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U.S. Department of Energy's Regional Carbon Sequestration Partnership Program: Overview

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Abstract

The U.S. Department of Energy (DOE) has formed a nationwide network of seven regional partnerships to help determine the best approaches for capturing and permanently storing gases that can contribute to global climate change. The Regional Carbon Sequestration Partnerships (RCSPs) are tasked with determining the most suitable technologies, regulations, and infrastructure for carbon capture, transport, and storage in their areas of the country and parts of Canada. The seven partnerships include more than 350 state agencies, universities, national laboratories, private companies, and environmental organizations, spanning 42 states, two Indian nations, and four Canadian provinces. The Regional Partnerships initiative is being implemented in three phases:

- ***Characterization Phase (2003 – 2005)***: The objective was to collect data on CO_2 sources and sinks and develop the human capital to support and enable future carbon sequestration field tests and deployments. The completion of this Phase was marked by release of the Carbon Sequestration Atlas of the United States and Canada –Version 1 which included a common methodology for capacity assessment and reported over 3,000GT of storage capacity in saline formations, depleted oil and gas fields, and coal seams.

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Keywords: Type your keywords here, separated by semicolons ; Regional Carbon Sequestration Partnerships, United States, Field Projects, Geologic Storage;

- ***Validation Phase (2005 – 2009)***: The objective is to plan and implement small-scale (<1 million tons CO_2) field testing of storage technologies in areas determined to be favorable for carbon storage. The partnerships are currently conducting over 20 small-scale geologic field tests and 11 terrestrial field tests.

- ***Development Phase (2008 – 2018)***: The primary objective is the development of large-scale (>1 million tons of CO_2) Carbon Capture and Storage (CCS) projects, which will demonstrate that large volumes of CO_2 can be injected safely, permanently, and economically into geologic formations representative of large storage capacity.

Even though the RCSP Program is being implemented in three phases, it should be viewed as an integrated whole, with many of the goals and objectives transitioning from one phase to the next. Accomplishments and results from the Characterization Phase have helped to refine goals and activities in the Validation and Deployment Phases. The RCSP Program encourages and requires open information sharing among its members by sponsoring both general workshops and meetings to facilitate information exchange. Although each RCSP has its own objectives and field tests, mutual cooperation has been an important part of the Program thus far. The primary goal of the RCSP initiative is to promote the development of a regional framework and the infrastructure necessary to validate and deploy carbon sequestration technologies within each Partnership's region.

1. Introduction

There is consensus within the scientific community that anthropogenic greenhouse gas emission is contributing to climate change (IPCC 2006). Fossil fuels is projected to be the primary source of energy for the United States and most developing countries over the next several decades. In the United States coal use is expected to increase by nearly 20 percent between 2006 and 2030 with annual growth increasing up to 1 percent a year between 2015 and 2030. Carbon dioxide (CO_2) emissions from coal fired power plants contribute over 30 percent of the CO_2 emissions in the United States and is predicted to increase over the next 20 years with the increasing need for reliable sources of base load power (EIA2008). To balance the demands of both reducing greenhouse gas emissions to the atmosphere and the world population's desire for reliable source of economical sources of energy the scientific community, industry, and government leaders have identified carbon capture and storage (CCS) as a viable technology option to address both issues (IPCC 2005).

The United States has been recognized as one of the largest and effective programs in the world to develop and deploy CCS technologies. The Carbon Sequestration Program is implemented by the DOE's Office of Fossil Energy and managed by the National Energy Technology Laboratory (NETL2007). The two key elements of the program are:

- *Core Research and Development Area* consist of five focus areas including pre combustion capture; simulation and risk assessment; geologic carbon storage; monitoring verification and accounting (MVA); and CO2 use and reuse

- *Infrastructure* – Consists of the Seven Regional Carbon Sequestration Partnerships (RCSPs) which are working to understand the CCS possibilities through regional characterization activities and the development of small and large scale field projects throughout the United States.

The core R&D program and the RCSPs are fully integrated areas of the sequestration program. The RCSPs field project sites serve as field laboratories to test the Core R&D technologies at scale and in real-world conditions. The results for the testing at these field projects help to provide critical feedback and performance results of technologies which shapes the requirements for research needs in the future.

North America is a nation with wide variations in topography, geology, climate, population density, infrastructure, and socioeconomic development. DOE determined that the optimal approach for implementing a nationwide CCS program should be on a regional basis. Thus, DOE formed the Regional Carbon Sequestration Partnerships (RCSPs), which were initiated in September 2003. Through an open and competitive solicitation the DOE awarded cooperative agreements to seven partnerships, each covering a specific region of the United States

and Canada. Under this arrangement, the various partnerships could focus on the CCS opportunities within their specific region, while collectively building an effective and robust nationwide initiative.

The RCSPs is being implemented in the following phases, each of which build upon the activities of the previous:

Characterization Phase (2003 – 2005): The objective was to collect data on CO_2 sources and sinks and develop the human capital to support and enable future carbon sequestration field tests and deployments. This Phase was completed in 2005 and was marked by release of the Carbon Sequestration Atlas of the United States and Canada which included a common methodology for capacity assessment and reported over 3,000GT of storage capacity in saline formations, depleted oil and gas fields, and coal seams. During this time the partnerships also developed public outreach strategies and materials; completed a comprehensive review of the regulatory requirements for CCS; and identified the most promising opportunities for CCS in their regions. DOE has invested over $15 million into the Characterization Phase.

Validation Phase (2005 – 2009): The objective is to plan and implement small-scale (<1 million tons CO_2) field testing of storage technologies in areas determined to be favorable for carbon storage. The partnerships are currently conducting over 20 small-scale geologic field tests and 11 terrestrial field tests. The early successes of these projects have been the validation of simulation modelling and deployment of monitoring protocols at these early field projects. The projects have all be complying with the regulatory requirements, engaging public stakeholders; and addressing the other infrastructure needs of developing field projects all adding to the lessons learned for CCS. DOE is investing approximately $120 million into the Validation Phase.

Deployment Phase (2008 – 2017): The primary objective is the development of large-scale (>1 million tons of CO_2) Carbon Capture and Storage (CCS) projects, which will demonstrate that large volumes of CO_2 can be injected safely, permanently, and economically into geologic formations representative of large storage capacity. DOE is investing approximately $500 million into the Deployment Phase.

The RCSPs are a government/industry collaborative that involve more than 350 organizations covering 42 states and four Canadian provinces. The partners include representatives from the agricultural industry, coal companies, national laboratories, oil and gas companies, regional universities and academic institutions, special interest groups, state and local government organizations, foreign government agencies, engineering and research firms, electric utilities, and other industrial partners. The Table 1 provides website, acronym, lead organization, and geographic coverage information for the RCSPs.

The following provides a summary of the recent accomplishments and major programmatic shifts in the DOE RCSPs Initiative over the past two years as the Partnerships have continued to characterize their regional opportunities for sequestration; develop small scale field projects during the Validation Phase (Phase II) in saline, oil and gas, and coal seams to validate injectivity and capacity; develop large scale field projects during the Development Phase (Phase III) to inject 1 million tonnes or more of CO_2 into regional significant geologic sinks across North America; and the development and application of public outreach and education and regulatory compliance related to the field projects.

2. Regional Characterization

A primary function of the RCSPs is to continue the characterization of the regions geology for adequate reservoirs to store CO_2 and maintain regional digital atlases which are also available through the NATCARB system. Data reported in the *2008 Carbon Sequestration Atlas of the United States and Canada* and listed on the NATCARB website (www.natcarb.org) identified over 4,700 stationary sources that generate close to 3.3 billion metric tons of CO_2 annually. Aggregate CO_2 sink capacity, including saline formations, oil and gas reservoirs, and coal seams, is estimated at over 12,500 billion metric tons – enough to sequester CO_2 emissions at current annual generation rates for hundreds of years (NETL 2008a).

Table 1. Regional Carbon Sequestration Partnerships

Regional Partnerhips/ Website	Acronym	Lead Organization	States/Provinces Covered
Big Sky Carbon Sequestration Partnership http://www.bigskyco2.org/	Big Sky	Montana State University – Bozeman	ID, MT, SD, WY, and portions of WA and OR
Midwest Geological Sequestration Consortium http://www.sequestration.org/	MGSC	U of Illinois, Illinois State Geological Survey	IL and portions of IN, KY
Midwest Regional Carbon Sequestration Partnership http://216.109.210.162/	MRCSP	Battelle Memorial Institute	MD, MI, NY, OH, PA, WV, and portions of IN , KY
Plains CO_2 Reduction Partnership http://www.undeerc.org/pcor/	PCORP	U of North Dakota Energy and Environ Research Center	IA, MN, MO, NE, ND, WI, SD, Alberta, Manitoba, Saskatchewan, and portions of British Columbia, MT, WY
Southeast Regional Carbon Sequestration Partnership http://www.secarbon.org/	SECARB	Southern States Energy Board	AL, AR, FL, GA, LA, MS, NC, SC, TN, VA, and portions of KY, TX, WV
Southwest Regional Partnership on Carbon Sequestration http://www.southwestcarbonpartnership.org/	SWP	New Mexico Inst of Mining and Technology	CO, KS, OK, NM, UT, and portions of AZ, NV, TX, WY
West Coast Regional Carbon Sequestration Partnership http://www.westcarb.org/	WESTCARB	California Energy Commission	AK, CA, NV, OR, WA, HI, British Columbia, and portions of AZ

This represents a significant increase in storage capacity in the United States as storage resources along the Gulf Coast of the United States were added to the assessment. The data contained and reported through the NATCARB systems has significantly improved over the past 2 years. Most of the resource estimates in NATCARB are now reported on a formation level and on a 10 kilometer square grid across the geographic area assessed by the RCSPs. This increased the amount of data being maintained by the NATCARB system by several orders of magnitude but allows the users to now query information for capacity of specific storage formations and in specific geographic areas within a basin (NETL 2008b).

3. Validation Phase Small Scale Field Projects

The Validation Phase started in 2005 to focus on developing CO_2 storage field tests to validate the efficacy of CCS technologies in a variety of geologic and terrestrial sinks throughout the United States and Canada. The field tests being conducted during the Validation Phase are addressing the following goals:

- Collect physical data to confirm capacity and injectivity estimates made during the Characterization Phase
- Validate the effectiveness of simulation model to predict and MVA technologies to measure CO_2 movement in the geologic formations and confirm the integrity of the seals and indirect storage in terrestrial ecosystems.
- Develop guidelines for well completion, operations, and abandonment in order to maximize storage potential and mitigate leakage
- Develop strategies for optimizing storage capacity for various reservoir types
- Develop public outreach strategies and communicate the benefits of CCS to various stakeholders
- Satisfy the regulatory permitting requirements for CCS projects

The RCSPs applied the knowledge and results of Characterization Phase activities to identify promising opportunities for CCS in their respective regions during the Validation Phase. As a result, more than 20 geologic field tests and 11 terrestrial field tests have been initiated. Figure 1, illustrates all of the pilot-scale tests conducted in by the RCSPs and their commercial partners to inject CO_2 into saline formations, depleted oil and gas reservoirs for EOR and EGR, and coal seams for ECBM applications. The figure also shows the location and types of terrestrial sequestration projects developed during the validation Phase to test the indirect storage of carbon in terrestrial ecosystems. Table 2 provides a list of the geologic field projects and a summary of their current status.

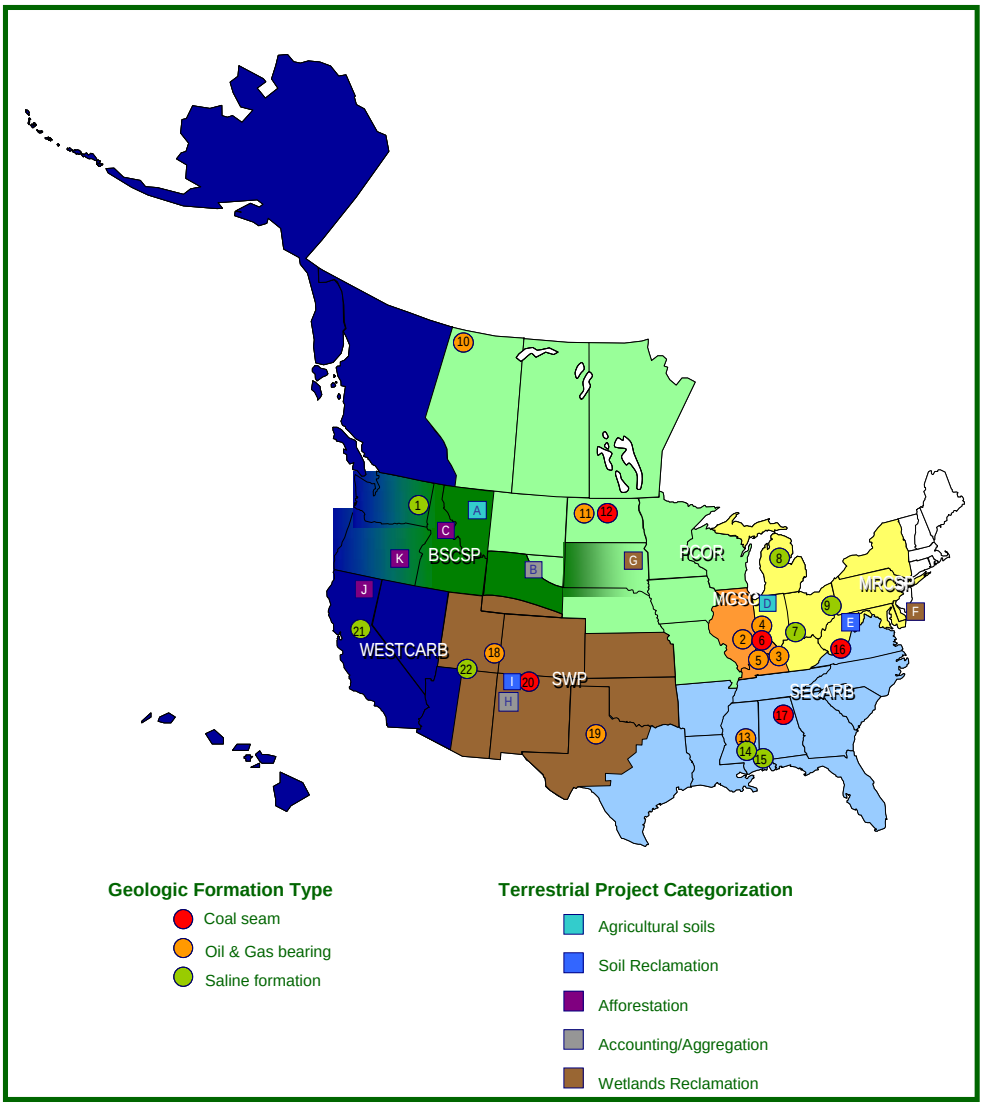

Figure 1. RCSP Validation Phase Field Tests

Figure 23. RCSP Validation Phase Tests

Table 2. RCSPs Validation Phase Project Status

Test	Partnership	Geologic Province	Corresponding Above Ground Location	Test Type	Injection Volume (tonnes)	Status
1	Big Sky	Columbia Basin Province: Columbia River Basalt Group	Eastern WA	Saline	3,000	Seismic Survey Complete
2	MGSC	Illinois Basin (Louden Field - Mississippian Weiler Sandstone)	Louden Field in Fayette County, Illinois	Oil-bearing – EOR - Huff and Puff	50	Injection Complete
3	MGSC	Illinois Basin (Louden Field - Mississippian Weiler Sandstone)	Louden Field in Fayette County, Illinois	Oil-bearing – Well Conversion	1000	Injection –Dec 2008
4	MGSC	TBD	Western KY	Oil-bearing – EOR - Pattern Flood I	3000	Injection –Dec 2008
5	MGSC	Illinois Basin (Louden Field - Mississippian Weiler Sandstone)	Louden Field in Fayette County, Illinois	Oil-bearing - Pattern Flood II	3000	Injection in March 2009
6	MGSC	Illinois Basin (Springfield Coal)	Wabash County, IL	Coal	200	Currently Injecting
7	MRCSP	Cincinnati Arch (Mt. Simon sandstone)	Duke Energy East Bend Plant, Rabbit Hash, Kentucky	Saline	3,000	Seismic Complete UIC Permit Application Submitted
8	MRCSP	Michigan Basin (Devonian age Bois Blanc through Sylvania Sandstone)	Otsego County, Michigan	Saline	3,000	Injection Complete
9	MRCSP	Appalachian Basin (Salina, and Oriskany Sandstones(	FirstEnergy R.E. Burger Plant, Shadyside, Ohio	Saline	10,000	Currently Injecting
10	PCORP	Keg River Formation (Pinnacale Reef)	Alberta, Canada	Oil-bearing	100,000	Currently Injecting
11	PCORP	Deep depleted oil fields in the Williston Basin, carbonate rocks	North Dakota	Oil-bearing	10000	Undergoing Site Selection
12	PCORP	Williston Basin (Fort Union Coals)	Burke County, North Dakota	Coal, lignite	300	Site Developed, Awaiting UIC Permit
13,14	SECARB	Gulf Coast Mesozoic/Cenozoic - lower Tuscaloosa	Adams County, Mississippi	Oil Bearing	500,000	Currently Injecting
15	SECARB	Massive Sand Unit of the lower Tuscaloosa Formation - Mississippi Salt Basin	Mississippi Power Company's Plant Daniel, Jackson County, Mississippi.	Saline	3,000	Currently Injecting
16	SECARB	Central Appalachian Basin (Pocahontas and Lee Formation Coals)	Russell County, Virginia	Coal	1000	Injection in Jan 2009
17	SECARB	Black Warrior Basin (Coal seams in the Black Creek, Mary Lee, and Pratt coal zones of the Pennsylvanian-age Pottsville Formation)	Tuscaloosa County, Alabama	Coal	1000	Injection in March 2009
18	SWP	Aneth EOR-Paradox Basin, UT (Sandstone)	Bluff, UT	Oil-bearing	450000	Currently Injecting
19	SWP	Permian Basin, Texas: SACROC(Sandstone)	Snyder, TX	Oil Bearing	900,000	Currently Injecting
20	SWP	San Juan Basin (Sandstone)	Near Navajo City, New Mexico	Coal	75,000	Currently Injecting
21	WESTCARB	Sacramento Valley (Sandstone)	Solano County, CA	Saline	2000	Injection in June 2009
22	WESTCARB	Colorado Plateau (Sandstone/Carbonate)	APS Cholla Power Plant, Joseph City, AZ	Saline	2000	Awaiting UIC Permit

Currently two RCSPs Validation Phase projects have completed CO_2 injecting into a depelted oil field and saline formations; eight projects are currently injecting CO_2 into a saline formation, two coal seams; and five depeletd oil reservoirs; and 11 projects will begin injection before October 2009. The RCSPs projects have made significant progress toward developing the field projets to test CO_2 injection into a variety of different geologic settings. Each of the projects is conducting a significant amount of research in the field and laboratory teaming with regional Universities, National Laboratories and industry to help validate simulations of injectivity, containment, and capactiy. The projects are utilizing a number of technologies for regulatory compliance and research to characterize and determine the effects of CO_2 on the geology as well as monitor the fate of the CO_2 in the storage formations (NETL 2008b).

3. RCSP Development Phase Large Scale Field Tests

Leaders of the United States and the European Union agreed in 2007 that the deployment of CCS technologies will require the development of CCS projects at adequate scale (US-EU Summit 2007). The RCSPs large-scale field projects are necessary to validate and improve model predictions concerning the behavior of injected CO_2 at scale, establish the engineering and scientific processes for successfully implementing and validating long-term safe storage of sequestered carbon, and achieve cost-effective integration with power plant systems for capture. The RCSPs will place emphasis on MVA protocols and risk assessment frameworks that will provide detailed information on the dynamics of the systems being studied.

The DOE award seven large scale Development Phase field tests between October 2007 and May 2008. These projects will be implemented in three stages over 10 years that will follow a sequential set of project steps:

- Site selection, characterization, NEPA compliance, permitting, and infrastructure development (1 to 3years)
- CO_2 injection and monitoring operations (3 to 6 years)
- Site closure and post injection monitoring (2 to 3 years)

Tests during the Development Phase involve the injection of at least one million tons of CO_2 into a range of geologic formations. Each formation is considered a major storage reservoir in their RCSPs region. These formations are expected to have the potential to store hundreds of years of stationary source CO_2 emissions based on previous Regional Characterization efforts. A summary of the field project is provided in Table 3 below:

Development Phase tests will establish at large scale that CO_2 capture, transport, injection, and storage can be achieved safely, permanently, and economically. Tests during the Development Phase will address practical issues, such as sustainable injectivity, well design for both integrity and increased capacity, and reservoir behaviour with respect to prolonged injection. Regional variations among the RCSPs will provide vitally important information and experience as they test injection into variety of technologies and geologic settings at scale.

The RCSPs are all working toward a common set of programmatic goals set forth by DOE, summarized below:

- *Assess Injectivity and Capacity* - This goal will validate that storage capacity and injectivity are sufficiently present in regionally significant geologic formations to scale-up for commercial projects.

- *Assess Storage Permanence* - The RCSPs will validate that CO_2 will be contained in the target formations and not impact underground sources of drinking water (USDWs) and/or release to the atmosphere.

- *Determine Areal Extent of Plume and Leakage Pathways* - The RCSPs will monitor the aerial extent and vertical migration of the CO_2 during and for at least 2 years after injection. The RCSPs will apply best practices to assess the presence/absence of leakage pathways such that the proposed mitigation strategy can sustain a near-zero leakage.

- *Develop Risk Assessment Strategies* The RCSPs will identify risk parameters, probability and potential impact of occurrence, and develop mitigation strategies.

Table 2. RCSP Deployment Phase Field Projects Status

Partnership	Project Title	Geologic Formation	Type	CO_2 Injected (tonnes)	Injection Scheduled	Source of CO2	Status
MGSC	Large-Volume Sequestration Test in Central Illinois	Mount Simon Sandstone	Saline	1,000,000	December, 2009	ADM Ethanol Production Facility	Draft UIC Permit Issued Site Characterization
PCORP	Williston Basin CO2 Sequestration and EOR Project North Dakota	Duperow (Carbonate)	EOR	4,000,000	June, 2012	Basin Electric Antelope Valley Station Post Combustion Capture	Site Selection and Characterization
	Fort Nelson CO2 acid gas injection project BC	Sandstone TBD	Saline	4,000,000	January, 2011	Spectra Energy Gas Processing Plant	Site Characterization and Preliminary Design
MRCSP	Large Volume injection of CO2 In Western Ohio	Mount Simon Sandstone in the Cincinnati Arch	Saline	1,000,000	March, 2010	TAME Ethanol Facility	Site Characterization and Preliminary Design
SECARB	Phase III Saline Formation Demonstrations – Early and Anthropogenic Injection Tests Gulf Coast Region	Tuscaloosa Formation Sandstone	Saline	1,500,000 Early Test; 600,000 Anthropogenic Test	January, 2009 (Early Test) and June, 2011 (Anthropogenic Test)	Jackson Dome CO2 Pipeline and Southern Company Power Plant	Early Test Site Permitted, Draft NEPA Completed and Under Review
SWP	Farnham Dome Deep Saline Deployment Project	Jurrasic Sandstone	Saline	2,000,000	March, 2010	Farnham Dome Natural Deposit	Site Characterization and Preliminary Design
WestCarb	Kimberlina, California Large-Volume CCS Test	Olcese and Vedder Sandstones	Saline	1,000,000	June, 2012	Clean Energy Systems (CES) Oxyfuel Combustion System	Site Characterization and Preliminary Design

- *Develop Best Practices for Industry* - The RCSPs will develop Best Practice Manuals for site selection, characterization, operational, and closure practices.

- *Engage in Public Outreach and Education* - The RCSPs will engage and educate the public about the benefits and goals of the field projects.

- *Contribute to the Progression of Permitting Requirements* - The RCSPs will engage in the development of an effective regulatory and legal framework for the safe, long-term injection and geologic storage of GHGs.

Results obtained from these efforts will provide the foundation for commercialization efforts for future, large-scale CCS field tests across North America and will address future challenges associated with public acceptance, infrastructure (pipelines, compressor stations, etc.), and an acceptable regulatory framework. These initial large scale projects represent the first step towards validating that CCS technologies can be deployed commercially through the United States. Additional large scale CCS projects will be necessary to validate storage projects integrated with carbon capture technologies and storage in low permeability formations, coal, and hydrocarbon rich shale.

4. Conclusions

Even though the RCSP Program is being implemented in three phases, it should be viewed as an integrated whole, with many of the goals and objectives transitioning from one phase to the next. Accomplishments and results from the Characterization Phase have helped to refine goals and activities in the Validation and Development Phases. The RCSP Program encourages and requires open information sharing among its members by sponsoring both general workshops and meetings to facilitate information exchange. Although each RCSP has its own objectives and field tests, mutual cooperation has been an important part of the Program thus far to meet the programmatic goals established by DOE.

The field test being developed in the Validation and Development Phases are critical to understanding that adequate injectivity, containment, and capacity exist in storage formation throughout the United States and Canada. This will allow for commercial deployment of CCS technologies at an adequate scale to reduce GHG emissions from fossil fuel based energy systems. The RCSP are navigating the regulatory requirements, establishing best practices, and educating public stakeholders on the benefits of CCS. All of these supplemental activities are necessary for the future deployment of CCS.

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