New Mexico, in depleted oil reservoirs, and in coal-bed methane fields in the Powder River Basin area. These areas, together with the basalt formations, have the potential to store up to an estimated 547 billion metric tons of CO_2. On a much smaller scale, but with the potential to store carbon in amounts that offset the region's current CO_2 emissions, are the extensive terrestrial sinks. Estimates indicate that changes in cropland management practices, for example, can store approximately 6.7 million metric tons of CO_2 per year.

The findings from the pilot storage tests are transferable to other regions and countries where similar geological and terrestrial options exist. This transferability is enhanced due to the extensive number of international partners that are collaborating on the design and implementation of these field tests. The project provides the basis for large-scale deployment of these storage options, providing for both commercial technology development/transfer to rural communities and educational and workforce training in these advanced energy systems.

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