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CO_2 Sequestration Capability: Where Are We?

(An Overview of the Advances Being Made in CO_2 Geologic Storage by DOE/NETL's Regional Carbon Sequestration Partnerships)

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The United Nations Intergovernmental Panel on Climate Change (a Nobel Prize winning organization) concluded that CO_2 Capture and Storage (CCS) was a key component of an effective climate strategy. As discussed in previous USCSC educational papers, there are a number of challenges to the broad global deployment of CCS, including expanding our knowledge on the geologic storage of CCS – the subject of this educational paper. While much work has been done in this area, more needs to be done. A paper on the status of CCS, titled "Carbon Capture and Storage: Technology Status, Cost, Deployment Timing for Electric Power Generation", concludes that "*There is consensus that CO_2 permanent storage in deep underground geologic formations (basically, salt water in porous rocks) has great technological potential and may be deployable on a widespread basis. However, there are still financial, institutional, regulatory, and technical challenges that remain. To address these challenges, multiple integrated CO_2 capture and storage system projects are needed to prove out the technology. Also needed is an array of small, intermediate and large-scale, CO_2 injection field tests in diverse geologies to adequately characterize and validate the U.S. geologic resource. DOE and industry-funded sequestration R&D, led by the Regional Carbon Sequestration Partnerships (RCSP), provides a good example of the suite of field tests and other projects that are required to help ensure that we can store the necessary amounts of the two billion tons of CO_2 expected to be generated annually by U.S. coal plants." (1)*

CCS R&D is being aggressively pursued globally. The United States, and its private and public partners, alone, will have invested well over 20 billion dollars on CCS and related technology development and demonstration from the time the United States initiated its CCS development efforts through 2020 (the date by which CCS technology is anticipated to be available for broad commercial deployment).

At the forefront of CO_2 storage R&D is the Department of Energy's (DOE) Regional Carbon Sequestration Partnership (RCSP) initiative led by the National Energy Technology Laboratory (NETL). The seven partnerships that currently form this network include 350+ state agencies, universities, and private companies, spanning 43 states, three Native American Organizations, and four Canadian provinces. In addition, agencies from six member countries of the Carbon Sequestration Leadership Forum are participating in the Validation Phase field tests.

The Regional Partnerships have made major strides in advancing the understanding of CO_2 storage on many levels: fundamental science, engineering, and the education of state and regional agencies, and the broader public. This paper highlights the advances made by the Partnerships and the expected outcome of their ongoing efforts.

Introduction

Carbon dioxide capture and storage (CCS, or sequestration) consists of separating CO_2 from other gases at emission sources, transporting it to a storage location, and ensuring its long-term isolation from the atmosphere. Successful development and deployment of CCS is vital to a low-carbon future and longer-term climate goals. This conclusion is supported by independent and respected international organizations, who have reached the conclusion that global growth in CO_2 cannot be avoided without the rapid development and deployment of affordable CO_2 capture and storage technology. (2)

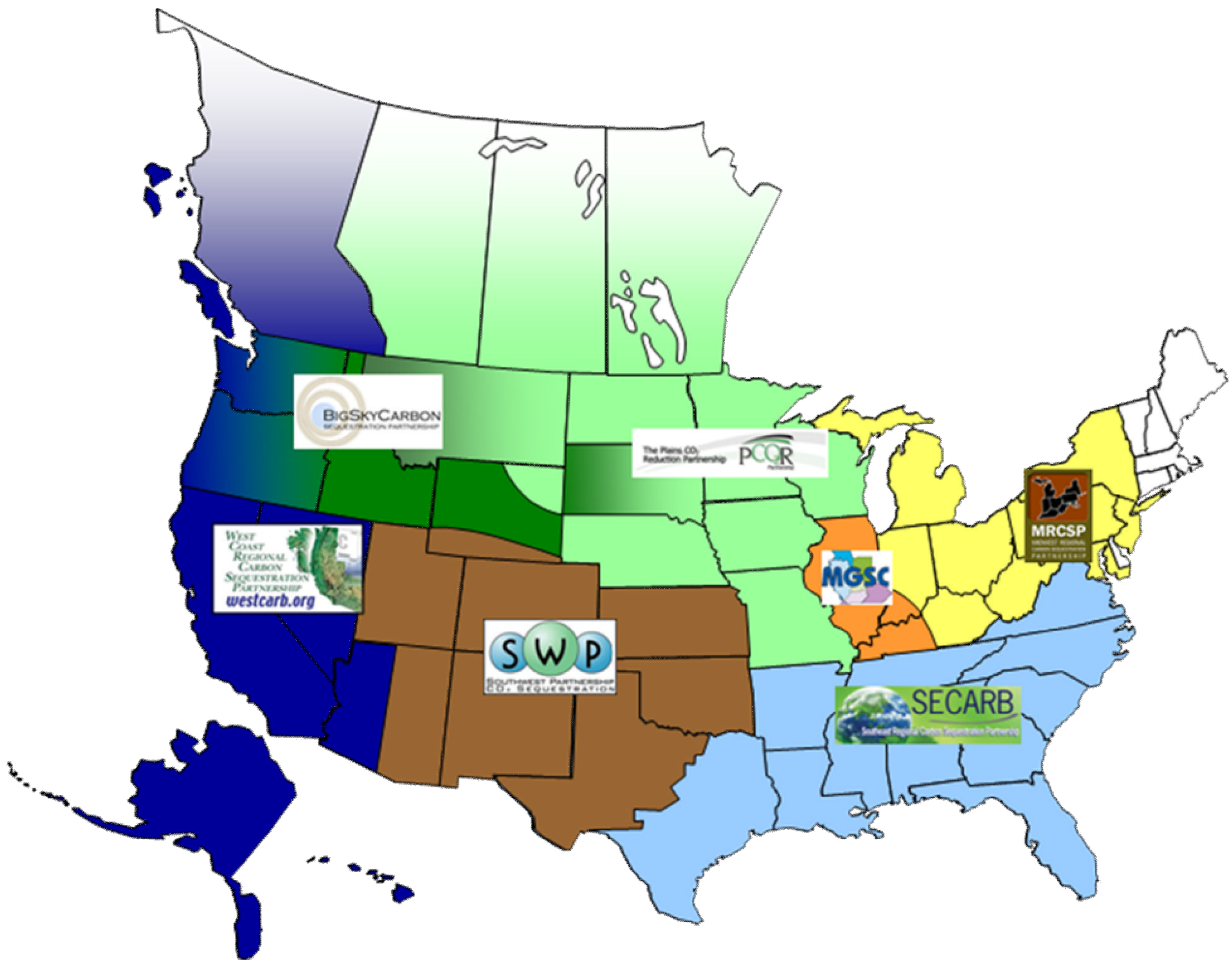
DOE's Regional Carbon Sequestration Partnership Program Has Contributed Significantly to Advancing CCS

Successful capturing and storing of CO_2 requires research to locate appropriate sites, as well as ongoing and meticulous monitoring and verification efforts after the CO_2 is injected to ensure it remains securely stored. So far, research efforts of NETL scientists and their research partners have successfully located potential CO_2 storage sites and demonstrated their reliability as storage units on a small scale. This effort has provided a solid foundation for commercial-scale demonstrations of capture and sequestration to prove that the billions of tons of carbon emissions emitted from the world's fossil-fuel fired plants each year can be sequestered.

DOE has sponsored a well-conceived CCS research, development, and demonstration program which has been underway for over 10 years, that includes CO_2 field tests at different scales in different formations with consideration of regional and geologic variability – the scope and pace of which is limited only by available funding. The challenge is to analyze and translate data collected by the DOE and others into a useable form to guide the implementation of an effective regulatory structure and resolve potential liability issues, and to do this in a timely manner consistent with anticipated regulatory or legislative action in this area. The Administration and the U.S. Congress also need to consider mechanisms for strengthening Government/industry partnerships in this area as well as the adequacy of current Federal funding available for all matters related to CO_2 capture and storage, especially R, & D funding, given the national importance of managing CO_2 emissions. (3)

DOE has brought together the best scientists and engineers to tackle the challenges on a regional and national level – led by the seven competitively selected RCSPs. The RCSPs represent a collaborative effort between government and industry to determine the most suitable technologies, regulations, and infrastructure needs for carbon capture and storage in different areas of the country. The RCSPs are listed below, together with links to each Partnership's website:

- Big Sky Carbon Sequestration Partnership – http://www.bigskyco2.org
- Midwest Geological Sequestration Consortium – http://www.sequestration.org
- Midwest Regional Carbon Storage Partnership – http://www.mrcsp.org
- Plains CO_2 Reduction Partnership – http://www.undeerc.org/pcor
- Southeast Regional Carbon Sequestration Partnership – http://www.secarbon.org
- Southwest Regional Partnership on Carbon Sequestration – http://www.southwestcarbonpartnership.org
- West Coast Regional Carbon Storage Partnership – http://www.westcarb.org.



The Regional Partnerships Are Assessing CCS Potential And Injecting Progressively Larger Amounts of CO_2 Into Suitable Formations

The RCSP Program was initiated in September 2003 and has been implemented in three interrelated phases.

1. The Characterization Phase (FY 2003 – FY 2005). This phase, completed in 2005, focused on characterizing regional opportunities for CCS, identifying regional CO_2 sources, and identifying priority opportunities for field tests. Each RCSP developed GIS information systems that house regional geologic data on CO_2.
2. The Validation Phase (FY 2005 – FY 2010). This phase focuses on field tests to validate the predictability of CO_2 when injected into a variety of geological storage sites throughout the United States and Canada. Using the extensive data and information gathered during the Characterization Phase, the seven RCSPs identified the most promising opportunities for CCS projects in their Regions and are conducting 21 geologic field tests). In addition, the RCSPs are verifying regional CO_2 sequestration capacities, satisfying project permitting requirements, and conducting public outreach and education activities.
3. The Development Phase (FY 2008 – FY 2017+). 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 behavior with respect to prolonged injection. Regional variations among the RCSPs will provide vitally important information and experience as they test injection and monitoring technologies in a variety of geologic settings at scale.

Each of these phases is designed to provide increasing assurance that carbon capture and storage can be a safe, effective and permanent method to reduce greenhouse gas emissions, and, in turn, to address climate change. Evaluating the feasibility of CO_2 storage at increasing volumes will allow the energy industry to prove the viability of an evolving technology and that will allow power plants and other industries to mitigate carbon emissions as our Nation develops a strategy to deal with the buildup of greenhouse gases in the atmosphere. Ultimately, carbon capture and storage projects will help protect the investments made in these industries. (3)

The Partnerships Have Determined That Adequate Information Exists to Determine Suitable Geological Sites for CO_2 Storage and Have Made Their Findings Available in a National Geological Storage Atlas

During the characterization phase, the partnerships accumulated a wealth of geographic and geological data needed to determine the suitability of various sites for CO_2 injection. This information has subsequently been used to select the best sites for initial CO_2 injections. The Partnerships have created and maintained the national carbon sequestration portal for matching CO_2 sources with nearby sinks. This Internet portal, called NATCARB, was developed by the University of Kansas and brings together data from every partnership region into one convenient location. The portal is updated regularly by region, and is available to the general public through their website, www.natcarb.org. NATCARB provides a summary of the carbon storage potential in the United States and Western Canada, and allows users to display and analyze CO_2 sources and potential storage sites.

NETL's Carbon Sequestration Atlas of the United States and Canada, Atlas II (4), represents a coordinated effort by experts from industry, academia, and local, state, and provincial governments who worked with the RCSPs. Carbon sources and potential sinks in the US and parts of Canada were assessed to provide a comprehensive overview of where ideal sites for CO_2 injection can be found.

To create the Atlas, the RCSPs worked together to establish common assumptions and methodologies for estimating the CO_2 storage capacities of various geological formations, including oil and gas formations, unmineable coal seams, and deep saline formations. Without this information, it would be impossible to assess whether or not CCS could be broadly applied across the United States and Canada. Future efforts will focus on coordinating Atlas mapping with Canadian and Mexican scientists.

The Partnerships Have Conducted Many Successful Small-Scale Field Tests during Phase II (Validation Phase)

The Validation Phase, begun in 2005, focuses on conducting small-scale CO_2 storage tests to validate that small amounts of CO_2 can be safely, effectively, and permanently stored in a variety of geologic formations throughout the United States and Canada. The field tests have addressed the following goals:

- Collect physical data to confirm capacity and injectivity estimates made during the Characterization Phase.
- Validate the effectiveness of models to predict, and monitoring technologies to measure, CO_2 movement in the geologic formations and confirm that overlying cap rocks prevent CO_2 from moving upward out of the storage formation.
- 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 projects have made significant progress toward testing CO2 injection into a variety of different geologic settings during the field validation projects. Each of the projects entails a significant amount of research in the field and laboratory. The RCSP team, with regional universities, National Laboratories, and industry has created and validated simulations of injectivity, containment, and capacity, as well as other modeling and monitoring activities. The following accounts are representative of the Phase II projects.

For the Midwest Regional Carbon Sequestration Partnership (MRCSP), led by Battelle, the injection of 1,000 tons of CO_2 into Mount Simon Sandstone at Duke Energy's East Bend Generating Station near the town of Rabbit Hash, KY was completed in September 2009. Predictions by MRCSP geologists of the geological structure and injectivity potential at the site proved to be largely consistent with field observations from drilling and injection rates which were about 45 metric tons per hour of CO_2 (equivalent to over 1,000 metric tons per day). These rates, which were determined by the capacity of the injection equipment at the site, indicated good injectivity into this segment of the Mount Simon Sandstone, a deep saline formation that is widespread under much of the Midwestern United States, and is believed to have very large storage capacity.

The project is the first-ever such injection into the Mt. Simon reservoir. It adds significantly to the understanding of the CO_2 storage potential in this regional reservoir. Duke Energy, one of the 30-plus members of the MRCSP, volunteered its East Bend station as the test site and assisted in conducting the demonstration, which was completed in less than 4 months from the start of drilling operations. The collection of water quality data from 11 shallow groundwater wells on the site will continue for approximately the next 2 years to confirm that the CO_2 does not migrate into drinking water supplies.

The test at the East Bend Station in Kentucky follows two other MRCSP injection tests: the Appalachian Basin Test at the R.E. Burger Power Plant in Shadyside, OH and the Michigan Basin Test near Gaylord, MI, where over 60,000 tons of CO_2 have been safely injected into a deep saline formation called the Bass Islands Dolomite.

In a different type of geological formation, the PCOR Partnership injected about 90 tons of CO_2 approximately 1,200 feet underground into an unmineable lignite seam in Burke County, ND, to determine the long-term effect CO_2 will have on the lignite and to determine the potential for coal bed methane recovery. Previous work suggested that the region's coal seams could store up to 8 billion tons of CO_2 while producing more than 17 trillion cubic feet of methane. Because this was the first CCS project to focus on ignites, the demonstration has provided previously unavailable insights broadly applicable not only within the region but to the many lignite deposits across western North America. PCOR began injection in FY2007. During the injection, researchers used sampling techniques to indicate the presence of gas in the vicinity of the coal seam. Indications are that the injected CO_2 has migrated along the cleat direction of the coal and has been contained within the expected injection zone.

The PCOR Partnership, working closely with Eagle Operating, Inc., conducted field and laboratory activities to determine the effects of injecting CO_2 into a carbonate formation in the Northwest McGregor oil field in North Dakota. The purpose of the activities was to evaluate the potential dual objectives of CO_2 sequestration and EOR in carbonate rocks deeper than 8,000 feet. A variety of activities were conducted to 1) determine the baseline geological characteristics of the injection site and surrounding areas, 2) inject CO_2 into the target oil reservoir using a huff 'n' puff approach, and 3) evaluate the effect that injected CO_2 had on the ability of the oil reservoir to sequester CO_2 and produce incremental oil. The PCOR Partnership estimates that the additional oil recovery potential through regional EOR applications exceeds 1.4 billion barrels, with a value of approximately $100 billion at U.S. $70 per barrel.

In yet another geological formation (a mature oil field), an enhanced oil recovery (EOR) test known as a huff-n-puff was conducted by the Midwest Geological Sequestration Consortium (MGSC) at the Loudon Field in Fayette County, IL. This test evaluated the potential for geological sequestration of CO_2 in mature Illinois Basin oil reservoirs. During EOR, CO_2 is injected into a producing well, the well is shut in and CO_2 is allowed to penetrate the formation, and then the well is placed back in production. During the test, a small amount of CO_2 was injected over a 5-day period into a sandstone formation at a depth of approximately 1,550 feet. This test determined that incremental oil production occurred during the first 2 months. This result, in turn, indicates that the Illinois Basin oilfields may be a good location to establish a sequestration industry with the potential benefit of increasing oil production.

The SWP region is rich in many types of geological sinks, including depleted oil and natural gas fields, saline formations, and coal beds. EOR using CO_2 has been conducted in the region for over 30 years. Several hundred miles of CO_2 pipelines through the region provide access to CO_2 near many candidate project sites. The SWP pilot-scale injection tests are being deployed in two types of geologic sinks, piggy-backing upon commercial projects:

1) **Paradox Basin, Utah: Aneth EOR-Sequestration Test**
   Since August 2007, the SWP has been testing EOR combined with sequestration by injecting about 135,000 metric tons of CO_2 per year into the Desert Creek formation, which is approximately 5,800 feet deep, in the Aneth Oil Field in San Juan County near Bluff, UT. The injection schedule ran for 2 years and post-injection monitoring is underway. The CO_2 for this project comes from the McElmo Dome, a natural CO_2 reservoir located in southwestern Colorado.
2) **Permian Basin, Texas: SACROC EOR Sequestration Test**
   This test includes a post-audit modeling analysis of injected CO_2 for EOR over the last 30 years at the Scurry Area Canyon Reef Operators Committee (SACROC) Unit in the Permian Basin of Texas, in addition to intense Monitoring, Verification and Accounting (MVA) analyses of ongoing CO_2 injection at SACROC. Results will be used to define an optimized commercial approach to EOR with sequestration in the Claytonville field, a nearby oil production field with similar geology that has not yet been subjected to CO_2 injection. CO_2 injection is expected to begin at this site in late 2010. The SACROC pilot represents an opportunity for making CO_2 storage history—matching in tandem with large-scale MVA operations during injection of between 800–1.5 million metric tons of CO_2.
3) **San Juan Basin, New Mexico: Pump Canyon Sequestration/ECBM Test**
   Injection at the Pump Canyon site, into the Fruitland coals, approximately 3,000 feet deep, started in July 2008 and lasted one year. A total of 18,400 short tons of CO_2 was injected with a declining injection rate due to coal swelling as a result of the CO_2 being adsorbed onto the coal while displacing methane. A variety of monitoring, verification and accounting methods (MVA) were deployed to track the CO_2 plume inside and outside the reservoir such as but not limited to, tilt meters, CO_2 sensors and tracers. The CO_2 sensors suggest that a minute breakthrough has occurred at the site, but a steady increase in CO_2 content at one of the direct offset wells could be a sign of imminent breakthrough. A very thorough simulation model was built and able to replicate the production and injection behavior of the reservoir, showing an incremental methane production of 26MMscf due to injection.

These projects are providing a comprehensive assessment of the sources and potential sinks for CO_2 in the Southwest region. This 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 is providing information to evaluate potential commercial-scale sequestration projects in the Southwest. Some value-added benefits of the project include enhanced recovery of oil, natural gas, and coal bed methane. 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, in the Southwest region, all such enhanced resource recovery operations 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, it is estimated that the region could achieve at least a 10 percent reduction in GHG intensity. (5)

The SECARB Partnership has determined that the "stacked formations," that is, oil fields overlying deep saline reservoirs, along the Gulf Coast, and more specifically in the states of Alabama, Florida, Louisiana, Mississippi, and Texas, are a prime target area for geologic CO_2 storage. SECARB's research estimated 34 billion tonnes of potential storage capacity in the region's depleted oil and natural gas fields. Coal seams are among the most attractive potential CO_2 sinks occurring in the Southeastern United States, where a prolific coal bed methane industry, which has produced more than 2.3 trillion standard cubic feet (Tscf) of natural gas, is approaching maturity. SECARB estimates that about 44 billion metric tonnes of potential storage capacity exists in the region's unmineable coal seams.

Saline formations, however, provide the primary CO_2 geologic storage options for the SECARB region because of the extensive saline formations that underlie many of the power plants in the region. SECARB's research estimated a low-end storage potential quantity of 2,275 billion tonnes of potential sequestration in saline formations in the region.

SECARB has conducted four geologic sequestration field tests during the Validation Phase.

1) **Gulf Coast Stacked Storage Project -** The Gulf Coast Stacked Storage project has demonstrated the concept of phased use of subsurface storage volume. This sequestration approach combines the early use of CO_2 for EOR followed by subsequent injection into associated saline formations. This results in both short- and long-term benefits, as there is the immediate commercial benefit of EOR as a result of the injection of CO_2 (offsetting infrastructure development costs), followed by large volume, long-term storage of CO_2 in saline-bearing formations. The field test is being conducted in the lower Tuscaloosa Formation in the Cranfield unit, located in southwestern Mississippi, at a depth of 10,300 feet. Injection rates of CO_2 in the commercial EOR flood are estimated at about 225,000–450,000 metric tons per year. This one-year Validation Phase study has been followed by a large-volume injection into the brine-bearing formations down dip of the oil ring during the Development Phase.
2) **Central Appalachian Basin Coal Test -** This test will validate sequestration opportunities in the unmineable coal seams of the Central Appalachian Basin, a basin encompassing 10,000 square miles in southwestern Virginia and southern West Virginia. The project is evaluating the injection of 900 metric tons of CO_2 into multiple coal seams of the Pocahontas Formation and Lee Formation at depths ranging between 1,400 and 2,200 feet. The project also includes coal bed methane (CBM) recovery operations. The primary project objective is to demonstrate geologic sequestration in unmineable Appalachian coals as a safe and permanent method to store CO_2.
3) **Black Warrior Basin Coal Test -** As in the Central Appalachian Basin, the objectives of the Black Warrior Basin test are to determine if sequestration of CO_2 in mature CBM reservoirs is both safe and effective and to determine if sufficient injectivity exists to efficiently drive CO_2-enhanced coal bed methane (ECBM) recovery. The test has taken place in Tuscaloosa County, AL.
4) **Saline Reservoir Field Test: The Mississippi Test Site -** The primary objective of this project is to locate and evaluate suitable saline formations for storage of CO_2 in close proximity to large coal-fired power plants along the Mississippi Gulf Coast. The target formation for this field test is the Lower Tuscaloosa Massive Sand Unit in Jackson County, MS. The test includes building detailed geological and reservoir maps to further assess the test site and conducting reservoir simulations to estimate injectivity, storage capacity, and long-term fate of injected CO_2. Injection of 2,720 metric tons of CO_2 at an approximate depth of 9,500 feet has taken place at Mississippi Power Company's Plant Daniel, located in southern Mississippi.

The WESTCARB Partnership has indicated that California offers outstanding opportunities for CO_2 sequestration because of its many deep sedimentary basins and the potential of value-added benefits from EOR and enhanced gas recovery (EGR). In Oregon and Washington, sedimentary basins also offer excellent sequestration opportunities – a series of basins in the western portions of both states contain sediments up to 20,000 feet (6,000 meters) thick. In Washington, the Puget Sound Basin also contains deep coal formations suitable for sequestration that may have potential for ECBM production. In Nevada, many small basins have been identified. In Alaska, the oil and natural gas fields on the North Slope are of prime interest because of the large potential for EOR using CO_2. Further, a deep sedimentary basin below the Cook Inlet is near some of Alaska's major CO_2 sources. Finally, in Arizona, sediments underlying the Colorado plateau offer potential storage sites and are in the vicinity of major coal-fired power plants. WESTCARB is pursing two projects:

1) **Shell Northern California Saline Formation CO_2 Storage Pilot -** A geologic CO_2 storage pilot in a saline formation is planned for the western Sacramento Valley in northern California. WESTCARB's partner, Shell Oil Company, will enhance the project team's expertise in the areas of earth sciences, drilling, and CO_2 injection. The test will involve drilling injection and monitoring wells to 10,000–12,000 feet, injection of 1,815 metric tons of CO_2, and monitoring with geophysical and geochemical sampling techniques.
2) **Arizona Utilities CO_2 Storage Pilot -** This project involves drilling a well approximately 3,800 feet deep to evaluate saline formation CO_2 storage in Arizona's Colorado Plateau region. The same amount of CO_2 as the previous test will be injected into the chosen saline formation, and CO_2 dispersion into the formation will be monitored.

The Big Sky Partnership is evaluating the CO_2 storage potential of basalt formations, which are geologic formations of solidified lava. Basalt formations have a unique chemical makeup that could potentially convert all of the injected CO_2 to a solid mineral form, thus isolating it from the atmosphere permanently. Research is focused on enhancing and utilizing the mineralization reactions and increasing CO_2 flow within a basalt formation. The highlight of Big Sky's Phase II effort is a pilot-scale test to inject approximately 1,000 tons of supercritical CO_2 into a deep basalt formation in Washington State. The test will assess the mineralogical, geochemical, and hydrologic impact of injected CO_2 within a basalt formation, and incorporate site monitoring and verification activities.

Benefits of this project will include providing a comprehensive evaluation of the sources and potential sinks for CO_2 in the Northern Rockies and Great Plains Region and a previously-unavailable source of real-world information on the issues and practices surrounding injection of CO_2 into basalt formations. 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 potential exists in the deep saline formations, 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 550 billion metric tons of CO_2.

The combined RCSP Validation Phase projects are demonstrating that geologic storage is not just an option for the distant future, but is ready to be scaled up in many types of geological formations for both environmental and commercial reasons.

The Partnerships Have Identified Limitations to the Standard Methodology for Characterizing

Site Porosity and Permeability

The majority of the RCSPs' small scale field tests have been successful. However, two tests, the MRCSP field test located near the Burger power plant in Ohio and WESTCARB's project near the Cholla power plant in Arizona both indicated that subsurface conditions may not always prove to be as anticipated, particularly in areas with little prior oil and gas exploration.

The initial injection targets at the Burger site were sandstones at depths between 5,500 and 8,000 feet in the Appalachian Basin. This region is geologically complex and little is known about these formations, especially in the western portion of the basin. Results of the initial two tests indicated that the porosity, void space, and permeability of the target formations were lower than expected, a finding that confirms the complex nature of the formations within the basin. However, this result does not mean that the entire western flank of the Appalachian Basin will have these same properties. Because the nearest well penetrations are more than 20 miles away from the Burger injection well, additional data collected from the region will be useful in determining the suitability of potential field test locations for CO_2 storage in the future. Additional testing will be required to determine the CO_2 storage properties of the broader Appalachian Basin, and especially areas close to the Burger power plant.

In a somewhat analogous situation, the initial target formation for storage at the Cholla power plant site in Arizona was in a region where little is known about the properties of the deep subsurface formations. In this case the target was a carbonate rock formation at a depth of about 3,500 feet, and, based on information from the very few wells in the region surrounding Cholla, appeared to have suitable storage properties. It did not, however, exhibit suitable storage properties in the exploration well. WESTCARB's test at Cholla found highly saline formation waters and good cap rocks, but insufficient permeability for CO_2 injection. Though not a target at the Cholla site, the well did reveal a sandstone formation at shallower depth which could be of potential interest in the future at other locations in the Colorado Plateau. In fact, WESTCARB is planning to drill another characterization well about 60 miles north of the Cholla site.

The Burger and Cholla test results do not preclude the potential for storage in the regions surrounding the site; instead, the tests confirm the complex nature of the formations within the basins. The work demonstrates the importance of extensive drilling, formation evaluation, and testing to characterize and identify appropriate formations for CO_2 storage nationwide prior to injection.

The Partnerships Have Begun to Make Significant Advancements in Injecting Large Amounts of CO_2 into Various Geological Formations during the Development Phase (Phase III)

While projects in the Validation Phase were designed to determine whether regional sequestration sites have the *potential* to store hundreds of years' worth of CO_2 emissions in the United States, the large-volume sequestration tests in the Development Phase are focusing on how CO_2 storage sites will be managed. These tests will address practical issues, such as rates and pressures at which the CO_2 can be pumped into the storage reservoir without fracturing the formation, well design, and how the reservoir will function over prolonged injection periods. Such issues can only be addressed by scaling up the size and duration of sequestration projects. Additionally, because each region possesses its own distinctive geologic formations and storage site characteristics, each site will yield valuable and unique operational information.

The DOE awarded 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 3 years).
- CO_2 injection and monitoring operations (3 to 6 years).
- Site closure and post injection monitoring (2 to 3 years).
- The majority of tests during this 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.

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

- Goal 1: *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.
- Goal 2: *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.
- Goal 3: *Determine Areal Extent of Plume and Potential Leakage Pathways* - The RCSPs will monitor the areal 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.
- Goal 4: *Develop Risk Assessment Strategies - The RCSPs will identify r*isk parameters, probability and potential impact of occurrence, and develop mitigation strategies.
- Goal 5: *Develop Best Practices* - The RCSPs will develop Best Practice Manuals for site selection, characterization, operational, and closure practices.
- Goal 6: *Engage in Public Outreach and Education* - The RCSPs will engage and educate the public about CCS.
- Goal 7: *Contribute to the Improvement 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.

The Regional Partnership Phase III (development) field tests are progressing well. A very important milestone occurred in the Southeast Regional Carbon Sequestration Partnership (SECARB) at the Cranfield site in southwestern Mississippi in October 2009. The DOE-sponsored storage project is one of only five sites worldwide which exceed 1 million tons (or more) of injected CO_2. (In June 2010, this project surpassed the two million ton mark.) However, the successes of the Cranfield project are likely to be replicated throughout the U.S. Gulf Coast region, as the geology of the Cranfield site is representative of other potential CO_2 storage sites in this area.

Many believe that a particular positive aspect of the Cranfield project is that its CO_2 storage is coupled with EOR with the CO_2 injected in the water leg of the formation. CO_2 EOR currently accounts for 4 percent of the Nation's oil production, and DOE studies suggest that a widespread CO_2 EOR program in large, favorable reservoirs, like Cranfield and other large-scale geologic sequestration sites can provide a significant contribution to domestic U.S. oil production. Cranfield is currently the largest CCS project injecting CO_2 in the United States, but several other RCSP projects are close at its heels. Following Canfield's Deployment Phase success is a second wave of RCSP Phase 3 projects including:

1) The Midwest Geological Sequestration Consortium (MGSC)—MGSC is working with partner Archer Daniels Midland Company (ADM) to conduct a large-volume saline sequestration test at ADM's ethanol fermentation facility in Decatur, IL. The test will inject about 370,000 tons of CO_2 per year for 3 years into the Mount Simon Sandstone, a major saline formation in the Illinois Basin, at a depth of about 7,000 feet. The Eau Claire Shale which forms the reservoir seal is a 500 foot thick unit. The Mount Simon Sandstone is Cambrian in age and forms the lowest sandstone reservoir in the Illinois Basin of Illinois, southwest Indiana, and western Kentucky. An injection well was drilled in 2009 and perforations, tubing, and packer set by January 2010. Also in January 2010, a baseline 3D seismic survey was completed. A compression/dehydration facility will be completed in late summer 2010 and injection is expected to begin around February 2011. A pressure observation and fluid sampling well is to be drilled in fall 2010 and baseline data collected prior to initial injection. A unique aspect of this test is the drilling and completion of a 3,500 foot deep well into which a string of 31 geophones was permanently cemented to allow easy collection of repeat Vertical Seismic Profiles to define CO_2 location as injection proceeds.

2) The Plains CO_2 Reduction Partnership (PCOR)—PCOR's Fort Nelson project will store more than 1 million tons of CO_2 per year captured from the largest gas processing plant of its kind in North America. The CO_2 will be compressed and transported via pipeline to the target injection location, which is 3 miles from the gas plant, where it will be stored at a depth greater than 5,000 feet. While providing a substantial reduction in CO_2 emissions, the project will also facilitate the development of significant shale gas reserves to provide North American markets with clean natural gas. The research aspects of the project will provide proof of concept for geological CO_2 storage in deep saline formations and serve as a model for follow-on CCS projects using geological CO_2 management at other gas-processing facilities in the region and around the world.

   The Fort Nelson CCS project has several strategic advantages that make it ideal for an early project:

   - The Fort Nelson gas-processing plant currently captures CO_2.
   - The Northeast British Columbia natural gas boom is expected to double production.
   - The site is located near deep saline formations potentially suitable for permanent CO_2 storage.
   - No net additional fuel/power is required.
   - There is a potential to generate electric power through waste heat recovery, which can be fed to the grid or back to the plant.

The Regional Partnerships Have Worked Closely with Local, State, Regional, and Federal Officials to Determine Their Information Needs Regarding Permitting and Have Either Provided the Requested Information or Developed a Plan for Providing the Information

In collaboration with the Interstate Oil and Gas Compact Commission, the Regional Partnerships developed a permitting model for transportation and geologic sequestration, based on a review of the existing regulatory structure for enhanced CO_2 oil recovery efforts and an assessment of the gaps to be addressed. (6) This model has served as a basis for several CCS state regulations that have been implemented.

In addition, during the process of receiving permits to conduct both small and large-scale field tests, the RCSPs have had many opportunities to improve their understanding of permitting requirements to facilitate the best approach for field testing and commercial sequestration projects. In addition, the Environmental Protection Agency and many state agencies require various permits before drilling and injection can begin. Obtaining these permits can be both difficult and complex because many agencies can be involved in the process, and a significant amount of data is required. Reference 7 of this document contains a link to the WESTCARB Partnership's permit to inject a small amount of CO_2 into a saline formation in Arizona. In addition, because CCS is a relatively new technology, most permitting agencies have little or no experience with issuing permits for CO_2 injection and storage projects. Many of the Partnerships have taken an active role in helping the permitting authorities to acquire more familiarity with CO_2 injection and storage issues.

The following is a partial list of the information requested (and provided) by the Partnerships prior to receiving their Underground Injection Control (UIC) permits:

- Extensive data on regional and local geology.
- Extensive data on well design and drilling operations.
- Detailed modeling of the injection to determine the expected spread of the CO_2 underground.
- Extensive characterization of the CO_2 to be injected.
- Average and maximum surface injection pressure.
- Diagrams depicting the location, well name, and operator of all wells within a certain radius of the injection site.
- Detailed analysis of the water quality from nearby fresh water wells.
- A legal description of land ownership near the injection sites and a certification that all landowners in the area were notified of the injection well.

To demonstrate that the Regional Partners have been providing the type of data that EPA needs to grant CO_2 injection permits and assist the agency in its proposed rulemaking regarding CO_2 injection, the following excerpt from EPA's Notice of Data Availability on its rulemaking (8) is quoted verbatim "SECARB is conducting a CO_2 injection test in Jackson County, MS into a deep saline reservoir along the Gulf Coast that had not previously been characterized for oil and gas exploration. The injection zone, 9,500 feet (2,896 meters) deep in the Lower Tuscaloosa Massive Sand Unit, is overlain by two confining layers. The site is near the Victor J. Daniel Power Plant. The CO_2 was delivered to the injection site via truck. Characterization of the site is based on a wealth of geophysical and core-derived information, including well core samples, open-hole and cased-hole well logging, baseline vertical seismic profiling, and pressure transient testing. Baseline sampling and analysis of formation fluids and soil flux sampling were also performed. The SECARB team performed a 3-dimensional simulation to estimate injectivity, storage capacity, and long-term fate of the injected CO_2. The model estimated that the plume would extend up to 350 feet (106.7 meters) at the end of the injection test. …. **To date, there has been no indication of the return of the injected CO_2 in the shallow subsurface. …**This SECARB project employs, demonstrates, and validates the EPA's proposed Class VI well construction, operational, and monitoring requirements. The use of surface and near-surface monitoring techniques provides the EPA with preliminary information regarding the efficacy and appropriateness of these technologies at certain sites; and supports the need for a site-specific monitoring plan that will allow use of a range of monitoring technologies suitable for each unique GS site. **This information and public comments on this research will be used to inform the Agency's final rulemaking."** (Emphasis added)

The Partnerships Experience with Permitting Can Be Used To Support Future CCS Projects

In some areas, in addition to the previously mentioned permit requirements, (PCOR and WESTCARB, in particular) aquifer exemption permits were also required. These permits, in turn, required the following: determination of the aquifer water quality before and after CO_2 injection, estimation of the distance of the exempted aquifer from public water supplies, and an analysis of future water supply needs within the area.

Even after the permits to inject were obtained, additional information was required by many regulatory agencies prior to injection. For example, SECARB reported that an additional mechanical integrity test to determine that the CO_2 could be safely injected was required by EPA. The MGSC Partnership indicated that it was necessary to submit a well completion report that described the data collected during drilling and the results of a fracture test, which needed to be witnessed by the regulator before injection could commence.

Given the situation described above, where several permits may be required for one project, successful efforts by the Partnerships have done a great deal to advance the permitting process, which should make it much easier for the permitting of future CCS projects. In particular, the Southwest Partnership has prepared a best practices manual that summarizes permitting requirements by different agencies as well as contacts in each of these agencies throughout their region. This manual should prove useful for future permitting efforts.

The Partnerships Have Contributed To the Resolution of Pore Space Ownership Issues

Some of the Regional Partnerships needed to address and resolve pore space ownership issues prior to injection. For example, SECARB negotiated an agreement with a landowner, mineral owner, and gas lessee to allow injection at one of their sites. In this instance, royalties were negotiated with mineral owners and access fees were paid for surface rights. For some partnerships, no pore space issues were encountered, especially for the small-scale projects. For example, for the Midwest Geological Sequestration Consortium's Phase III test, pore space ownership is not an issue because the injected CO_2 is expected to stay beneath the property of their industrial partner who owns the site. In the WESTCARB partnership, the surface owner also owned the pore space for the pilot Phase II test undertaken at the Cholla power plant in Arizona, where there was a single property owner. Other partnerships have also reported that pore space issues were similarly avoided during the development of their small-scale projects. However, ownership rights and access issues could arise during large-scale test projects, and would certainly need to be considered for commercial projects. Nonetheless, the Partnerships have been instrumental in highlighting and initiating resolution of pore space ownership related to CCS and have actively engaged in educating policymakers on this issue.

The Partnerships Have Identified Local Community Concerns Near Planned CO_2 Injection Sites and Have Implemented Successful Community Outreach Strategies

The RCSPs will continue to engage in the development of an effective regulatory and legal framework for the safe, long-term injection and geologic storage of CO_2. 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. The 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 seams, and hydrocarbon rich shale.

Public outreach plays a significant role in the RCSPs' activities. There is an outreach coordinator for each partnership who leads the development and implementation of detailed outreach plans during each phase of research. Development Phase outreach efforts will employ the best practices learned in the first two phases and is expected to yield further best practices as large-scale projects are undertaken. Each of the partnerships has developed information relating to the geology and projects within its region. In general, this information includes:

- General information about the partnership and its region; the project team, its partners, the partnership's lead organization; announcements and technical reports as they are published.
- General information about carbon storage, climate change, and CO_2.
- Access to the national or regional atlas of CO_2 sources and emissions in the region; information on geologic CO_2 storage potential in the region; and regulatory and permitting information.
- Detailed information about the Phase II and Phase III storage projects.
- Information and educational products developed by the partnership, including fact sheets, briefing materials, links to the latest carbon storage news stories, and links to scientific topical reports.
- Links to photographs, video clips, and other multi-media resources.
- Frequently Asked Questions page.
- Links and resources with additional information.
- Links to educational resources and pages for "kids" to help school-age children learn more about the climate and the weather, potential climate change, and the greenhouse effect through online games, climate animation, and other activities.

Ten years ago, carbon sequestration was a little-known concept in the United States. Now stories about carbon sequestration appear in local or national media almost every day. What is carbon sequestration and how is it done? Is it really a solution to climate change? What challenges face the commercial deployment of this technology?

In order to answer these questions, NETL has published a best practices manual for public outreach, based on the RCSP's work. The objective of the Best Practices for Public Outreach and Education for

Carbon Storage Projects Best Practices Manual (10) is to communicate the lessons learned and to recommend best practices emerging from the first 6 years of public outreach conducted by the seven Partnerships. The manual is intended to assist project developers in understanding and adopting best practices in outreach to support CO_2 storage projects.

The primary lesson learned from the Partnerships' experience is that public outreach should be an integrated component of project management. Conducting effective public outreach will not necessarily ensure project success, but underestimating its importance can contribute to significant delays, increased costs, and lack of community acceptance. Outreach is not simply an add-on activity— it is integral to implementation of the project.

In addition to the finding that public outreach should be an integral component of project management, the manual outlines an additional nine best practices. In combination, the best practices represent a framework for designing an outreach program that is tailored to the specific characteristics of a planned project, the project developers, and the community in which the project is located.

The Regional Partnerships have taken some innovative approaches to help the general public understand the importance of carbon capture and storage projects and how they work. For example, the depth and scale of CO_2 storage projects are usually not readily understood by the public. Carbon dioxide storage sites must be more than one-half mile deep, and can often be one to two miles deep, whereas typical water wells might be 100 to 200 feet deep. That is a significant difference in terms of the path length that CO_2 would have to travel to reach the surface. WESTCARB staff has found that scale diagrams of geological formations can reinforce the point that a significant number of rock layers help to keep any CO_2 that might happen to leave the storage zone from reaching the surface. Therefore, WESTCARB staff has recommended that public presentations should show diagrams to true scale without compression of the vertical axis, which is common in professional communications among geologists. In addition, CO_2 quantities are typically expressed in tons, which few individuals can conceptualize. For its small-scale injections tests, WESTCARB has likened the size of a 2,000 ton subsurface CO_2 plume to the volume of water in a community swimming pool. Commercial projects will entail much larger volumes, but they are still small relative to the volume of water in a lake or reservoir, which can be used as comparative references. An understanding of a CO_2 storage project can also be facilitated by general interest information on the geology of an area, particularly if natural features offer dramatic display, such as in the canyon lands of Western states.

The MGSC approached outreach with the idea that showing audiences what sequestration might look like would be the best way to open the CO_2 storage discussion. They have had success with two different physical demonstrations that focus on key questions often asked in the context of CO_2 storage: (1) how will you keep the CO_2 in the ground, and (2) what happens to the CO_2 once it is injected into the ground? Demonstration kits were made for key MGSC staff. The kits include a whole core sample of the carbon storage unit (Mt. Simon Sandstone), a whole core sample of the cap rock seal and a small water dropper. Using this kit allows a simple discussion of porosity, permeability, and the impermeable nature of the seal. MGSC also created a three-dimensional table top model that demonstrates EOR and storage of CO_2 in a deep saline reservoir. The model has several rock units, represented by different gravel material, that are isolated from each other. Oil can be placed in the EOR reservoir. When CO_2 is added to water and injected into an "injection well" oil and formation water are produced. The deep saline reservoir has a single injection well and a pressure-valve system for injection. When liquid CO_2 (oil for the purposes of the model) is injected, the observer sees CO_2 dispersing into pore spaces and being held in place by the cap rock seal above. The MGSC has reported that the main value of these physical tools has been to provide learning opportunities for multiple audiences, from farmers to business executives and teachers to legislative decision makers. These models served as door openers during public meetings. Presenters often found that when stakeholders did not know who to approach or what questions to ask, these models provided an easily accessible way to ask questions in a non-threatening manner.

The leaders of the Regional Partnerships are also frequently requested to address general audiences regarding various aspects of their work. For example, representatives from the Southwest Regional Partnership, affiliated with the University of Utah's Energy & Geosciences Institute were asked to discuss their work at the Utah Museum of History.

The Regional Partnerships Have Contributed Significantly To Public Policy on CCS

As mentioned in a previous section of this report, EPA has indicated that the information and public comments on the field tests conducted by the Regional Partnerships will be used to inform the Agency's final rulemaking on a Class VI well category for CCS projects.

In addition, some of the Partnerships have been called upon to provide information on CCS to policymakers in support of CCS regulatory development at the state level.

Many Domestic Groups Have Recognized the Achievements of the Regional Partnerships

DOE was selected to receive the American Association of Petroleum Geologists' Corporate Award for Excellence in Environmental Stewardship based upon the work of the Regional Partnerships. The Association's Division of Environmental Geosciences presented the award during the AAPG Annual Convention in 2007 in Long Beach, CA.

The first *Carbon Sequestration Atlas of the United States and Canada* (Atlas I), was among 120 Grand Award winners selected from nearly 4,500 entries in 2008 by editors at Communications Concepts, Inc., the publisher of *Writing That Works*, an authoritative monthly newsletter on practical writing, editing, and communications. Winners in the 20th Annual Grand Award for Publication Excellence (APEX) competition were selected based on excellence in graphic design, editorial content, and overall communications effectiveness. Judged a "first-rate effort" in the One-of-a-Kind Publications category, the Atlas was complimented for richness of data and exceptional visuals, including effective info-graphics and clear, understandable copy. (11)

On November 17, 2008, the Interstate Oil and Gas Compact Commission (IOGCC) presented its prestigious Chairman's Stewardship Award in Environmental Partnership to the Energy & Environmental Research Center (EERC) (PCOR) Partnership. (www.iogcc.state.ok.us/iogcc-recognizes-environmental-efforts-by-industry)

The Lignite Energy Council's Awards Committee designated Ed Steadman and John Harju to receive the "Distinguished Service – Research and Development Award" for their leadership and counsel on R&D projects related to carbon sequestration through the PCOR Partnership. The awards were presented on October 8, 2009, in Bismarck, ND.

A documentary about terrestrial carbon sequestration produced with support from DOE (via the PCOR Partnership) received a 2009 Gold Aurora Award in the documentary category for nature/environment and a Communicator Award for its high level of quality and excellence in communications. Aurora Awards are an international competition designed to recognize film and video excellence. Titled Out of the Air – Into the Soil: Land Practices That Reduce Atmospheric Carbon Levels, the 30 minute documentary, which was co-produced by Prairie Public Broadcasting and the PCOR Partnership, discusses the effects that proper landscape management can have on carbon absorption. WESTCARB forestry projects for carbon sequestration are among the projects profiled in the video. It premiered on Prairie Public Television on September 26, 2008, and is the third in a series of documentaries being produced by the PCOR Partnership and Prairie Public Broadcasting.

The SECARB Phase III Early Test was recognized on November 5, 2009, by DOE for furthering CCS technology and meeting G-8 goals for deployment of 20 similar projects by 2010. The "Early Test" is the fifth project worldwide to reach the CO_2 injection volume of one million tonnes and the first in the United States. In addition , the PCOR Partnerships' Fort Nelson CCS project has been identified in the Global CCS Institute /IEA/CSLF Report to the Muskoka 2010 G-8 summit as a project that could contribute to the achievement of the G8 leaders goal of launching 20 large–scale CCS projects by 2010(http://www.iea.org/papers/2010/ccs_g8.pdf)

In addition, many groups have used the work of the Regional Partnerships to help them advance various aspects of their CCS projects, For example, in January 2010, the Petroleum Technology Research Center in Canada (PTRC), during development of a communications plan for its deep saline reservoir storage project, Aquistore, found that the USDOE's Best Practices for Public Outreach and Education for Carbon Storage Projects document offered a framework for identifying key milestones within the project. PTRC was able to more clearly identify its own milestones based on this information, and, in turn, created a critical path/timeline for public engagement. In addition, the Aquistore Communications Steering Committee included representatives from the Regional Partnerships in its initial planning sessions to provide input into the strategic plan. Both MSGC and PCOR Partnership related case studies were cited and copies of the MSGC Communications Plan were distributed (12).

The International CCS Community Has Also Recognized the Work of the Regional Partnerships

A well respected international agency, the International Energy Agency's Greenhouse Gas Research and Development Program, has concluded that the RCSP's Development Phase (Phase III) is "an excellent program that will significantly advance and accelerate the field of CCS."(13) Scientific experts from the IEA validated that DOE's RCSPs and their large-scale CO_2 tests are the world's most ambitious and will significantly advance CCS in the United States, Canada, and internationally. The IEA found that the seven RCSPs are unique in that no other country or region has initiated such an ambitious CCS effort. The IEA's findings indicate that the projects are realistic, achievable, and should be implemented immediately to benefit national and international organizations that will be responsible for establishing CCS projects. The IEA found that the RCSPs are comprehensive and together comprise a major research initiative; and that Phase III is an excellent program that will achieve major results for the United States, Canada, and the world.

In addition to the IEAGHG, in 2005, the Carbon Sequestration Leadership Forum (CSLF) formally recognized the contributions that the Regional Partnerships are making to advance CCS. The RCSP's projects have been recognized as CSLF projects. The CSLF is a Ministerial-level international climate change initiative that is focused on the development of improved cost-effective technologies for the separation and capture of CO_2 for its transport and long-term safe storage. The mission of the CSLF is to facilitate the development and deployment of such technologies via collaborative efforts that address key technical, economic, and environmental obstacles. The CSLF is also promoting awareness and championing legal, regulatory, financial, and institutional environments conducive to such technologies. The CSLF has provided recognition to two PCOR Partnership projects: the Zama Acid Gas Enhanced Oil Recovery CO_2 Sequestration and Monitoring Project, which injects CO_2 and hydrogen sulfide gas to enhance oil recovery at the Zama Field in Northern Alberta (http://cslforum.org/projects/zama.html); and the Fort Nelson Carbon Capture and Storage Project in northeastern British Columbia, Canada, which will permanently sequester approximately 2 million tonnes of CO_2 emissions per year from a large natural gas-processing plant into deep saline formations of the Western Canadian Sedimentary Basin (http://cslforum.org/projects/fortnelson.html).

There Are Still Remaining CCS Challenges Which Must Be Met to Enable Broad Commercial Deployment of CCS

While interest in CCS has grown considerably over the past 10 years in North America and around the globe, many challenges remain before this technology is ready for broad commercial deployment. For example, the World Resources Institute and others have identified several of these challenges, including: 1) the need for consistent funding for large-scale demonstration projects to resolve technical and application uncertainties; 2) the need to further refine a flexible and adaptable regulatory framework; 3) the need to continue to address public acceptability; and 4) the need for even more detailed geological data to determine the suitability of various geological formations for CO_2 injection. (14) Development of less expensive capture technologies is also a priority. Legal issues such as pore space ownership and long-term liability are also important and need to be resolved.

The best approach for CCS projects has been to select proper sites that will hold the CO_2 in the chosen location; engineer the injection facility to have the best environmental controls and to monitor over both the short and long run to be sure the CO_2 stays in place. An ideal regulatory program would include permitting requirements to demonstrate both to regulators and to the public that CCS is safe and permanent. This program should continue to cover:

- Extensive site characterization to identify important geological variables to determine site suitability for CO_2 injection.
- Proper definition of the extent of the area to review and monitor.
- Appropriate requirements for injection well construction.
- Engineering testing of the well and distribution network.
- Site specific monitoring.
- Assurances of financial responsibility of the CCS project operator/owner.
- Site safety requirements and bonding.
- Well closure plans and requirements.
- Post closure plans and requirements.

- Clear determination of ownership issues, including ownership of the pore space into which the CO_2 will be injected.
- Public participation.

As this paper has indicated, major advances have been made in these areas, but more work needs to be done and is planned. There are challenges with each, and taken as a whole, they represent a sizable set of hurdles between where we are now and broad commercial deployment of CCS anticipated by the G-8 and others in 2020. Accordingly, there is great value in testing and proving each of these steps, continuing to identify and resolve issues, advancing best practices, and in general accelerating the commercialization and use of this important technology.

While Major Advances Have Been Made, Additional Work is Underway to Address the Remaining Challenges Which Must Be Overcome Before CCS Technology is Ready for Broad Commercial Deployment

The RCSP's and others continue to work toward large scale CCS development to verify the safe, effective, and permanent storage of CO_2 in geological formations. For example, SECARB's future work includes performing and closing out the final field test for Phase II by September 30, 2010. This Partnership is also expected to issue a final report on a detailed CO_2 pipeline study by September 30, 2010. Phase III efforts include continuation of the Early Test at Cranfield (which continues through Summer 2011); and completing the permitting requirements and Environmental Assessment for the Anthropogenic Test at Plant Barry and beginning monitoring of the CO_2 injection at the Citronelle field. SECARB also expects to complete an evaluation of offshore geologic storage options around March 2011. More detailed characterization of onshore sources and sinks is expected to continue throughout the entire program period, and data will be added to the NATCARB database as needed.

The RCSP Atlas III is expected to be published in November, 2010 as well.

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The U.S. Carbon Sequestration Council (www.uscsc.org) is a not-for-profit, 501(c)(3), organization established as an authoritative source of information to inform and to educate on all matters pertaining to carbon sequestration.