NETL

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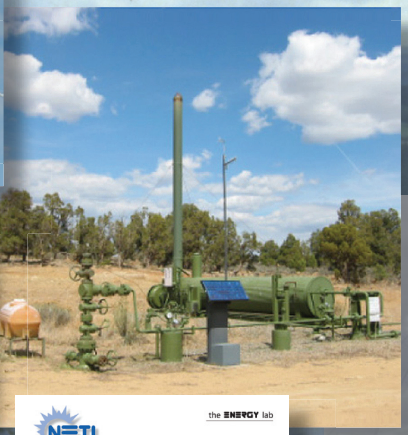
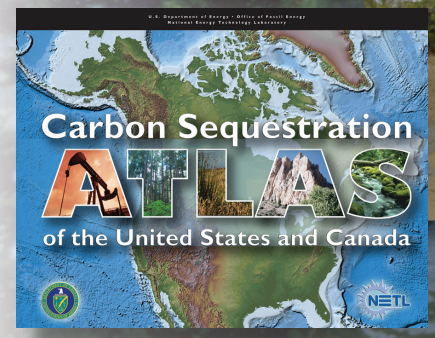
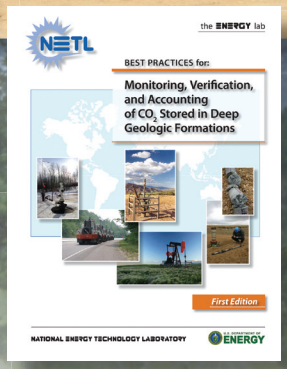
Carbon Sequestration Program

FY2008–2009

Accomplishments







November 2010

DOE/NETL-2010/1423

U.S. DEPARTMENT OF ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

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National Energy Technology Laboratory

www.netl.doe.gov

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List of Acronyms and Abbreviations

Acronym/Abbreviation	Definition
ACS	American Chemical Society
ADM	Archer Daniels Midland
APEX	Award for Publication Excellence
APP	Asia-Pacific Partnership
Atlas I	Carbon Sequestration Atlas of the United States and Canada
Atlas II	2008 Carbon Sequestration Atlas of the United States and Canada
BPM	Best Practice Manual
BSCSP	Big Sky Carbon Sequestration Partnership
CarBen	Carbon Sequestration Benefits Model
CBM	Coalbed Methane
CCS	Carbon Capture and Storage
CED	Clean Energy Dialogue
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2-EOR	Carbon Dioxide-Enhanced Oil Recovery
COE	Cost of Electricity
CSLF	Carbon Sequestration Leadership Forum
CT	Computerized Tomography
DOE	U.S. Department of Energy
DOI	U.S. Department of Interior
DOT	U.S. Department of Transportation
DSS	Decision Support System
DTPS	Distributed Thermal Perturbation Sensor
ECBM	Enhanced Coalbed Methane
EIA	Energy Information Administration
EOR	Enhanced Oil Recovery
EPA	Environmental Protection Agency
ES&H	Environment, Safety, and Health
F-T	Fischer-Tropsch
FAQ	Frequently Asked Question

Acronym/Abbreviation	Definition
FE	DOE's Office of Fossil Energy
FEPs	Features, Events, and Processes
FERC	Federal Energy Regulatory Commission
FOA	Funding Opportunity Announcement
FY	Fiscal Year
GCCC	Gulf Coast Carbon Center
GFZ	GeoForschungsZentrum Potsdam
GHG	Greenhouse Gas
GIS	Geographical Information System
GWP	Global Warming Potential
GWPC	Ground Water Protection Council
H_2	Hydrogen
IBM-IS	Intelligent Bioreactor Management Information System
IEA	International Energy Agency
IEA GHG	IEA Greenhouse Gas R&D Programme
IEP	Innovations for Existing Plants
IGCC	Integrated Gasification Combined Cycle
IOGCC	Interstate Oil and Gas Compact Commission
IPCC	Intergovernmental Panel on Climate Change
ISGS	Illinois State Geological Survey
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
MGSC	Midwest Geological Sequestration Consortium
MMS	Minerals Management Services
MRCSP	Midwest Regional Carbon Sequestration Partnership
MVA	Monitoring, Verification, and Accounting
MW	Megawatt
NACAP	North America Carbon Atlas Partnership
NAEWG	North American Energy Working Group
NARUC	National Association of Regulatory Utility Commissioners
NATCARB	National Carbon Sequestration Database and Geographical Information System

Acronym/Abbreviation	Definition
NCCC	National Carbon Capture Center
NEPA	National Environmental Policy Act
NETL	National Energy Technology Laboratory
NGO	Non-Governmental Organization
NO_X	Nitrogen Oxide
ORD	NETL's Office of Research and Development
OSAP	NETL's Office of Systems, Analyses, and Planning
PC	Pulverized Coal
PCOR	Plains CO_2 Reduction Partnership
PFT	Perfluorocarbon Tracer
PSDF	Power Systems Development Facility
psi	Pounds per Square Inch
PTRC	Petroleum Technology Research Centre
R&D	Research and Development
RCSP	Regional Carbon Sequestration Partnership(s)
RD&D	Research, Design, and Demonstration
Recovery Act	American Recovery and Reinvestment Act of 2009
RMOTC	Rocky Mountain Oilfield Testing Center
SECARB	Southeast Regional Carbon Sequestration Partnership
SO_2	Sulfur Dioxide
STB	Surface Transportation Board
SWP	Southwest Regional Carbon Sequestration Partnership
TFRR	Thermal Flow Reversal Reactor
UIC	Underground Injection Control
UNDEERC	University of North Dakota's Energy & Environmental Research Center
USDW	Underground Sources of Drinking Water
VAM	Ventilation Air Methane
WESTCARB	West Coast Regional Carbon Sequestration Partnership
WWG	Water Working Group

Carbon Sequestration Program FY2008-2009 Accomplishments

The U.S. Department of Energy's Carbon Sequestration Program

The mission of the U.S. Department of Energy's (DOE) (http://www.energy.gov/) National Energy Technology Laboratory (NETL)-managed (http://www.netl.doe.gov/) Carbon Sequestration Program (http://www.netl.doe.gov/technologies/carbon_seq/overview/index.html) is to create a public benefit by discovering and developing methods to economically separate and permanently store greenhouse gas (GHG) emissions from the combustion of fossil fuels. The technologies developed through the program will be used to maintain fossil fuel power plants as viable, clean sources of electric power. This goal will be accomplished by reducing the cost of these technologies and conducting demonstrations based on sound science to ensure that commercial applications can reliably and safely capture, transport, store, and monitor carbon dioxide (CO_2) injected into geologic formations.

The Carbon Sequestration Program consists of a portfolio of laboratory and field research and development (R&D) projects focused on technologies with the potential for reducing GHG emissions. In addition to these projects, DOE's participation in initiatives, such as the Carbon Sequestration Leadership Forum (CSLF) (http://www.cslforum.org/) and the International Energy Agency Greenhouse Gas R&D Programme (IEA GHG) (http://www.ieagreen.org.uk/), promotes the global implementation of carbon capture and storage (CCS) technologies. The program also undertakes global collaborations through the support of projects that partner with international projects, including the Weyburn project in Canada, the In Salah project in Algeria, the Sleipner and Snøhvit projects in Norway, Australia's Otway project, the German CO_2SINK project, and Canada's Fort Nelson and Zama Acid Gas Injection projects.

Additionally, NETL's Office of Research and Development (ORD) (http://www.netl.doe.gov/onsite_research/index.html) conducts onsite research that provides the scientific basis for carbon storage options through its Geological and Environmental Systems Focus Area (http://www.netl.doe.gov/onsite_research/geological.html), which seeks to assess the capacity, suitability, and permanence of potential carbon storage reservoirs; to assess the ability of unconventional reservoirs to produce gas and oil and assist in that production; and to improve environmental performance of existing power plants. Also, research to understand and improve CO_2 capture and utilization are conducted through ORD's three other

Carbon Sequestration Program Focus

Develop a suite of technologies that can safely and economically capture and store CO_2 from coal-based energy systems, permanently removing them as contributors to global climate change.

> **"I believe we must make it our goal to advance carbon capture and storage technology to the point where widespread, affordable deployment can begin in [eight] to [ten] years."**
>
> — ***U.S. Energy Secretary Steven Chu*** *in a letter to world energy ministers and other scientific leaders calling for an aggressive global effort to advance CCS. (Oct. 12, 2009)*

The Carbon Sequestration Program collaborates with a number of states, governmental agencies, industries, national laboratories, universities, and private companies.

Focus Areas: Energy Systems Dynamics (http://www.netl.doe.gov/onsite_research/EnergySystem.html), Computational and Basic Science (http://www.netl.doe.gov/onsite_research/computational.html), and Materials Science and Engineering (http://www.netl.doe.gov/onsite_research/materials-science.html). NETL's Office of Systems, Analyses, and Planning (OSAP) conducts analyses to demonstrate how R&D activities support national and international priorities related to energy supply, energy use, and environmental protection (http://www.netl.doe.gov/technologies/carbon_seq/systems.html). OSAP examines the following three areas of analysis (with respect to the Carbon Sequestration Program): (1) *Systems* – places research objectives (e.g., improvements in the cost and efficiency of CO_2 capture technologies) in the context of their impacts on commercial power generation systems and other industrial processes; (2) *Policy* – places CCS in the context of regulatory compliance and environmental policy; and (3) *Benefits* – combines technology and policy to show economic and environmental costs and benefits that a successful Carbon Sequestration Program will provide both domestically and internationally.

Furthermore, the Carbon Sequestration Program collaborates with a number of states, governmental agencies, industries, national laboratories, universities, and private companies. For example, the program's Regional Carbon Sequestration Partnership (RCSP) Initiative includes representatives from more than 400 organizations. The program has worked with agencies, such as the U.S. Environmental Protection Agency (EPA), the U.S. Department of Interior's (DOI) Minerals Management Service (MMS), DOI's Bureau of Land Management (BLM), the Interstate Oil and Gas Compact Commission (IOGCC), Ground Water Protection Council (GWPC), and the U.S. Department of Transportation (DOT) on issues related to CO_2 storage and transport.

With regard to CO_2 storage, activities with these agencies include: participating in EPA's CCS Working Group, participating in the preparation of several BLM reports to Congress, assisting MMS with developing rules for offshore CO_2 injection, examining the legal and regulatory framework for CO_2 storage with the IOGCC, and examining state regulatory program data management for CO_2 storage with the GWPC. The Carbon Sequestration Program has also collaborated with DOT, the Federal Energy Regulatory Commission (FERC), the National Association of Regulatory Utility Commissioners (NARUC), and Surface Transportation Board (STB) to examine the regulatory framework for CO_2 pipeline siting, operation, and tariffs, and has participated in the IOGCC Pipeline Transportation Taskforce on CO_2 pipelines for carbon storage.

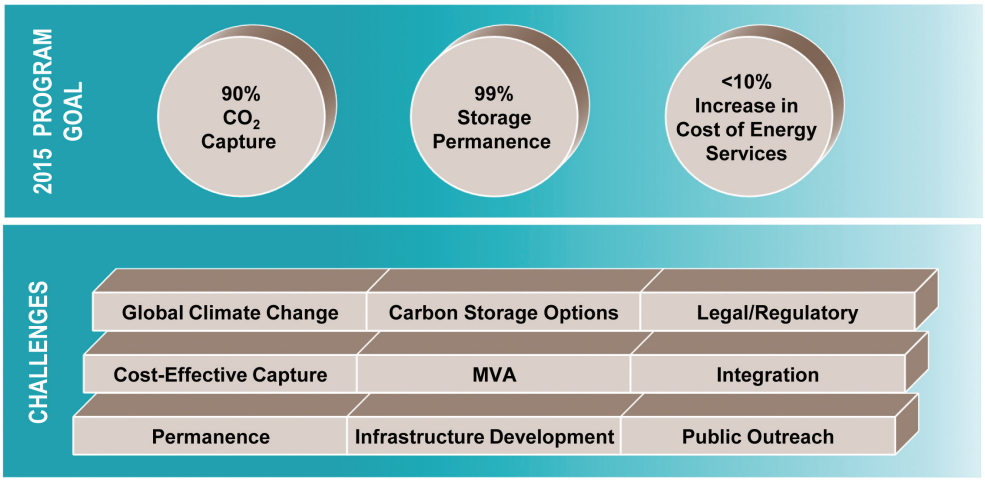
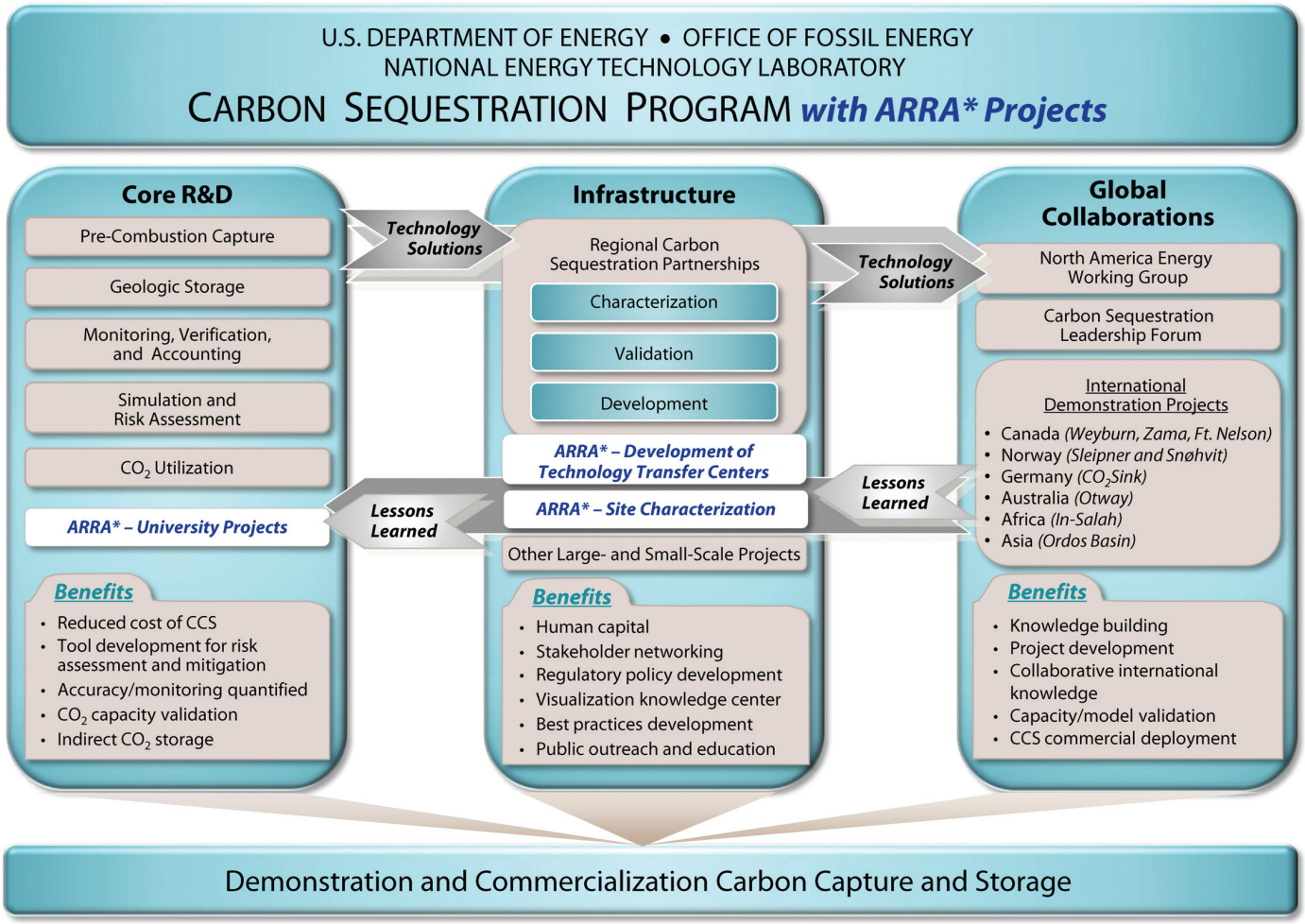


Figure 1. Carbon Sequestration 2015 Program Goals and Challenges.

The following depicts DOE's 2015 Carbon Sequestration Program Goal (Figure 1).

The Carbon Sequestration Program consists of three main elements: Core R&D, Infrastructure, and Global Collaborations (Figure 2).

- **Core R&D** – This element is developing new storage technologies to the point of pre-commercial deployment and includes core research performed externally under cost-shared, industry participation development projects/research grants, and internally by NETL's scientists and engineers. The Core R&D element is comprised of five technical focus areas: (1) pre-combustion capture (http://www.netl.doe.gov/technologies/carbon_seq/core_rd/CO_2capture.html); (2) geologic storage (http://www.netl.doe.gov/technologies/carbon_seq/core_rd/storage.html); (3) monitoring, verification, and accounting (MVA) (http://www.netl.doe.gov/technologies/carbon_seq/core_rd/mva.html); (4) simulation and risk assessment (http://www.netl.doe.gov/technologies/carbon_seq/core_rd/assessment.html); and (5) CO_2 utilization (http://www.netl.doe.gov/technologies/carbon_seq/core_rd/use-reuse.html). Research activities range in scope from laboratory-scale research through pilot-scale operations. The research in each area is based on the need to develop and apply technological solutions ready for large-scale testing.



* American Recovery and Reinvestment Act of 2009

Figure 2. Carbon Sequestration Program Overview.

- **Infrastructure** – The RCSPs serve as the primary component of the Infrastructure element (http://www.netl.doe.gov/technologies/carbon_seq/partnerships/partnerships.html). The RCSPs are a government/industry effort tasked with determining the most suitable technologies, regulations, and infrastructure needs for CCS in different areas of the United States and Canada. The seven RCSPs include representatives from more than 400 organizations, such as state agencies, national laboratories, universities, industry, and private companies, spanning 43 states and four Canadian provinces. The RCSP Initiative was established to examine regional differences in geology, land use practices, industrial activity, and permitting requirements that will lead to the deployment of carbon storage technologies by conducting a variety of field projects to confirm the efficacy of these technologies.

- **Global Collaborations** – The Global Collaborations element includes work performed with various international groups and also major international CO_2 storage projects that DOE is supporting either directly or by providing funding to researchers.

The following R&D objectives support the program goals and targets:

- **Geologic Storage (2011) –** Complete an initial version of a series of BPMs from the lessons learned during the RCSPs' Validation Phase field tests. By 2015, demonstrate enhanced CO_2 trapping and storage at pre-commercial scale, and demonstrate the ability to predict a CO_2 storage resource estimate with plus or minus 30 percent accuracy.
- **Simulation and Risk Assessment (2012)** – Assess the development of improvements to existing simulation codes that enhance the prediction of CO_2 movement in deep geologic formations to within 30 percent accuracy.
- **CO_2 Utilization (2013)** – Determine the viability of managing produced waters from storage projects for beneficial use and to increase storage potential by at least 10 percent.

Core R&D

Research efforts within the Core R&D element encompass cost-shared, industry participation technology development projects, research grants, and research conducted in-house at NETL. These efforts aim to demonstrate a portfolio of safe, cost-effective technologies to separate, capture, transport, and store carbon using either direct or indirect systems that result in a less than 10 percent increase in the cost of electricity. By 2015, the program is expected to have developed methodology capable of predicting a CO_2 storage resource estimate in geologic formations to within plus or minus 30 percent accuracy and to validate GHG capture, storage, and mitigation technologies that will be ready for commercial-scale demonstration and eventual market deployment.

Key R&D activities for this element include:

- **Pre-Combustion Capture** – The CO_2 pre-combustion capture effort aims at providing cost-effective carbon capture and removal solutions that will enable the United States to reduce GHG emissions, while continuing to use fossil fuel resources with only a modest increase in delivered energy costs. Pre-combustion capture applications involve advanced separation devices; high-efficiency solvents; high-temperature, high-pressure membranes; and high-capacity sorbents.

- **Geologic Storage** – Geologic CO_2 storage R&D examines five types of geologic formations, including deep saline formations, oil and gas reservoirs, unmineable coal seams, organic-rich shales, and basalts. The locations of these formations in the United States and portions of Canada are available in the 2008 Atlas of the United States and Canada (Atlas II) (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/atlasII.pdf). Research efforts are

investigating the potential effects of CO_2 injection on reservoir fluids, rocks, seals, and faults/fractures, and achieving an improved understanding of caprock integrity. Efforts also include researching technologies to increase CO_2 storage potential and mitigation techniques and strategies to ensure permanence.

- **Monitoring, Verification, and Accounting (MVA)** – MVA efforts aim to measure the amount of CO_2 stored at a specific storage site, monitor the site for possible deterioration of storage integrity over time, and verify that the CO_2 remains in place. MVA techniques include subsurface and near-surface monitoring techniques. Subsurface technologies are used to track the CO_2 plume and monitor injection well integrity, detect changes in subsurface chemistry, assess reservoir integrity, and validate seal rock integrity. Near-surface techniques include soil/air monitoring, groundwater monitoring, and remote sensing. More information on available MVA techniques is available in DOE's "Best Practices for Monitoring, Verification, and Accounting of CO_2 Stored in Deep Geologic Formations" (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/MVA_Document.pdf).

- **Simulation and Risk Assessment** – Simulation models are critical in predicting the CO_2 flow in the target formation, chemical changes that may occur within the reservoir, and the effect that increased pressures might have on the target formation and/or seal(s) that contain the CO_2. Risk assessment efforts will develop effective protocols and models that are specifically tailored to unique storage sites. A preliminary (qualitative or screening) risk assessment is often performed at the early stages of a project to help with site selection, communicating project goals and procedures to the public, and to aid regulators in permitting projects. After more complete site characterization and modeling, a more accurate, quantitative risk assessment may be performed.

- **CO_2 Utilization** – CO_2 utilization efforts investigate pathways and novel techniques for reducing CO_2 emissions, including the conversion of CO_2 to useable products and fuels, production of water from saline formations during storage for other uses, and other breakthrough concepts that will also mitigate CO_2 emissions.

Infrastructure

The primary component of the Infrastructure element of the Carbon Sequestration Program is the RCSPs, whose purpose is to promote the development and deployment of CCS technologies developed within the Core R&D element (Figure 3). Different geographic regions of the United States offer diverse opportunities for carbon storage in underground formations. These formations include oil and gas formations, unmineable coal seams, saline formations, basalts, and organic-rich shales. Within these regions, formation types differ in their lithology, as well as in the locations of sinks relative to CO_2 emissions sources and pipelines. Some regions have an abundance of several different types of geologic sinks, while other regions are dominated by a specific type of sink. Given this diversity, DOE implemented a regionally based infrastructure to examine storage opportunities throughout the United States and western Canadian provinces.

The seven RCSPs are funded and managed by NETL, but implemented by regional entities. The RCSP approach is founded on the belief that local organizations and individuals bring vast knowledge and experience to regional infrastructure development issues and that local organizations can function more effectively and efficiently than a centralized organization. More information about each RCSP can be found at:

- **Big Sky Carbon Sequestration Partnership (BSCSP)** – (http://www.bigskyCO_2.org/)

- **Plains CO_2 Reduction (PCOR) Partnership** – (http://www.undeerc.org/pcor/)

The RCSPs are responsible for developing a regional framework to enhance the development of new technologies and benefits, including human capital, stakeholder networking, regulatory and policy development, visualization knowledge centers, BPMs, and public outreach and education.

The following milestones will gauge the progress of the Infrastructure element:

- **FY2010** – Conduct post-injection assessment and monitoring of injected CO_2 at small-scale field sites.
- **FY2009-2013*** – Complete characterization for large-volume CO_2 sequestration tests.
- **FY2009-2014*** – Initiate development of infrastructure for large-volume CO_2 sequestration injection.
- **FY2012-2015*** – Initiate injection at all large-scale field projects.

* Note: Projects with more data, infrastructure, and less time required for regulatory approval may meet the earlier timeframe of the milestone.

- **Midwest Geological Sequestration Consortium (MGSC)** – (http://www.sequestration.org/)
- **Midwest Regional Carbon Sequestration Partnership (MRCSP)** – (http://www.mrcsp.org/)
- **Southeast Regional Carbon Sequestration Partnership (SECARB) –** (http://www.secarbon.org/)
- **Southwest Regional Partnership on Carbon Sequestration (SWP)** – (http://www.southwestcarbonpartnership.org/)
- **West Coast Regional Carbon Sequestration Partnership (WESTCARB)** – (http://www.westcarb.org/)

RCSP activities are divided into three phases, each with individual goals and objectives:

- **Characterization Phase (2003-2005)** – This phase included the selection of the seven RCSPs and characterized regional CCS opportunities and identified priority opportunities for field tests (http://www.netl.doe.gov/technologies/carbon_seq/partnerships/characterization-phase.html). The data collected during this phase resulted in Atlas I and the National Carbon Sequestration Database and Geographical Information System (NATCARB) database, which is a regional database and a geographical information system (GIS) that integrates carbon storage data from the RCSPs and other various sources (http://www.NATCARB.org/). This phase was successfully completed and Characterization Phase final reports are available on the NETL website (http://www.netl.doe.gov/technologies/carbon_seq/partnerships/phase1/workproducts_table.html).

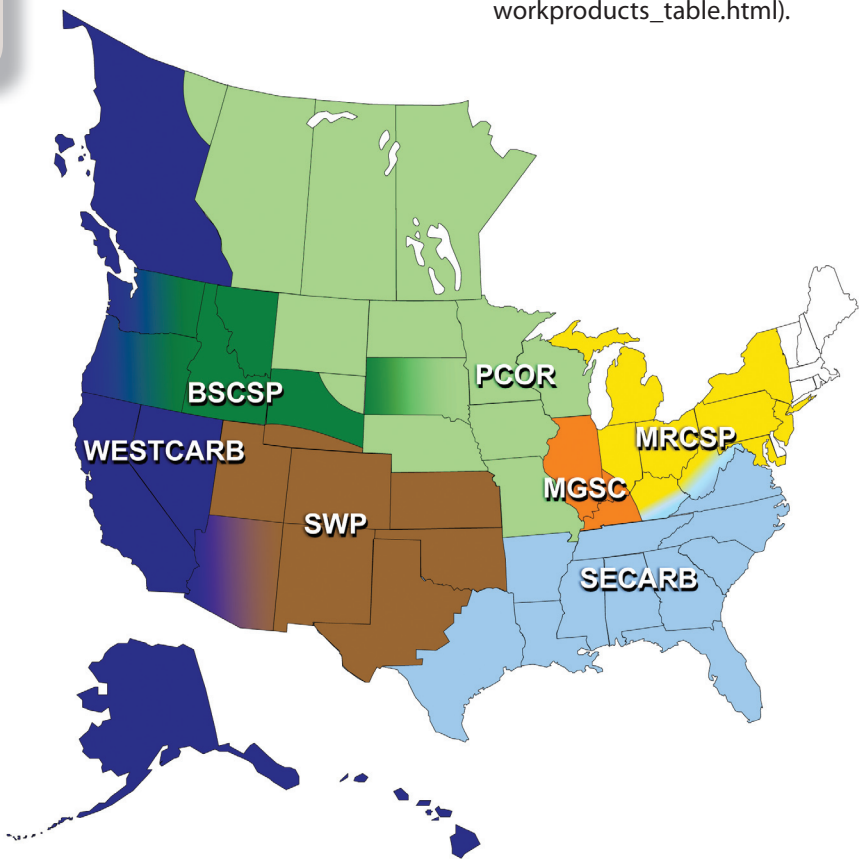


Figure 3. DOE's Regional Carbon Sequestration Partnerships.

- **Validation Phase (2005-2010)** – This phase, which is nearing completion, includes the implementation of small-scale CO_2 injection field tests to validate the efficacy of carbon storage technologies in a variety of geologic and terrestrial sinks throughout the United States (http://www.netl.doe.gov/technologies/carbon_seq/partnerships/validation-phase.html). The field tests include 21 geologic injection tests and 11 terrestrial pilot projects. The lessons learned during Phase II will result in a series of Best Practice Manuals (BPMs) to facilitate the development of future carbon storage projects.

- **Development Phase (2008-2017+)** – This effort includes several large-volume storage tests of 1 million tons or more of CO_2 that will be conducted in a variety of geologic formations typical of each RCSP region to demonstrate that CO_2 capture, transport, injection, and storage can be achieved safely, permanently, and economically at a large scale (http://www.netl.doe.gov/technologies/carbon_seq/partnerships/development-phase.html). Development Phase efforts are underway throughout the RCSPs. For example, SECARB recently injected more than 1 million tons of CO_2 at its Cranfield site[1] (this project was initiated during Phase II), becoming the first project in the United States to inject this amount. In addition, the PCOR Partnership initiated core sampling for its Fort Nelson project and MGSC completed 3-D seismic monitoring and drilled an injection well in preparation for the injection of 367,000 tons of CO_2 per year for three years at Archer Daniels Midland's (ADM) ethanol-by-fermentation facility in Decatur, Illinois. BSCSP, MRCSP, SWP, and WESTCARB are all in various stages of site selection and project development. The Development Phase tests will include at least one to three years of site characterization, two to five years of injection, and several years of post-injection MVA, depending on the project. Results obtained from these efforts will provide a firm foundation for commercialization efforts for future, large-scale CCS field tests across North America.

The RCSP Initiative's Phase II and Phase III projects injected nearly 2 million tonnes of CO_2 through FY09.

BPMs will be based on the following topics:

- **MVA** (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/MVA_Document.pdf)
- **Public Outreach and Education** (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM_PublicOutreach.pdf)
- **Site Screening, Selection, and Characterization** (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM-SiteScreening.pdf)
- **Simulation and Risk Assessment**
- **Well Construction, Operations, and Completion**
- **Terrestrial**

[1] http://www.netl.doe.gov/publications/press/2009/09076-DOE_Project_Hits_Million_Ton_Miles.html.

Global Collaborations

The Global Collaborations element involves DOE participation in international projects and other international efforts to advance CCS, such as the CSLF, the IEA GHG, the North American Energy Working Group (NAEWG) (http://www.pi.energy.gov/naewg.htm), Clean Energy Dialogue (CED) (http://www.energy.gov/news2009/7552.htm), and the Asia-Pacific Partnership (APP) (http://www.app.gov/about/index.htm). This element serves as an opportunity to demonstrate the scope of CCS efforts, increase the number of DOE-coordinated projects, satisfy international objectives, and increase the overall database of global projects and the scope of issues and solutions for CCS. The CSLF, established by the leadership of DOE and U.S. Department of State, is a voluntary climate initiative of developed and developing nations that account for approximately 75 percent of all anthropogenic CO_2 emissions. Members engage in cooperative technology development aimed to facilitate the advancement of cost-effective carbon storage technologies.

The economic rewards achieved through new business opportunities in the United States and abroad will provide leverage to assist other countries to engage in carbon storage projects. The IEA GHG is a multilateral organization that promotes energy security, economic development, and environmental protection throughout the world. IEA GHG experts have endorsed the efforts[2] of DOE's RCSP Initiative and their large-scale tests as a successful approach to advance CCS in the United States, Canada, and internationally (http://www.netl.doe.gov/technologies/carbon_seq/partnerships/partnerships.html). The NAEWG is a trilateral effort among the United States, Mexico, and Canada that fosters communication and cooperation on energy-related matters of common interest and enhances North American energy trade and interconnections consistent with the goal of sustainable development. The CED is an effort established by President Barack Obama and Prime Minister Stephen Harper to expand clean energy R&D and develop and deploy clean energy technology in order to reduce GHGs and combat climate change in the United States and Canada. Finally, the APP, comprised of the United States, Australia, Canada, China, India, Japan, and South Korea, is an effort to collaborate with private sector partners to meet goals for energy security, national emission reduction, and climate change in ways that promote sustainable economic growth.

NETL's Worldwide CCS Database

(http://www.netl.doe.gov/technologies/carbon_seq/database/index.html) reveals 192 proposed and active CCS projects worldwide as of November 2009. The projects are located in 20 countries across five continents. The 192 projects include 38 capture, 46 storage, and 108 for capture and storage. While most of the projects are still in the planning and development stage, or have been recently proposed, eight are actively capturing and injecting CO_2:

- In Salah Gas Storage Project, Algeria
- CRUST Project – K12-B Test, The Netherlands
- Sleipner Project, Norway
- Snøhvit Field LNG and CO_2 Storage Project, Norway
- Zama Field, Canada
- SECARB Cranfield, United States
- Weyburn-Midale, Canada
- Mountaineer CCS Project, United States

[2] "Expert Review of Regional Carbon Sequestration Partnerships Phase III," http://www.netl.doe.gov/technologies/carbon_seq/refshelf/Expert_Review_of_DOE_Regional_Patrnerships_Phase_III_-_ExecS.pdf.

American Recovery and Reinvestment Act of 2009

On February 17, 2009, President Barack Obama signed the American Recovery and Reinvestment Act of 2009 (Recovery Act) (http://www.energy.gov/recovery/index.htm). The Office of Fossil Energy (FE) has received $3.4 billion in Recovery Act funding to commence a series of initiatives that will investigate the research, design, and demonstration (RD&D) of technologies that advance the development and deployment of CCS (http://www.netl.doe.gov/publications/press/2009/stimulus.html). The Recovery Act investments will accelerate and contribute to finding and testing new ways to produce energy from coal and improving techniques to reduce or capture and store GHG emissions from coal-fired power plants.

FE Recovery Act projects will use Federal funding to stimulate private sector investment; accelerate delivery of CCS technology; and, in partnership with industry, demonstrate the integration of coal-based energy systems and industrial processes with capture and safe, permanent CO_2 storage in a variety of geologic formations. In turn, Recovery Act activities will accelerate commercial-scale demonstrations of CCS technology, thus increasing potential public benefits and reducing program risk.

The Carbon Sequestration Program will manage 60 Recovery Act-related projects worth a total of approximately $95 million (Table 1).

The primary objectives of the Fossil Energy portion of the Recovery Act are to:

- Demonstrate CCS technology to reduce GHG emissions from the electric power and industrial sectors of the U.S. economy.
- Become the world's leader in CCS science and technology.
- Implement projects to support economic recovery by creating new jobs in pursuit of a secure energy future.

Table 1. Carbon Sequestration Program Recovery Act-Related Projects and Activities

Project Name	Objective	Total Project Values	DOE Share	Participant Cost Share
Geologic Sequestration Site Characterization	Accelerate the comprehensive characterization of large-volume geologic reservoirs augmenting existing data under the RCSPs.	$72 million	$48.4 million	$23.6 million
Geologic Sequestration Training and Research Grants	Develop the next generation of scientists and engineers by expanding ongoing training and research efforts.	$22.3 million	$19.9 million	$2.4 million

The 10 geologic sequestration site characterization projects awarded will examine the applicability of potential geologic storage sites, including saline formations, depleting/depleted oilfields, and gas fields (Figure 4) (http://www.fossil.energy.gov/recovery/projects/site_characterization.html). In addition, the projects will also expand existing data in the NATCARB database and assist technical working groups when determining best practices for site characterization and approving storage site selection methods. The information gained from these projects will further DOE's effort to refine a national assessment of CO_2 storage capacity in deep geologic formations. This assessment will be accessible to the public and industry seeking to understand future commercial CCS opportunities. The projects are located in Alabama, California, Colorado, Illinois, Kansas, South Carolina, Texas, Utah, and Wyoming.

The 43 geologic sequestration training and research projects (representing 23 states) will offer training opportunities in simulation and risk assessment; MVA; geological-related analytical tools; methods to interpret geophysical models; and CO_2 capture for graduate and undergraduate students at universities across the United States (Figure 5) (http://www.fossil.energy.gov/recovery/projects/geologic_sequestration_training.html). These projects will provide the human capital and skills required for implementing and deploying CCS technologies and contribute to the scientific, technical, and institutional knowledge needed to establish frameworks for the development of commercial-scale CCS projects.

The seven regional CCS technology training projects will facilitate the transfer of knowledge and technologies required for site development, operations, and monitoring of commercial CCS projects (Figure 6) (http://www.netl.doe.gov/publications/press/2009/09062-DOE_Awards_CCS_Training_Projects.html). The training activities will focus on the applied engineering and science of CCS for site developers, geologists, engineers, and technicians. The projects will result in a CCS workforce with skills and competencies in geology, geophysics, geomechanics, geochemistry, and reservoir engineering disciplines.

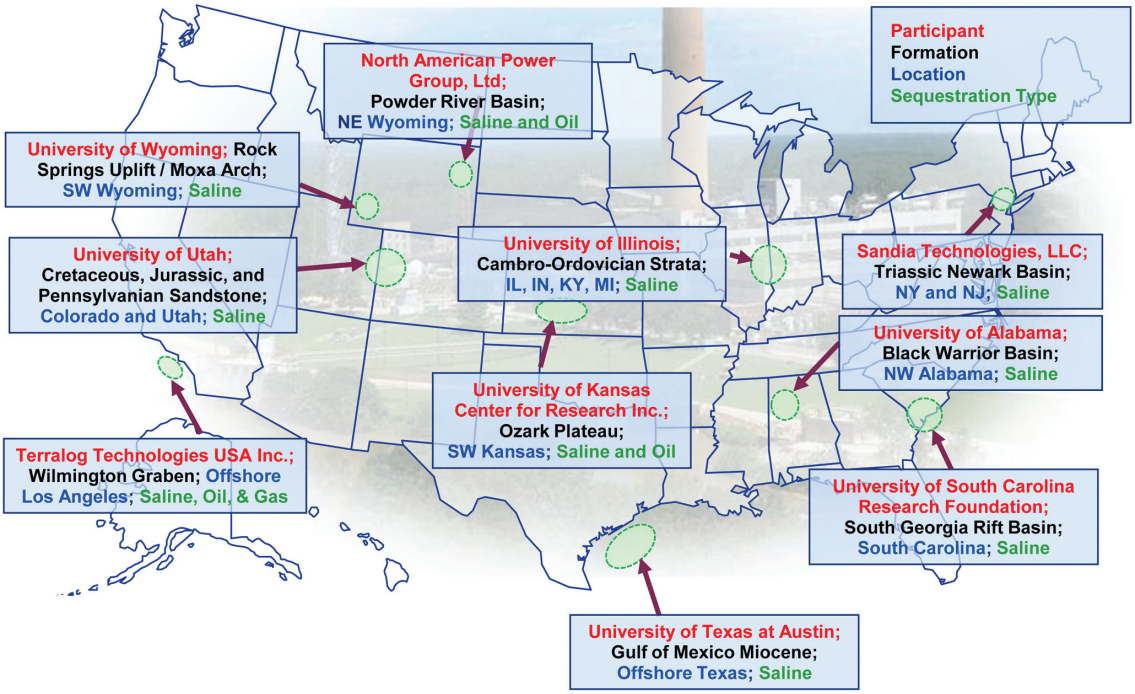


Figure 4. Geologic Sequestration Site Characterization Projects Funded by the Recovery Act.

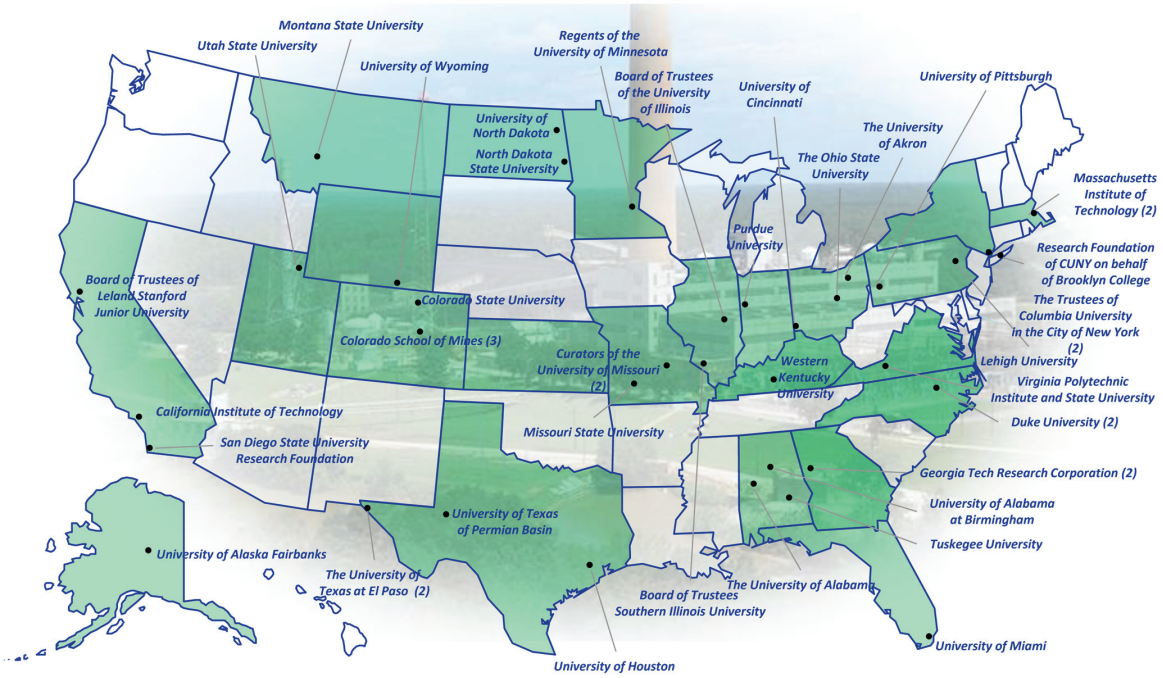


Figure 5. Geologic Research and Training Grants Funded by the Recovery Act.

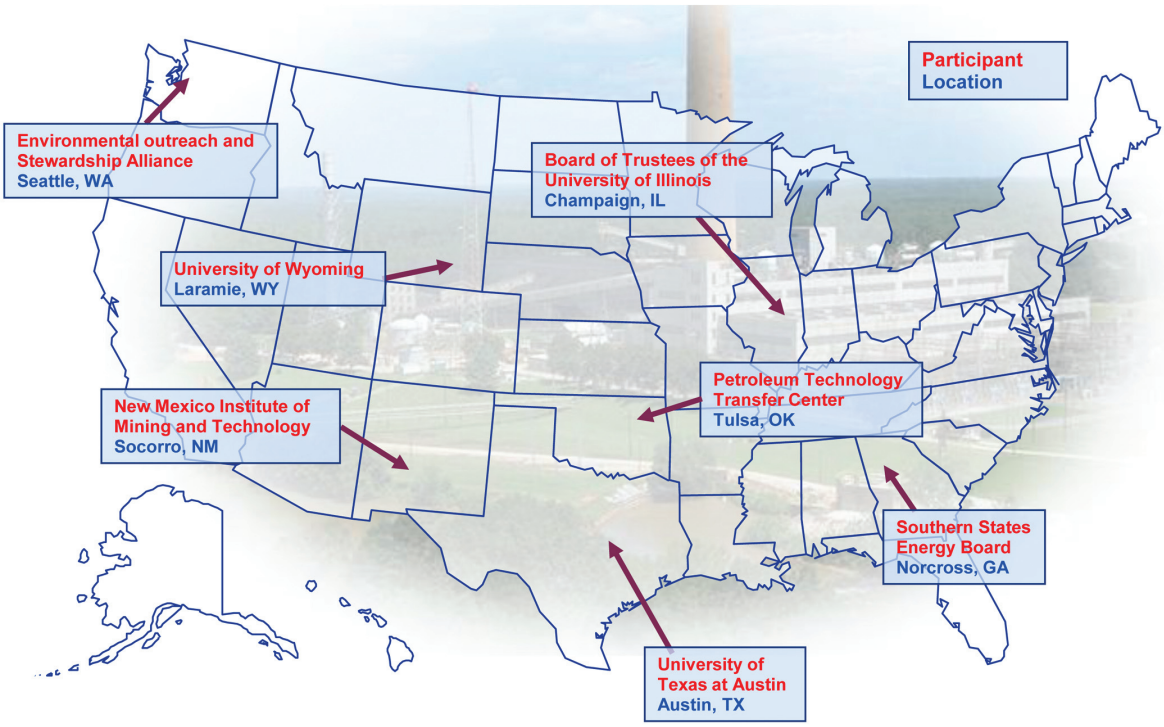


Figure 6. CCS Training Project Grants Funded by the Recovery Act.

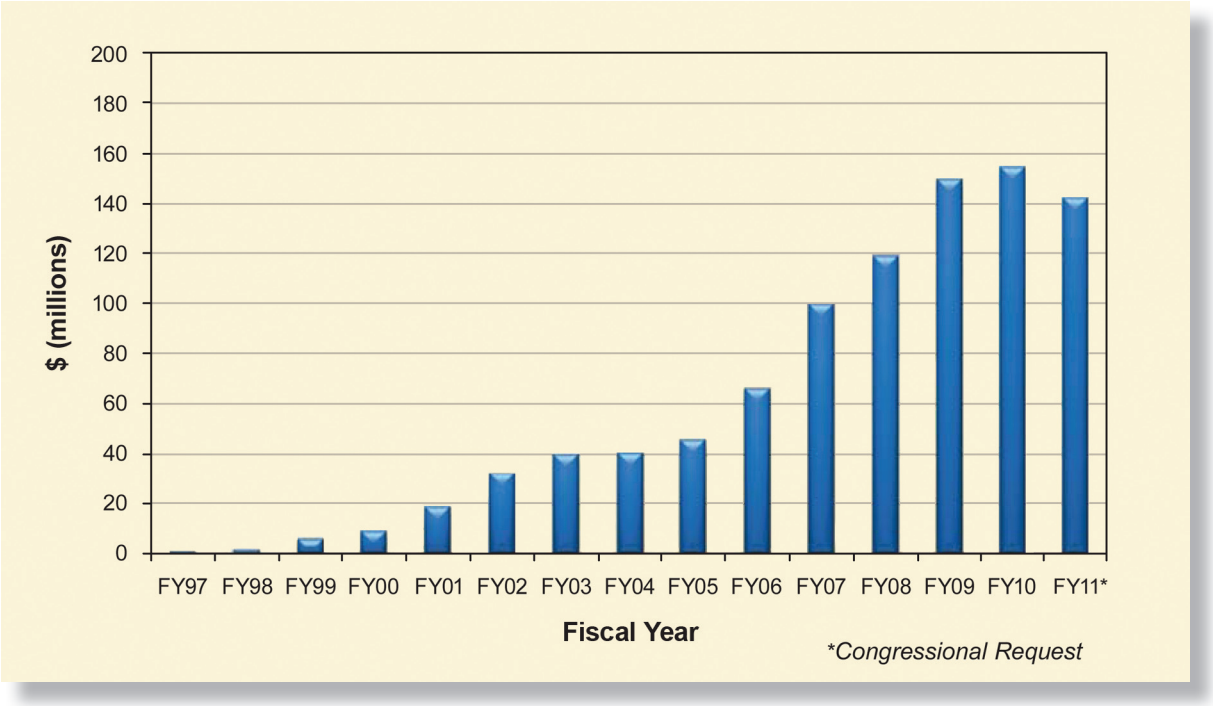


Figure 7. Carbon Sequestration Program Multi-Year Budget (excluding Recovery Act funding).

As demonstrated above, the Carbon Sequestration Program, which was launched in 1997 as a small-scale research effort, has significantly grown into a multifaceted R&D effort with large public-private partnerships testing new CCS technologies that are capable of capturing, transporting, and safely and permanently storing CO_2 in geologic formations (Figure 7). Consequently, technologies for achieving CCS have developed well beyond research curiosity and are defining realistic pathways in which GHGs can be permanently diverted from the atmosphere. The program's Core R&D element has directly supported a number of projects that will contribute to the implementation of large-scale carbon storage projects that address the important technical and infrastructure issues necessary to validate the science and lead to the eventual commercialization of CCS.

The RCSPs serve as the primary vehicle for promoting the development and deployment of CCS technologies developed within the Core R&D element. The efforts of the RCSP small- and large-scale field test program include: (1) validating that storage capacity and injectivity are present in regionally significant geologic formations to scaleup for commercial projects; (2) verifying that CO_2 will be contained in the target formations and not impact underground sources of drinking water (USDWs) and/or be released to the atmosphere; (3) determining the extent of the CO_2 plume underground and effects of pressure; (4) developing mitigation strategies in the unlikely event of CO_2 release; (5) developing BPMs for several CCS-related topics; (6) engaging the public; and (7) supporting the development of future CCS regulations. The accomplishments cited in the remainder of this document show that the Carbon Sequestration Program is making meaningful progress in various aspects that will result in a series of best management practices guidelines that will be helpful in the carrying out of commercial-scale CCS projects.

In particular, the initiation of the RCSP Initiative's Development Phase brings the realization of the most promising carbon

mitigation solution within reach. These large-scale projects are possible due to the leadership and vision of both private and public sector partners, which has led to successful outcomes of numerous Core R&D projects and the first two phases of the RCSP Initiative. The goal of the Development Phase is to demonstrate the large-volume injection of CO_2 at a scale that duplicates industry activity; these demonstrations will exhibit how the deployment and eventual commercialization of such technologies can play a major role in a robust CO_2 mitigation strategy. Moreover, NETL's CCS field projects are helping DOE to develop technologies, that when deployed commercially, are capable of capturing 90 percent of CO_2 emissions with 99 percent storage permanence and less than 10 percent increase in the cost of energy.

The Recovery Act provides additional funding for R&D projects that will significantly advance several important ongoing Carbon Sequestration Program activities. The Recovery Act will accelerate CCS deployment by increasing the number of competitively selected projects and providing a broader CCS commercial-scale experience with respect to CCS technologies, applications, fuels, and CO_2 storage formations. For example, the $50 million for geologic storage site characterization will complement and build upon the existing characterization base created by the RCSPs (NATCARB) and expand the range of geologic basins that have been extensively studied to date. Thus, when combined with the Carbon Sequestration Program's current activities, this portion of the Recovery Act will produce the data and knowledge needed to establish the technology base, reduce project risks, and enable commercial deployment of CCS over the next 8 to 10 years. The funding of revolutionary CCS research will help the United States to realize continued improvement in technology and potentially transform the Nation's energy infrastructure.

Furthermore, the successful commercialization of CCS technologies will not only allow the United States to continue to use fossil fuels in an environmentally responsible manner but, when coupled with the enhanced recovery of resources, these technologies will also provide an opportunity for greater recovery of domestic oil, natural gas, and coalbed methane (CBM).

The Carbon Sequestration Program has achieved numerous accomplishments through the growth, expansion, and introduction of new concepts and opportunities as a result of an adapting effort that incorporates novel activities to resolve issues uncovered by R&D activities and social demands. In the remainder of this document, significant accomplishments are reported for each aspect of the Carbon Sequestration Program. These accomplishments are identified for the last three FYs (2007-2009) and organized in reverse chronological order by Carbon Sequestration Program element (Core R&D, Infrastructure, and Global Collaborations). A section containing Carbon Sequestration Program Recovery Act-related Accomplishments follows.

Core R&D

The Core R&D element contains five focal areas for applied research and carbon storage technology development: (1) Capture; (2) Geologic Storage; (3) MVA; (4) Simulation and Risk Assessment; and (5) CO_2 Utilization. Core R&D is driven by technology needs and is accomplished through laboratory- and pilot-scale research aimed at developing new technologies and new systems for GHG mitigation.

Capture

Pre-combustion CO_2 capture applies to Integrated Gasification Combined Cycle (IGCC) plants, where fuel is converted into gaseous components by applying heat under pressure in the presence of steam. Carbon dioxide can be captured from the syngas that emerges from the coal gasification reactor before

NETL's pre-combustion CO_2 capture area calls for the following R&D goals:

- By 2015, develop a portfolio of bench-scale technologies which, if combined, will enable the new power production technology with CO_2 capture (e.g., IGCC) to produce electricity at a cost of no more than 10 percent when compared to a conventional (off-the-shelf) non-capture power plant. Performance is measured by validating technology improvements of an advanced power plant with carbon capture technology.
- By 2017, complete pilot-scale testing of the CO_2 capture technologies that were successful at bench scale and identify opportunities for integration of these technologies into the power plant.

DOE CO_2 Capture Efforts

Prior to FY2008, DOE/NETL's CO_2 emissions control R&D effort was conducted under the Carbon Sequestration Program. In FY2008, NETL's Innovations for Existing Plants (IEP) Program redirected its focus to include CO_2 emissions control for existing pulverized coal (PC)-fired plants. This new focus on post- and oxy-combustion CO_2 emissions control technology and CO_2 compression is derived from the priority for advanced technological options for the existing fleet of coal-fired power plants in order to address climate change. The Carbon Sequestration Program continues to focus on pre-combustion CO_2 emissions control and geological sequestration.

In addition to funding R&D projects conducted externally, the IEP Program also conducts in-house research to develop new breakthrough concepts for CO_2 capture that could lead to dramatic improvements in cost and performance relative to today's technologies. The IEP CO_2 emissions control R&D activity also sponsors systems analysis studies of the cost and performance of various carbon capture technologies. The program goal is to develop advanced CO_2 capture and separation technologies for existing power plants that can achieve at least 90% CO_2 removal at no more than a 35% increase in cost of energy services. For more information related to post- and oxy-combustion technologies for existing plants, please visit IEP's CO_2 Emissions Control webpage (http://www.netl.doe.gov/technologies/coalpower/ewr/co2/index.html).

In post-combustion capture, CO_2 is exhausted in the flue gas at atmospheric pressure and a concentration of 10 to 15 volume percent. Post-combustion capture is challenging because: (1) the low pressure and dilute concentration dictate a high actual volume of gas to be treated; (2) trace impurities in the flue gas tend to reduce the effectiveness of the CO_2 adsorbing processes; and (3) compressing captured CO_2 from atmospheric pressure to pipeline pressure (1,200 to 2,000 pounds per square inch [psi]) represents a large parasitic load. On the other hand, oxy-combustion combusts coal in an enriched oxygen environment using pure oxygen diluted with recycled CO_2 or water. Finally, research being conducted by DOE's Gasification Program is expected to improve gasification technology so that costs without capture will be comparable to electricity costs from pulverized coal without capture, potentially reducing the cost of pre-combustion CO_2 capture in the future (http://www.netl.doe.gov/technologies/coalpower/gasification/index.html).

it is mixed with air in a combustion turbine. Near-term applications of CO_2 capture from pre-combustion systems will likely involve physical or chemical absorption processes. Mid- to long-term opportunities to reduce capture costs through improved performance could come from membranes, solvents, and sorbents currently at the laboratory stage of development. Membrane separation units that can selectively permeate hydrogen (H_2) and retain carbon monoxide (CO) and CO_2 are also promising for IGCC power plants.

Capture Accomplishments

DOE Selects Projects to Develop Pre-Combustion Carbon Capture Technologies for Coal-Based IGCC Plants (FY2009). DOE selected nine projects that will develop pre-combustion carbon capture technologies that can reduce CO_2 emissions in future, coal-based IGCC power plants. The projects, which total nearly $14.4 million and are managed by NETL, cover four research areas: high-temperature, high-pressure membranes; high-efficiency solvents; solid sorbents; and novel concepts. High-temperature, high-pressure membranes generically refer to a barrier or a medium that selectively separates out a desired gas species, such as H_2 or CO_2, at commercially-relevant conditions. The focus of this research area is membrane-based separation devices approaching optimal CO_2 removal. In the high-efficiency solvents research area, applications were sought for R&D leading to optimal performance of novel, high-efficiency solvents for CO_2 absorption using less energy compared to conventional solvents. Applications were sought in the solid sorbents research area for R&D leading to optimal performance of novel sorbents for adsorbing CO_2 with fast adsorption-desorption, and regeneration kinetics, and minimal energy to regenerate the sorbent material. Lastly, DOE solicited novel concepts on pre-combustion removal of the carbon content of the fuel and separation devices beyond current benchmarks of performance and cost that can separate H_2 or CO_2 from the water-gas-shift mixtures. In either option, H_2 must be available for the IGCC plant at practical rates and purity (http://www.netl.doe.gov/publications/press/2009/09036-DOE_Awards_Carbon_Capture _Projects.html).

DOE Establishes National Carbon Capture Center (FY2009). DOE announced the creation of a new National Carbon Capture Center (NCCC) to develop and test technologies to capture CO_2 from coal-based power plants (http://nationalcarboncapturecenter.com/). The goal of the NCCC is to focus national efforts on reducing GHG emissions through technological innovation and serve as a

test center for emerging carbon capture technologies. The center enables testing and analysis at a scale large enough to provide meaningful data under real operating conditions. A major benefit of the NCCC will be its flexibility, as it will offer multiple slipstream capabilities for testing candidate processes, with the ability to investigate different ranks of coal, biomass, and other fuels. In addition, multiple projects can be tested in parallel with a wide range of testing equipment. Long-term testing will also be available to establish the durability and reliability of new technologies. Technology development at the NCCC will include both pre- and post-combustion CO_2 capture. The pre-combustion CO_2 capture component will be located at the Power Systems Development Facility (PSDF) in Wilsonville, Alabama, and the post-combustion component will be developed at Plant Gaston, an Alabama Power coal-fired power plant adjacent to the PSDF (http://www.netl.doe.gov/publications/press/2009/09034-National_Carbon_Capture_Center_Est.html).

NETL Concept Integrates CO_2 Cycle from Generation to Deposition (FY2009). Having found that the CO_2 adsorption capacity of certain overburden materials is comparable to that of coal, NETL researchers conceived a novel carbon storage approach using waste materials generated during coal production. The assumption was that if power generation were co-located with coal extraction/preparation, carbon capture could be facilitated by a controlled sequential heating and cooling of these solids with the exhaust heat of combustion. The method avoids logistical problems and potentially significant transportation costs of delivering captured CO_2 from a power generation station to a remote storage site. In addition, there are limitations associated with carbon storage in unmineable coal seams that have shown a propensity to swell as the coal matrix imbibes CO_2. A feature article in the American Chemical Society (ACS) publication *Environmental Science & Technology* describes the approach.

NETL Reports Systematic Study of CO_2 Adsorbents (FY2008). NETL researchers reported a detailed study of the relationship between performance and molecular structure of CO_2 adsorbents in a manuscript that was submitted to the *Journal of the American Chemical Society*. In the continuing search for better CO_2 adsorbents, the relationship between performance and molecular structure is a key guiding principle. Such guidelines are best developed by measuring adsorption performance as one feature of the same basic structure is changed in a systematic way. The NETL paper reports a study of a series of closely related structures composed of layers and pillars. The layers consist of sheet-like nickel cyanide complexes. They are held apart by organic pillars of different length and flexibility. Carbon dioxide storage capacity was related to the relative size of the pores and greater capacity was associated with pillars of greater length. The adsorption strength was strongly affected by whether the pillars were rigid or flexible. The adsorbent made with the most flexible pillar had a collapsed pore structure that was ineffective in adsorbing CO_2, while those made with rigid pillars had open pores that readily took in CO_2. The pillared layered architecture has been found to be an excellent scaffold on which to study the effect of molecular structure on adsorbent behavior. This technique is now being extended by investigating the effect of attaching organic functional groups with stronger affinity for CO_2 to the pillars (http://www.netl.doe.gov/newsroom/labnotes/2008/04-2008.html).

NETL Method Produces Low-Cost CO_2 Capture Sorbent (FY2008). NETL was awarded a U.S. patent for a method of producing amine-enriched sorbents with a high capacity for CO_2 capture. In only a few steps, and without involving expensive reactants or solvents, the sorbents capture CO_2 at temperatures ranging from 25 °C to 65 °C. The sorbents are then regenerated by heating them to 90 °C, with little or no degradation occurring. Low-cost advantages afforded by the higher CO_2 capture capacity and low energy cycle requirements make the long-lived

sorbents suitable for large-scale processes, such as power plant emissions streams (http://www.netl.doe.gov/publications/press/2008/ResearchersReceiveFourPatents.html).

Powerspan Corporation Licenses NETL Carbon Capture Technology (FY2008). Powerspan Corporation licensed a novel NETL process that uses an ammonia-based solution to scrub CO_2 and other acid gases (primarily sulfur dioxide [SO_2] and nitrogen oxide [NO_X]) from flue gas. The spent solution can be regenerated to release storage-ready CO_2 and then recycled to the scrubbing unit. Powerspan has tested a 1-MW electrical pilot unit constructed at FirstEnergy Corporation's R.E. Burger Plant near Shadyside, Ohio, to demonstrate the technology. The license supports a broader Powerspan goal of removing all components from flue gas. Compared to existing technology, the process could significantly reduce the capital cost and energy load associated with CO_2 capture (http://powerspancorp.net/news/pressreleases.aspx?id=366).

NETL Reports First Regenerable Warm Gas Temperature CO_2 Removal Sorbent (FY2007). NETL researchers reported the first regenerable sorbent that can remove CO_2 at warm gas temperatures for the coal gasification process. The sorbent is described in a peer reviewed paper, titled, "Novel Regenerable Sodium Based Sorbents for CO_2 Capture at Warm Gas Temperatures," that was accepted for publication in the *Energy and Fuels* journal. There are no regenerable warm gas temperature (200 °C to 400 °C) CO_2 removal sorbents available for the gasification process. The commercially available CO_2 removal processes require gas cooling, which contributes to a loss in thermal efficiency of the process. The sorbent developed at NETL can be utilized without cooling the coal gas. This sodium-based sorbent showed high CO_2 capture capacity (>4 moles/kg) and greater than 99 percent CO_2 removal efficiency when operating at 315 °C. The sorbent can be regenerated at 700 °C. A 10-cycle test conducted at NETL showed that the capture capacity increased during the cyclic testing.

Researchers Make Progress in the Science of Gas Separations (FY2007). As part of their research to produce clean H_2 and storage-ready CO_2, NETL researchers investigated promising new materials as potential agents for the purification of these gases. One material is similar to the well-known inorganic dye, Prussian Blue. This material has a large preference for adsorbing CO_2 rather than H_2, a property uncovered by the use of a sophisticated analytical technique involving infrared spectroscopy. This study of the basic science of gas adsorption uncovered a property of a well-known compound that could be of use in gas separation applications. The results of the study were published in the scientific journal, *Journal of Physical Chemistry C*.

Geologic Storage

As part of the Geologic Storage component of the Carbon Sequestration Program, DOE is investigating the following types of geologic formations that offer suitable conditions for CO_2 storage:

- **Deep Saline Formations** – Saline formations are layers of porous rock that are saturated with brine. These formations are much more extensive than the other types of geological formations suitable for CCS, and represent an enormous potential for CO_2 geologic storage. However, less is known about saline formations than other geologic formations because they lack the characterization experience that industry has acquired through resource recovery from these formations.

- **Unmineable Coal Seams** – Unmineable coal seams are too deep or too thin to be economically mined. All coals have varying amounts of methane (CH_4) adsorbed onto pore surfaces, and wells can be drilled into unmineable coalbeds to recover this CBM. Initial CBM recovery methods, such as dewatering and depressurization, leave a considerable amount of CH_4 in the formation. Additional recovery can be achieved by sweeping the coalbed with CO_2. Depending on the type of coal, a variable amount of CH_4 is released, thereby

providing an excellent storage site for CO_2 along with the additional benefit of enhanced coalbed methane (ECBM) recovery. Similar to maturing oil reservoirs, unmineable coalbeds are good candidates for CO_2 storage.

- **Oil and Gas Reservoirs** – Oil and gas reservoirs consist of a layer of permeable rock with a layer of nonpermeable rock (caprock) above, such that the nonpermeable rock layer forms a trap that holds the oil and gas in place. The geologic conditions that trap oil and gas are also conducive to CO_2 storage. A small amount of the injected CO_2 dissolves in the oil, increasing the bulk volume and decreasing the viscosity, thereby facilitating flow to the wellbore. Research is focused on increasing the amount of CO_2 that remains in the ground as part of CO_2-enhanced oil recovery (EOR) injection.

- **Organic-Rich Shale(s)** – Shale, the most common type of sedimentary rock, is characterized by thin horizontal layers of rock with low permeability in the vertical direction. Many shales contain one to two percent organic material in the form of hydrocarbons, which provide an adsorption substrate for CO_2 storage similar to CO_2 storage in coal seams. Research is focused on achieving economically viable CO_2 injection rates, given the low permeability of shale.

- **Basalt Formations** – Basalt formations 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.

DOE Water Use/Conservation Efforts Related to CCS

Water is involved in every step of the CCS process, from the industrial sources where CO_2 is generated to long after the CO_2 is injected into the ground. Water is heavily relied upon for cooling, especially in power generation facilities, and is also needed for other processes, including the regeneration of solvents used during CO_2 capture. Current capture technologies require additional water supplies at the site of CO_2 generation, either as a direct result of the capture process, or indirectly through parasitic electrical demand and the associated cooling water requirements for thermoelectric power generation. A majority of the water used by power plants is currently provided by surface water and groundwater resources that face competition from agricultural and municipal uses across the United States. The additional water load required for CCS may require other solutions in water-stressed areas. New technological developments in capture and compression technologies also promise to reduce the impact of these technologies on increasing water demand.

The water issues associated with CCS revolve primarily around water usage at CO_2 sources and water extraction at CO_2 storage sites. On the storage side, impacts of CO_2 storage in appropriately targeted rock formations are expected to be minimal. CCS activities require great depth, and in most cases, the targeted formations will be separated from potable water resources by hundreds to thousands of feet of rock, including multiple low-permeability barriers. Extracting water from these storage formations is not necessary for carbon storage in most cases, though it may be beneficial in site specific circumstances to remove water for treatment and beneficial reuse, pressure management, and CO_2 plume management.

DOE/NETL is actively addressing issues and opportunities in this area. As one example, the Water Working Group (WWG) was formed within the RCSPs to address stakeholder concerns regarding CCS and its potential interactions with water resources. The RCSPs are actively working on testing the various phases of CCS to identify safe, efficient, stable, and cost-effective methodologies to minimize impacts to the surrounding environment, both aboveground and belowground. State and Federal regulations currently exist or are being developed to further ensure that CCS activities will be conducted in a responsible manner.

More information on DOE's water use/conservation efforts related to CO_2 capture is available on the Water-Energy Interface webpage (http://www.netl.doe.gov/technologies/coalpower/ewr/water/index.html).

Geologic Storage Accomplishments

Novel Instrument Quantifies CO_2 Influence on Coal Permeability (FY2009). Sorption of gases (particularly CO_2) normally causes swelling in a coal seam, which usually results in decreased fluid flow, making traditional flow-through methods of permeability measurement ineffective. NETL used a specially developed instrument that determines low permeability by measuring dynamic responses to applied pressure pulses across core samples. Results of an NETL permeability study completed with the instrument appear in the *International Journal of Coal Geology*. Quantifying the effects of CO_2 sorption is essential for screening coal seams with potential for storing CO_2.

Study Reveals Potential Uncertainties of Conventional Approaches for Determining CO_2 Storage Capacity of Coal (FY2009). Researchers at NETL discovered that exposure to room temperature helium at high pressure alters the texture of Upper Freeport coal. As helium volume is conventionally used to interpret CO_2 sorption isotherms on coal, the finding has major implications for the accurate characterization of CO_2 storage in unmineable coal seams and ECBM recovery. Results of the study appear in the *International Journal of Coal Geology*.

NETL Research Improves Estimates of CO_2 Storage Capacity in Deep Coal Seams (FY2008). A study by NETL researchers confirmed that pulverized coal powder samples can be used to estimate coal sorption capacity at relatively low CO_2 pressure. Carbon dioxide sorption measurements on crushed and pulverized coal powder can be misleading if used for the prediction of the CO_2 transport and storage in coal seams as they do not account for differences in texture and porosity. NETL researchers compared the storage capacity of the dry Upper Freeport coal powder and lumps in a nine-month-long study that eliminated effects of the differences in diffusion rates and the accessibility of the micro-pores. While powdered samples can be used to estimate sorption capacity at low pressure, storage is likely to involve the use of high-pressure (supercritical) CO_2. At these pressures, differences in the magnitude of the sorption mechanisms, such as enhanced capillary condensation, with or without subsequent dissolution, increase the importance of the changes in mesoporous texture caused by the grinding of coal lumps into powder.

NETL Wellbore Integrity Research Informs Federal Policy on CO_2 Injection (FY2008). In formulating a proposed rule on CO_2 injection, EPA relied on results of a study conducted by NETL and Carnegie Mellon University on the degradation of wellbore cement in the presence of CO_2. The research increased scientific understanding of the chemical reactions that occur among CO_2, brine water, and cement under CO_2 storage conditions, and indicated that corrosion of cement is unlikely to cause failure in a properly completed well. Results of a year-long test that were extrapolated to predict longer-term behavior show excellent agreement with both the nature and extent of chemical reactions evident in field samples taken from an EOR site exposed to CO_2 for 30 years. Both the nature and extent of reaction were as predicted by NETL's laboratory experiments. These findings were presented by NETL at a seminar at Princeton University. The cement used to install and/or plug existing wells is critical in keeping CO_2 permanently stored after injection. The work is described in the July 2008 edition of the ACS publication, *Environmental Science & Technology*.

NETL Researchers Lead Collaboration on CO_2 Brinefield Storage (FY2008). NETL researchers led a collaboration among West Virginia University, Clarkson University, and the University of Utrecht in the Netherlands that combined laboratory experiments, computations, and theory to develop more accurate and reliable equations for describing the flow of liquids through porous rock. This work helps improve the injection of CO_2 into brine-saturated geologic storage sites, as well as the injection of water into oilfields to increase petroleum production (http://www.netl.doe.gov/newsroom/netlog/apr2008/netlog_Apr08.html).

NETL Researchers Develop Method for Fabricating Laboratory Flow Cells to Improve CO_2 Storage in Brinefields (FY2008). NETL researchers developed a new method to design and fabricate flow cells for laboratory studies to improve CO_2 storage in brinefields. This method uses stereolithography to fabricate the cells. During production, a laser cures a thin layer of photosensitive resin on the surface of a vat of liquid resin; a moveable platform then submerges the cured layer and a new layer is cured on top of the previous one, creating a physical model from a computer-generated model. This layered fabrication of a computer-generated model has enabled the production of an experimental porous medium with improved fluid resistance properties, as compared to previously studied etched cells. This work was presented at the American Geophysical Union Fall Meeting in San Francisco, California, on December 10-14, 2007. A paper that describes this work was submitted to the peer-reviewed journal, *Experiments in Fluids* (http://seca.doe.gov/newsroom/netlog/jan2008/netlog_dec07.html).

Computerized Tomography (CT) Measurements Show Importance of Coal Heterogeneity in CO_2 Storage (FY2007). Measurements of a confined core of Pittsburgh #8 coal obtained by NETL researchers from a mine near Waynesburg, Pennsylvania, demonstrated a new technique for obtaining density distributions for stressed and confined coal samples and the changes in volumetric density distribution due to CO_2 adsorption. Furthermore, the kinetics of heterogeneous adsorption and swelling in coal can be determined. The coal core was investigated using computerized tomography. The confining pressure simulated an in situ lithostatic pressure. A dual X-ray energy technique was used to quantify variations in density and effective atomic number throughout the sample. The CO_2 sorption of the coal was then investigated at a series of different gas pressures. The density changes in the coal matrix were calculated and correlated with the CO_2 adsorbed for a multitude of regions of interest chosen in slices perpendicular to the coal bedding plane. The results show that even in small core samples, coal heterogeneity is high. Large variations of density were observed in small regions of interest compared to the average density of the coal. Also, the coal density distribution was changed significantly by the CO_2 uptake.

NETL Researchers Develop Method for Measuring Sorption Isotherms and Diffusion Rates in Coal for CO_2 Storage (FY2007). NETL researchers invented and successfully tested a new method for simultaneously measuring isotherms and diffusion rates for CO_2 storage in coal seams. Compared to other methods for non-powdered samples, NETL's ambient-pressure gravimetry is simple, direct, and inexpensive. Sorption isotherms and diffusion rates are needed as inputs for reservoir engineering computations of storage capacities and field-project designs. Sorption isotherms are conventionally measured on powdered coal by a pressure-drop (i.e., manometric) method; however, it is difficult to obtain diffusion rates from this experimental technique, and powdered samples may give unrealistic sorption capacities. In the ambient-pressure gravimetric technique, larger (centimeter-sized) pieces of coal are weighed and then exposed to CO_2 (or other gas) for the desired pressure, temperature, and sorption time. The high-pressure cell then is quickly depressurized, and the sample weight is automatically recorded on a conventional laboratory balance at fixed time intervals for a period of about one hour. A plot of sample weight vs. square-root of time yields a straight line. The rate of diffusion can be obtained from the slope of the line; the difference between the intercept of the line and the weight of the sample before exposure to the gas gives the amount of gas sorbed by the sample.

Monitoring, Verification, and Accounting

The primary goal of the MVA Focus Area is to develop and demonstrate a broad portfolio of monitoring tools, applications, and accounting requirements that can meet DOE's defined goal of demonstrating 99 percent retention of CO_2 through geologic storage by 2015. The 99 percent retention level is defined by the ability of a geologic storage site to permanently store 99 percent of the injected amount of CO_2. For additional information, please see DOE's "Best Practices for Monitoring, Verification, and Accounting of CO_2 Stored in Deep Geologic Formations."

The overall goal for monitoring is to demonstrate to regulatory authorities and the general public that the practice of geologic storage is safe, permanent, does not create significant adverse local environmental impacts, and is an effective GHG control technology. In general, the goals of MVA for geologic storage are to:

- Improve understanding of storage processes and confirm their effectiveness.
- Evaluate the interactions of CO_2 with formation solids and fluids.
- Assess environmental, safety, and health (ES&H) impacts.
- Evaluate and monitor any required remediation efforts should a leak occur.
- Develop the ability to account for all CO_2 stored in a particular reservoir.
- Provide a technical basis to assist in legal disputes in the unlikely event that any impacts from storage occur (groundwater impacts, seismic events, crop losses, etc.).

The life cycle of a geologic storage project involves four phases. Monitoring activities will vary among these phases:

- *Pre-Operation Phase:* Project design is carried out, baseline conditions are established, geology is characterized, and risks are identified.
- *Operation Phase:* Period of time during which CO_2 is injected into the storage reservoir.
- *Closure Phase:* Period after injection has stopped (wells are abandoned and plugged, equipment and facilities are removed, and agreed upon site restoration is accomplished). Only necessary monitoring equipment is retained.
- *Post-Closure Phase:* Period when ongoing monitoring is used to demonstrate that the storage project is performing as expected until it is safe to discontinue further monitoring. Once it is satisfactorily demonstrated that the site is stable, monitoring will no longer be required except in the unlikely event of release, regulatory requirements, or other matters that may require new information about the status of the storage project.

This portfolio is categorized into three types of monitoring technologies:

Primary Technology – a proven and mature technology or application capable of handling the minimum monitoring requirements that could meet the 99 percent CO_2 containment goals for CCS projects for 2015.

Secondary Technology – an available technology/protocol that can aid in accounting for injected CO_2 and/or provide insight into CO_2 behavior that will help refine the use of Primary Technologies.

Potential Additional Technology – a technology/protocol which is research related and might answer fundamental questions concerning the behavior of CO_2 in the subsurface and might have some benefit as a monitoring tool after testing in the field.

Monitoring, Verification, and Accounting Accomplishments

NETL Technologies Earn Prestigious R&D 100 Awards (FY2009). NETL researchers developed technologies that earned prestigious 2009 R&D 100 Awards, which are presented to the 100 most technologically significant products to enter the marketplace in

the calendar year. NETL researchers and NETL-supported technologies have now won more than 30 R&D 100 Awards since 2000. NETL's winning technologies included SEQURE™ Tracer Technology, a technology that uses perfluorocarbon tracers (PFTs) to ultra-sensitively detect low CO_2 emissions, if they are occurring, from geological storage reservoirs (http://www.netl.doe.gov/publications/press/2009/09048-NETLTechnologies_Earn_Prestigious.html).

DOE Selects Projects to Monitor and Evaluate Geologic CO_2 Storage (FY2009). DOE selected 19 projects to enhance the capability to simulate, track, and evaluate the potential risks of CO_2 storage in geologic formations. The projects' total value is approximately $35.8 million over four years, with $27.6 million of DOE funding and $8.2 million of non-Federal cost sharing. The selected projects will develop technologies and protocols that will improve the ability to: (1) monitor the movement of CO_2 into, through, and out of the targeted geologic storage area; (2) verify the location of CO_2 that has been placed in geologic storage; (3) account for the entire quantity of CO_2 that has been transported to geologic storage sites; (4) mathematically simulate the placement, storage, movement, and release of CO_2 into, through, and from geologic formations; and (5) assess the risks associated with the placement of the CO_2 in geologic formations and the potential release of CO_2 from these formations after it is stored. The projects that deal with MVA are investigating technologies to track the amount of CO_2 stored at a geologic storage site, monitor the site for deterioration of storage integrity over time, and verify that the CO_2 is sustaining expected levels of permanence. The simulation projects will develop advanced numerical models that simulate the behavior of geologically stored CO_2. The risk assessment projects will develop models and protocols to assess the programmatic and technical risks associated with storing CO_2 in a geologic formation (http://www.fossil.energy.gov/news/techlines/2009/09059-DOE_Selects_CO_2_Monitoring_Project.html).

DOE Releases Manual for Safe, Effective Geologic Storage (FY2009). NETL released a comprehensive document describing existing and emerging MVA techniques for CO_2 stored in geologic formations. The manual, titled, *Monitoring, Verification, and Accounting of CO_2 Stored in Deep Geologic Formations*, was prepared with input from the seven RCSPs in order to provide an overview of MVA techniques in use and under development; summarize DOE's MVA R&D program; and present information that can be used by regulatory organizations, project developers, and national and state policymakers to ensure the safety and effectiveness of carbon storage projects. Reliable and cost-effective MVA techniques are critical to making geologic storage a safe, effective, and acceptable method for reducing GHG emissions. In addition, MVA provides data that can be used to verify national inventories of GHGs; assess reductions of GHG emissions at geologic sequestration sites; and evaluate potential regional, national, and international GHG reduction goals. The document is available at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/MVA_Document.pdf (http://www.netl.doe.gov/publications/press/2009/09016-DOE_Releases_MVA_Report.html).

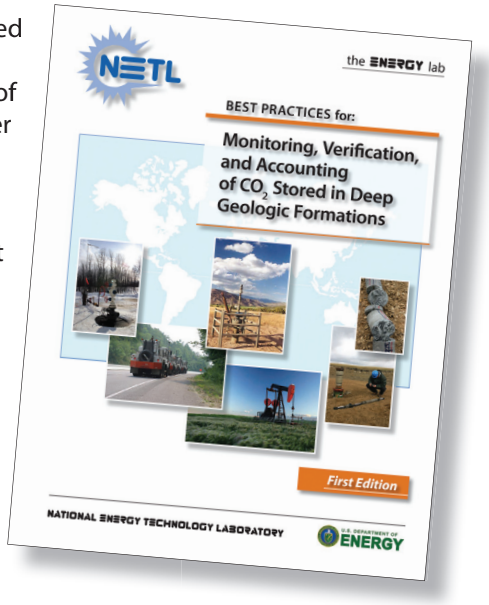


Figure 8. Monitoring, Verification, and Accounting of CO_2 Stored in Deep Geologic Formations.

NETL Researchers Test Novel CO_2 Monitoring Approach (FY2009). Bees, balloons, and pollen have roles in one of the innovative methods NETL is exploring to verify that there is no CO_2 release from carbon storage sites. They are part of a method to sample for the presence of NETL-developed tracers that are co-injected at low levels with the CO_2. The novel perfluorocarbon-based tracers can fingerprint the stored CO_2, differentiating it from natural CO_2 fluxes. With a large, helium-filled balloon, NETL researchers lifted a carousel of sealed sorbent tubes above a source of CO_2 that included tracers to obtain

Figure 9. The Carousel, lifted by Apogee's Balloon, Carries Sorbent Tubes to Sample for Tracer Above the CO_2 Injection Area.

sequential exposures of sorbent tubes at known times and known elevations to help assess boundary-layer mixing processes in the troposphere. At the surface—where point measurements of tracer concentration are normally obtained with small NETL-designed sorbent packets placed within a soil profile—sampling of beehive vent gases and sampling the pollen brought to beehives from a wide area could prove a more efficient approach for assessing tracer levels. NETL is conducting the study at the Center for Zero Emissions Research and Technology research site at Montana State University in Bozeman, Montana (http://www.netl.doe.gov/publications/press/2009/09049-Bees_Balloons_Pollen_Monitor_CO_2.html).

Novel Technology Locates Potential Carbon Storage Areas (FY2007). NETL researchers unveiled a breakthrough in carbon storage efforts with the development of SEQURE™ Well Finding Technology, a commercially available technology that can search vast areas for abandoned oil and gas reservoirs that could be used to permanently store CO_2. This novel technology was received an R&D 100 Award. SEQURE™ Well Finding Technology is a time-saving and cost-effective way to locate abandoned wells, allowing ground teams to evaluate them more efficiently. SEQURE's magnetic sensors detect any steel well casings in the area, depicting them on maps that are used for ground reconnaissance.

NETL Uses Well Finding Technology to Assist the Rocky Mountain Oilfield Testing Center in Locating Wells and CH_4 Leaks (2007). NETL's SEQURE™ well finding technology, which won an R&D 100 Award, was used to survey the Naval Petroleum Reserve No. 3 (NPR-3), a 15-square-mile oilfield near Casper, Wyoming. More than 1,500 line kilometers of magnetic and CH_4 data were acquired from a helicopter using boom-mounted magnetometers and a sensitive CH_4 and light hydrocarbon detector. NETL modified the flight plan and instrument payload previously used for the highly successful 2005 SEQURE™ well finding survey at nearby Salt Creek Oilfield to improve the detection of wells with weak magnetic signatures. In addition, the CH_4 detection device was added to detect any leaking infrastructure in the 100-year-old oilfield. To evaluate the effectiveness of the helicopter survey, NETL scientists conducted a thorough ground-level magnetic and CH_4 survey of a 100-acre test area within the NPR-3 survey area for comparison. NETL processed the airborne data and provided the Rocky Mountain Oilfield Testing Center (RMOTC) with GIS maps depicting anomalous magnetic features and CH_4 plumes as overlays. Initial maps using uncorrected magnetic data depict the location of numerous, weak, well-type anomalies—a preliminary indication that the survey was successful in this respect (http://www.netl.doe.gov/newsroom/netlog/sept2007/netlog_sept07.html).

NETL Demonstrates Use of Remote Sensing Technologies for CH_4 Detection (FY2007). NETL conducted an airborne survey of a one-square-mile test site located in an oilfield near Midwest, Wyoming, using a helicopter fitted with a total field/horizontal gradient cesium ion magnetometer for detecting steel-cased wells and an infrared laser absorption instrument for CH_4 detection. The surveys were conducted to establish whether abandoned oil and gas wells could be remotely detected prior to CO_2 injection

for geologic sequestration and enhanced oil or natural gas recovery. These old, abandoned wells are typically improperly plugged, and could act as conduits for the release of the CO_2. Preliminary interpretation of the results indicate great success; the airborne data was verified by conducting a corresponding ground-based survey over accessible parts of the area using a four-wheel drive vehicle equipped with a cesium magnetometer and a sensitive CO_2/hydrocarbon detection system. In addition to successfully locating known sources, the survey identified two significant and previously unknown CH_4 production leaks, which the operator fixed.

Simulation and Risk Assessment

Research in this focus area aims to develop advanced simulation models of the subsurface and integrate the results into a risk assessment that includes both technical and programmatic risks. As the simulation models are refined with new data, the uncertainty surrounding the identified risks decreases, providing a more accurate risk assessment and mitigation plan for each project site.

Simulation Models – Existing numerical models that simulate geochemical, mechanical, and flow behavior of geologically stored CO_2 are limited by scale and coupled effects occurring in geologic formations. Recently, significant progress has been made in the application of commercial simulators from the oil and gas industry for CO_2 storage. In addition, several models have been developed specifically for CO_2 storage in saline formations and coal seams. The development of refined and coupled geochemical, mechanical, and flow models will enhance the design and implementation of CCS field projects in terms of storage capacity, injectivity, and containment.

Research will continue to develop innovative, advanced simulation models that can be readily integrated with advanced MVA technologies and risk assessment protocols. These models will include full coupling of multiple physical and chemical processes and describe the effects of the coupled processes on CO_2 transport, including:

- Geochemical processes (subsurface chemical reactions among CO_2, groundwater/brine, and rock).
- Geomechanical processes (how faults and fractures affect fluid pressure and CO_2 migration, and the converse, whether fluid pressure induces rock deformation).
- Heat processes (temperature changes induced by CO_2 injection, associated CO_2 phase changes and chemical reactions).
- Fluid flow processes.

Risk Assessment – Risk assessment and management for CO_2 storage efforts include two primary aspects: (1) programmatic risks (including resource and management risks) that may inhibit project progress or costs, and (2) storage (technical) risks inherent to the scientific and engineering objectives of a storage project. For CO_2 storage, programmatic risks are dictated in part by the technical risks and vice versa. For example, the risk associated with long-term financing of a CO_2 storage project (a programmatic risk) is linked to some extent with the risk of CO_2 release through fractures in a geologic formation (a technical risk). For a CO_2 storage project, a useful risk assessment should:

- Identify all vulnerabilities associated with the effort.
- Estimate the likelihood of potential damage associated with each vulnerability.
- Estimate the costs of recovery from the potential damage.
- Identify and summarize possible protective measures and their costs.
- Estimate savings that may result from better protective measures.

There are several key technical risk features, events, and processes (FEPs) for geologic CO_2 storage, including:

- The potential release of small quantities of CO_2 from its storage location (e.g., via wellbores, faults, fractures, etc.).
- Potential injection pressure increases or seismic events.
- Gravity-driven CO_2 movement or residual trapping.
- Displacement of brine or other fluids.

Simulation and Risk Assessment Accomplishments

Field Data Validate NETL Simulations of CO_2 Storage Field Project (FY2009). An advanced model developed at NETL to account for coal shrinkage and swelling effects encountered when CBM production is enhanced by CO_2 injection has been validated with field data from the Allison Field in northern New Mexico—the site of the first commercial ECBM production project. Simulation results fit the field data well, yielding values for several geophysical and geochemical parameters. A paper describing the coal shrinkage/swelling model and the interpretation of the Allison Field data appears in the January 2009 issue of the *International Journal of Coal Geology*.

WVU Joins Developers' Group for NETL Computer Code (FY2009). West Virginia University joined the Developers' Group for NFFLOW™, which is a unique NETL code for reservoir engineering simulations of underground flow within highly fractured reservoirs (http://www.netl.doe.gov/technologies/oil-gas/EP_Technologies/ExplorationTechnologies/Adv%20Diagnostics/FracgenNFFLOW.html). Originally written for production and underground storage of natural gas, the code has since been modified for CO_2 storage in depleted natural gas formations. West Virginia University researchers applied NFFLOW™ in conjunction with neural networks and investigated options for enhancing the code with features of geomechanics.

Researchers Develop New Model for Highly Fractured Geologic Formations and Oil Reservoirs (FY2008). NETL researchers developed a "blocks-and-springs" model to study how second-generation fractures intersect first-generation fractures in underground reservoirs. Since flow in fractured underground reservoirs is significantly enhanced by clusters of interconnecting fractures, it is important to understand their interconnectedness. In these fractured reservoirs, two sets of fractures formed by two separate geologic events are often found. NETL studies find a percolation-like transition, in which the size of the cluster of fractures grows with increasing strain, leading to reservoir-spanning fractal clusters. Such systems are expected to increase underground flow, which is important for commercial energy production when the permeability of the matrix rock is low. Increasing the thickness of the fractured geologic layer leads to sparser system-spanning fracture clusters with smaller fractal dimension. NETL researchers studied how the thickness of the layer affects the fractal character of the fracture clusters, as well as their number distribution and the correlations within the large-fracture cluster. Insights and equations obtained with this model are important for both FRACGEN™, NETL's code for describing fracture networks from field data, and NFFLOW™, NETL's code for engineering simulations for fractured reservoirs. This work was presented at the American Physical Society Annual Meeting in New Orleans, Louisiana, on March 10-14, 2008.

NETL Computer Code Increases Accuracy of Reservoir Production Estimations (FY2008). NETL researchers established how to accurately model the flow of liquids and gases in underground reservoirs containing porous and/or fractured rock. NETL incorporated this information into its NETfLow™ modeling software program, which it recently modified to run on parallel computers, increasing computational speeds by up to three times those attained by the nonparallel version. Using

NETfLow™, NETL has developed physically sound equations for the displacement of brine water and oil by CO_2 during carbon storage, among other applications.

NETL Method Estimates CO_2 Storage Capacity (FY2008). NETL scientists developed a way to more accurately estimate the CO_2 storage capacity of the Oriskany Formation of central New York and northern Pennsylvania. Employing GIS data, two sets of mathematical equations were created: one to define the capacity of the formation's deep brine reservoirs to contain dissolved CO_2, and the other to calculate its capacity for holding pure, compressed CO_2. The first set of calculations (experimentally validated) demonstrated that the brine can store approximately 360 million metric tons of dissolved CO_2. When the CO_2 is in a supercritical form, the second set of calculations theorizes that as much as 8.8 billion metric tons of pure CO_2 may be stored. A paper describing the study appears in the February 9, 2008, issue of the ACS publication, *Environmental Science and Technology* (http://www.netl.doe.gov/newsroom/netlog/apr2008/netlog_Apr08.html).

NETL Develops Capability to Model Market Penetration of Capture Technologies Using CO_2 Supply-and-Demand Curves (FY2007). NETL developed a new version of its Carbon Sequestration Benefits Model (CarBen) desktop model that includes CO_2 supply curves that constrain the potential contribution of capture technologies based on capacity estimates. CarBen was originally developed to evaluate the environmental benefits derived from carbon capture generation technology development. Now, the model can also translate the opportunities for CO_2-EOR into the number of power plants that capture carbon and supply it to the EOR industry. This step is accomplished by aligning CO_2 demand from state-of-the-art CO_2-EOR applications with CO_2 supply from power plants. The research effort determines what is economically feasible by considering demand constraints based on economically recoverable resources and supply constraints based on power plant deployment economics. The research and model enhancement gave NETL the capability to model the market penetration of capture technologies based on economic incentives and constraints.

Computational Experiments at NETL Validate Storage Predictions (FY2007). Using the NETL-developed computer code NETfLow™, NETL scientists showed that equations describing CO_2 flow when CO_2 is injected into brine-saturated geologic formations are also valid under laboratory conditions for a large range of fluid parameters and porous materials. This "crossover" behavior had been predicted in the theoretical literature and could serve to accelerate the development of carbon storage methods and practices.

NETL Enhances Knowledge Base on Carbon Storage in Coalbeds (FY2007).

- **CO_2 Storage in Coalbeds (FY2007).** NETL developed a framework for improving conventional geomechanical approaches to modeling carbon storage in coalbeds. By considering coal properties at the macromolecular level, this approach is a major improvement over the mechanical engineering models that have been used in simulating CO_2 storage in coal seams. The cross-scale theory describes the structural rearrangement of coal after injection of high-pressure gaseous or supercritical CO_2, which was previously ignored or incorrectly accounted for by the mechanistic models. Improved modeling could avoid costly and unexpected problems, such as coal swelling around injectors and reduced injection efficiency that can stall or even terminate site development.

- **Advanced NETL Model Used to Describe Shrinkage and Swelling of Coal (FY2007).** An advanced model developed at NETL to describe the shrinkage and swelling of coal in the presence of CH_4 and CO_2 was used to fit field data from the Allison Field in northern New Mexico. Carbon dioxide was injected into the field for more than 10 years to enhance coalbed natural gas production, and the data are being used to help predict the behavior

of CO_2 when stored in coal seams. NETL research has shown that the effect of CO_2 sorption on coal properties can vary. In some cases, sorption causes the coal to swell, reducing its permeability and making injection difficult; in other cases, CO_2 sorption causes fractures to develop in the coal, making injection easier. Results from simulations using the NETL model were comparable to or better than other simulators and swelling models.

- **NETL Develops New Approach to Modeling CO_2 Interaction with Coal (FY2007).** NETL developed a new R&D framework to tie the geomechanical models of reservoir simulators to fundamental research of the coal properties. The framework accomplishes this by incorporating the local porosity changes driven by macromolecular thermodynamics of plastic deformations.

CO_2 Utilization

Carbon dioxide utilization efforts examine the pathways and novel approaches for reducing CO_2 emissions by developing beneficial uses for the CO_2. These approaches include the conversion of CO_2 to useable products and fuels and other breakthrough concepts that will further mitigate CO_2 emissions.

Applications that utilize CO_2 in this way could generate significant benefits. A number of such applications are described below:

- *Conversion of CO_2:* Use CO_2 to produce chemicals and find applications for the end products.
- *Non-Geologic Storage of CO_2:* Use CO_2 from an effluent stream to permanently immobilize the CO_2 by producing stable solid materials that are either useful products with economic value or a low cost produced material.
- *Indirect Storage:* Promote indirect carbon storage by removing CO_2 from the air (such as enhanced photosynthesis) or by enhancing carbon intake in terrestrial vegetation and soils.
- *Beneficial Use of Produced Water:* For produced water from the injection of CO_2 into saline formations, develop novel methods to use CO_2 to react with metallic ions to form less soluble carbonates that can be removed – and then find useful applications for the desalinated water.
- *Breakthrough Concepts:* Develop novel applications of CO_2, such as novel approaches using microbes that consume CO_2 and other materials to produce useful products or fuels.

CO_2 Utilization Accomplishments

Prior to FY2009, the Carbon Sequestration Program looked at non-CO_2 GHG mitigation technologies. In FY2010, the Carbon Sequestration Program issued a Funding Opportunity Announcement (FOA) for CO_2 utilization projects; accomplishments in this area will appear in future versions of this document.

Below are several accomplishments from the Non-CO_2 GHG Mitigation Area.

University of North Carolina-Charlotte's Landfill Bio-Tarp Project Makes Progress. There are more than 5,000 landfills in the United States that generate large quantities of CO_2 (45 percent) and CH_4 (45 percent). The purpose of the project was to design a tarp impregnated with immobilized CH_4 oxidizing bacteria and then field test it for use as an alternative daily cover that will reduce CH_4 emissions during the active life of a landfill. The project identified good bacterial immobilization techniques, tested a variety of immobilization schemes, and undertook field testing of the most promising designs. The project established a mixed culture of methanotrophic bacteria isolated from landfill cover where they are abundant. The enriched cultures were then either incubated in liquid media to maintain the cultures or directly added to a support for immobilization. Various immobilization methods were investigated and evaluated in batch tests. Finally, a continuous flow test chamber was constructed for evaluating the immobilized cultures in

an environment that simulated potential "bio-tarp" conditions on an active landfill cell (http://www.netl.doe.gov/technologies/carbon_seq/core_rd/non-CO_2/42433.html).

University of Michigan Developing Effective Landfill Cover Soils to Minimize GHG Emissions. NETL sponsored a joint university project at the University of Michigan and Western Michigan University that investigated the development of a more effective, efficient, and economic approach focused on landfill cover soils embedded with in situ microbial activity. The project effort developed holistic strategies to minimize net emissions of CH_4 and NO_x (these GHGs have global warming potentials [GWPs] approximately 19 and 280 times that of CO_2, respectively). The project site undertook field testing at a landfill near Kalamazoo, Michigan, utilizing the selected methodologies for landfill geochemistry and microbial ecology analyses to optimize and utilize landfill cover soil samples. Copper, which is known to strongly regulate activity of methanotrophs (cells responsible for CH_4 consumption), was investigated by both Michigan universities in collaboration with Iowa State University. To date, two invention disclosures have been submitted (http://www.netl.doe.gov/technologies/carbon_seq/core_rd/non-CO_2/42431.html).

CONSOL Coal Mine Ventilation Air Methane Project Enters Operational Phase. CONSOL completed the commissioning of a test unit that includes the MEGTEC VOCSIDIZER, a thermal flow reversal reactor (TFRR), and commenced operations on April 19, 2007. The TFRR is capable of oxidizing coal mine ventilation air methane (VAM) and reducing its GWP while facilitating the recovery of useful energy. The project evaluated the long-term technical and economic feasibility of applying a TFRR to the oxidation of VAM from an underground coal mine (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/project%20portfolio/2007/2007%20Project%20Portfolio/Non-CO_2/FactSheets%20Non-CO_2/Consol_Mine%20Vent_Project248.pdf).

Anaerobic Landfill Cell Construction Initiated for Site of GHG Intelligent Bioreactor Management Information System Study. The Intelligent Bioreactor Management Information System (IBM-IS) is being developed by the University of Delaware and will be tested at the bioreactor landfill cell. Probes for automatically measuring landfill gas pressure, temperature, and moisture content were installed in the landfill cell as part of the IBM-IS, allowing for in situ gas permeability and gas-filled porosity measurements. A gas flow model was then developed. The constructed IBM-IS enabled computer control of the gas collection system to optimize CH_4 collection, while minimizing fugitive CH_4 emissions. The field evaluation required monitoring of CH_4 emissions from the landfill surface, as well as measurement of other parameters of landfill performance (e.g., quality of landfill gas collected). This was the first demonstration of intelligent control of a gas collection system to mitigate fugitive CH_4 emissions from landfills. Typically, without a control IBM-IS, 15 percent to more than 30 percent of the CH_4 generated from a traditional anaerobic landfill is emitted to the atmosphere (http://www.netl.doe.gov/technologies/carbon_seq/core_rd/non-CO_2/42432.html).

Infrastructure

DOE formed a nationwide network of RCSPs to determine the best approaches for capturing and permanently storing GHGs that can contribute to global climate change. The RCSPs are a government/industry effort tasked with determining the most suitable technologies, regulations, and infrastructure needs for CCS in different areas of the United States. Geographical differences in fossil fuel use and storage sinks across the United States dictate regional approaches to CO_2 storage.

The efforts of DOE and the RCSPs to conduct field tests, engage regional stakeholders, and characterize their respective regions under the Infrastructure element has led to a number of awards, milestones, and accomplishments that have resulted from the cooperation between entities. For example,

the RCSPs provide data to NATCARB based upon a DOE-published methodology, which results in CO_2 storage resource maps for DOE's Carbon Sequestration Atlas of the United States and Canada. The following accomplishments reflect the collaborative nature of DOE's implementation of the Infrastructure element.

Infrastructure Accomplishments

NETL Report Estimates CO_2 Storage Potential Beneath Federal Lands (FY2009). According to an NETL-released report, titled, "Storage of Captured Carbon Dioxide Beneath Federal Lands," CO_2 storage capacity potentially ranging from 126 to 375 billion metric tons (approximately five percent of the national storage potential) lies beneath 400 million acres of leasable Federal lands (http://www.netl.doe.gov/energy-analyses/pubs/Fed%20Land_403.01.02_050809.pdf). Of that estimate, 68 percent can be found in the stratigraphy of Montana, Wyoming, North Dakota, and South Dakota. Furthermore, the majority of this storage potential (about 85 percent) is located west of the Mississippi River, where most of the leasable Federal acreage (92 percent) is found. The report also summarizes relevant laws, regulations, and legislation at the Federal and state levels, and locates wells on/near Federal land, pipeline rights-of-way, and point sources that might consider utilizing Federal lands for CO_2 storage. The report is based on information obtained from NATCARB and complements Atlas II (http://www.netl.doe.gov/publications/press/2009/09027-DOE_Publishes_Federal_Lands_Study.html).

DOE Releases Methodology Used to Estimate CO_2 Storage Potential (FY2009). DOE released a document, titled, "Methodology for Development of Geologic Storage Estimates for Carbon Dioxide," detailing the procedures used to produce the geologic resource estimates of CO_2 storage potential in Atlas II (http://www.fossil.energy.gov/programs/sequestration/publications/Project_Reports/carbonstorage_method08.pdf). The methodology document outlines the procedures for estimating CO_2 storage potential in three types of geologic formations found in the United States and Canada – saline formations, unmineable coal seams, and oil and gas reservoirs. The methodologies are based on widely accepted assumptions associated with fluid distribution and displacement processes commonly applied in petroleum and groundwater science (http://www.fossil.energy.gov/news/techlines/2008/08055-DOE_Releases_Carbon_Storage_Method.html).

Updated Carbon Sequestration Atlas of the United States and Canada (FY2008). NETL published the 2008 Carbon Sequestration Atlas of the United States and Canada (Atlas II), which contains extensive information assembled by the seven NETL-managed RCSPs. Atlas II features updated maps illustrating the number, location, and magnitude of CO_2 sources in the United States and portions of Canada. Preliminary estimates suggest that the various geologic formations in North America could store more than 1,100 years of annual CO_2 emissions from the identified sources. Also found in the new Atlas is information on NETL's Carbon Sequestration Program, results of Federal lands and CO_2 pipeline studies from NETL, estimates of CO_2 storage by state, and information about commercialization opportunities for CCS technologies in each area of the United States (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/) (http://www.fossil.energy.gov/news/techlines/2008/08060-DOE_Releases_Sequestration_Atlas.html).

Atlas Wins 2008 Grand Award for Publication Excellence (FY2008). NETL's 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, Atlas I was complimented for richness of data and exceptional visuals, including effective info-graphics and clear, understandable copy. Atlas I represents a coordinated effort by experts from industry, academia, and local, state, and provincial governments working as participants in the RCSPs to assess U.S. and Canadian CO_2 sources and potential sinks (http://www.fe.doe.gov/news/techlines/2008/08034-Sequestration_Atlas_Wins_Award.html).

NATCARB Produces "Best Paper of the Year" (FY2008). Researchers at the University of Kansas, who led development of NATCARB in cooperation with NETL, received the 2008 Geoscapes Best Paper of the Year Award from the Journal of Map and Geography Libraries/Geoscapes. The journal editors chose the paper, titled, "The NATCARB Geoportal: Linking Distributed Data from the Carbon Sequestration Regional Partnerships," for its public policy implications and relevance to the energy issues facing the world today (http://www.creeksidescience.com/files/carr_et_al_2007_NATCARB_jmgl.pdf).

NETL Partner Receives Prestigious Award for Environmental Stewardship (FY2008). The University of North Dakota's Energy & Environmental Research Center (UNDEERC) received a Chairman's Stewardship Award from the IOGCC for leadership in technology development as part of the PCOR Partnership. The PCOR Partnership field tests demonstrate the effectiveness of using CO_2 for enhanced hydrocarbon production, exhibit cost-effective use of oil reservoirs and lignite coal seams for safe CO_2 storage. Representing the highest IOGCC honor conferred for exemplary achievement in environmental stewardship, the award was presented by Chairman Brad Henry, Governor of Oklahoma, at the IOGCC Annual Meeting in Santa Fe, New Mexico (http://www2.und.edu/our/news/story.php?id=2555).

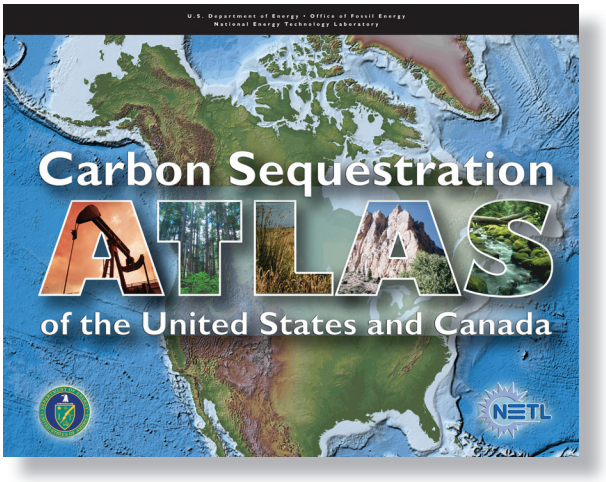


Figure 10. Carbon Sequestration Atlas of the United States and Canada (Atlas I).

Characterization Phase

The Characterization Phase began in September 2003 with the seven RCSPs working to evaluate the potential of various geological formations. The main goals of the Characterization Phase were to collect data on CO_2 sources and sinks and develop the human capital to support and enable future carbon storage field tests and deployments. The RCSPs also sought to evaluate and determine which of the numerous storage approaches are best suited for specific regions of the United States. In addition, the RCSPs began studying possible regulations and infrastructure requirements that would be needed if it was determined that CCS should be deployed on a wide scale in the future. The RCSPs succeeded in establishing a national network of representatives from academia, industry, the environmental community, as well as Federal, state, and local governments working to support CCS projects. They also created a network of regional carbon storage atlases for the United States and supplied data for NATCARB, which were used to identify the most promising CO_2 storage opportunities and raise awareness and support for carbon storage as a GHG mitigation option. The Characterization Phase ended in June 2005. The complete RCSP Phase I Accomplishments Report is

available on the Carbon Sequestration Reference Shelf (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/PhaseIAccomplishment.pdf).

Characterization Phase Accomplishments

Completed Characterization Phase (Phase I) of the RCSP Initiative (FY2005). The seven RCSPs achieved the following accomplishments in Phase I:

- Established a national network of diverse professionals working to support CCS projects. For a two-year investment of $19.9 million, including $6.9 million of cost share, DOE achieved the active participation of more than 500 individuals[3] representing more than 240 industrial companies, engineering firms, state agencies, non-governmental organizations (NGOs), and other organizations.

- Created the Carbon Sequestration Atlas of the United States and Canada (Atlas I) (Figure 11). DOE and the seven RCSPs compiled information on CO_2 emission stationary sources, geologic formations with storage potential, and terrestrial ecosystems with potential for enhanced carbon uptake – all referenced to their geographic location – to enable matching sources and storage sites. Atlas I contains information on more than 5,500 emissions sources representing roughly 45 percent of total U.S. CO_2 emissions. NATCARB provides much of the data available in the Atlas.

- Obtained an improved understanding of the permitting requirements for future CCS projects. During Phase I, the RCSPs recognized that the various states and regions and geologies have different requirements regarding CO_2 injection. Working in collaboration with the IOGCC and in consultation with the U.S. EPA, the RCSPs assessed requirements and procedures for permitting future commercial storage deployments.

- Raised awareness and widespread support for CO_2 storage as a GHG mitigation option within industry, the environmental community, and the general public. During Phase I, the seven RCSPs were successful in developing innovative and effective approaches for public outreach and education by raising awareness of CCS, while at the same time building public acceptance of CCS as a safe GHG mitigation option.

- Succeeded in characterizing regional opportunities for CCS, identifying regional CO_2 sources, and identifying priority opportunities for field tests to be carried out during the Validation Phase.

- Established a series of protocols for project implementation, GHG accounting, and contracts.

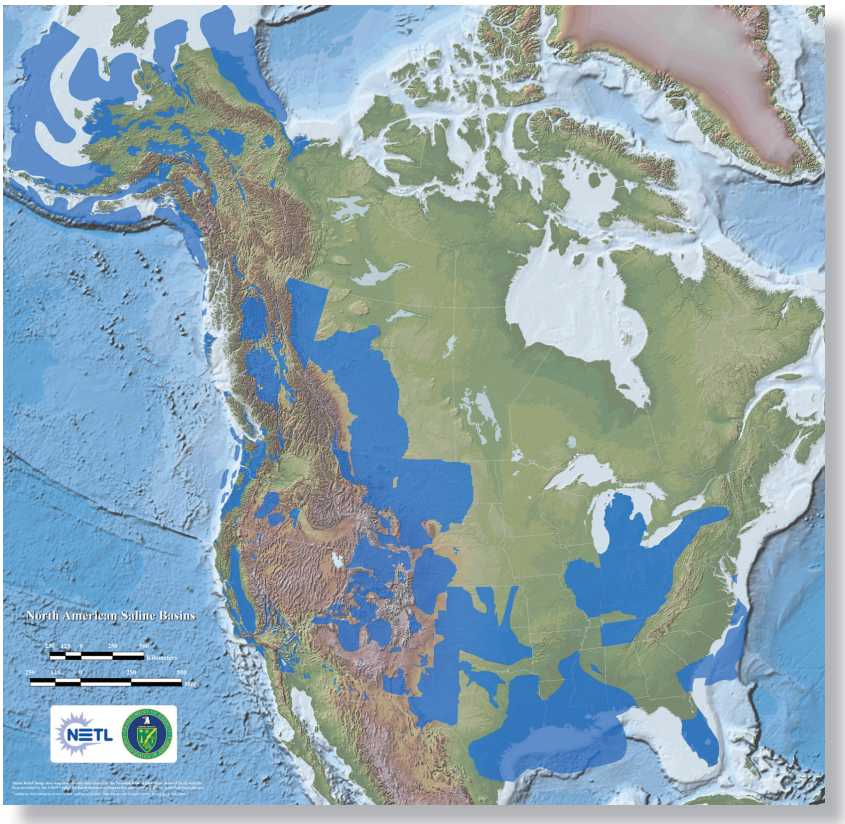


Figure 11. Example NATCARB Depiction of Available Saline Formations (Characterization Phase).

[3] Phase II had approximately 350 district organizations and Phase III has approximately 400 distinct organizations as partners with the seven RCSPs (April 2010).

Validation Phase

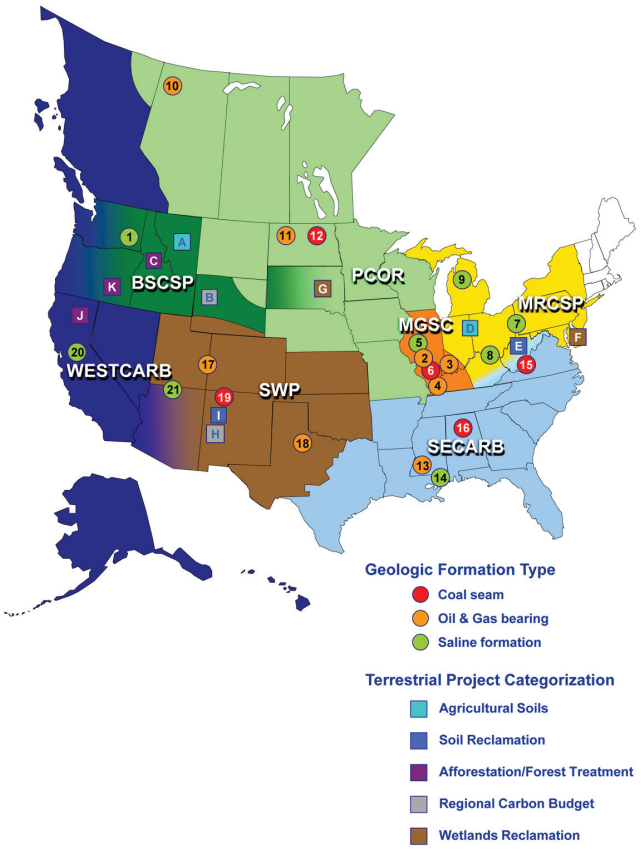
The Validation Phase (Phase II) focuses on validating the most promising regional opportunities to deploy CCS technologies by building upon the accomplishments of the Characterization Phase. Efforts are being conducted to: (1) validate and refine current reservoir simulations for CO_2 storage projects; (2) collect physical data to confirm CO_2 storage potential and injectivity estimates; (3) demonstrate the effectiveness of MVA technologies; (4) develop guidelines for well completion, operations, and abandonment; and (5) develop strategies to optimize the CO_2 storage potential of various geologic formations. Twenty one small-scale CO_2 injection field tests into various geological formations have been conducted during the Validation Phase. Terrestrial sequestration has also been validated by conducting 11 field tests. These tests are summarized and depicted in the graphic above (Figure 12).

Validation Phase Accomplishments

Big Sky Carbon Sequestration Partnership

(http://www.netl.doe.gov/publications/factsheets/project/Proj440.pdf)

BSCSP Completes Drilling for Carbon Storage Test (FY2009). BSCSP completed drilling an approximately 4,000-foot-deep pilot injection well in April 2009 for a field test involving the injection of roughly 1,000 tons of supercritical CO_2 into a



	Partnership	Geologic Province/ Location	Geologic: Total CO_2 Injection (metric tons CO_2)	Geologic: Approximate Depth (feet)	Terrestrial: Estimated CO_2 Capacity
1		Columbia Basin	0*	2,500 – 4,000	
A	Big Sky Carbon Sequestration Partnership	North Central MT			60 Mt over 20 years
B		Eastern WY			30 Mt over 10 years
C		Region-wide			640 – 1,040 Mt over 80 years
2	MGSC	Loudon Oil Field	< 39	1,550	
3		Mumford Hills Oil Field*	3,375*	1,551	
4		Sugar Creek Oil Field	6,500	1,548	
5		Illinois Basin	91	1,000	
6					
7	MRCSP Midwest Regional Carbon Sequestration Partnership	Appalachian Basin	< 50	5,900 – 8,300	
8		Cincinnati Arch	1,000	3,200 – 3,500	
9		Michigan Basin	60,000	3,200 – 3,500	
D		Region-wide			25 Mt over 20 years
E		Region-wide			100 Mt over 20 years
F		Cambridge, MD			TBD
10	PCOR Partnership	Keg River Formation	25, 400	4,900	
11		Duperow Formation	400	8,050	
12		Williston Basin	80	1,100	
G		Great Plains wetlands complex (PPR)			14.4 Mt
13	SECARB Southeast Regional Carbon Sequestration Partnership	Gulf Coast* } stacked	1,500,000*	10,304	
14		Gulf Coast } stacked		10,400	
15		Mississippi Coastal Plain	2,740	8,600	
16		Central Appalachian	907	1,600 – 2,300	
		Black Warrior Basin	252	1,500 – 2,500	
17	SWP	Paradox Basin–Aneth Field	630,000	5,600 – 5,800	
18		Permian Basin	86,000	5,800	
19		San Juan Basin	16,700	3,000	
H		Region-wide			TBD
I		San Juan Basin Coal Fairway (Navajo City, NM)			TBD
20	West Coast Regional Carbon Sequestration Partnership westcarb.org	Sacramento Basin	0	8,000	
21		Colorado Plateau	0	4,000	
J		Shasta County, CA			4,600 Mt over 80 years (CA)
K		Lake County, OR			900 Mt over 80 years (OR)

* Currently injecting or will begin injecting in 2010

Information current as of June 2010

Figure 12. RCSP Validation Phase Projects (as of May 2010).

deep basalt formation (Grande Ronde Basalt) in western Walla Walla County in eastern Washington State. The test will assess the mineralogical, geochemical, and hydrologic impact of the injected CO_2 within a basalt formation and incorporate site MVA activities. Although the basalts have inherently low porosity and permeability, it is believed that significant CO_2 injectivity and storage capacity can be obtained by one or several brecciated zones between major basalt flows. Furthermore, preliminary calculations show that rapid conversion of injected CO_2 to carbonate minerals can occur in basalt formations, with complete conversion of fluid phase CO_2 to solid phase carbonate minerals in a few hundred years. If these laboratory-based estimates can be verified in the field, basalt formations may offer a unique geologic medium for carbon storage. BSCSP also completed CO_2 injection simulations for two basalt flows. Two shallow soil gas probes were installed in the vicinity of the injection well and gas samples were collected on a monthly basis to detect any anomalous gas composition readings and to establish background concentrations for CO_2 and other gases. A seismic survey was completed in December 2007.

Midwest Geological Sequestration Consortium

(http://www.netl.doe.gov/publications/factsheets/project/Proj441.pdf)

MGSC Begins Carbon Storage Test (FY2009). An MGSC project in Hopkins County, Kentucky, began injecting CO_2 into a mature oilfield to assess the region's CO_2 storage capacity and feasibility for EOR. The Kentucky test injected about 8,000 tons of CO_2 into an existing brine-water injection well at approximately 1,900 feet underground. Following injection, the oil, gas, and water produced was measured to evaluate the field's EOR characteristics. With technical support from the Kentucky Geologic Survey, MGSC has implemented a monitoring program at the site to track the fate of the CO_2. The program will consists of tracking the rate and volume of injected CO_2, and the pressures and temperatures within the well. These measurements will provide an indication of how efficiently the CO_2 displaces oil within the reservoir and how efficiently the reservoir stores the CO_2 (http://www.fossil.energy.gov/news/techlines/2009/09041-DOE_Partner_Begins_Carbon_Storage_.html).

Figure 13. BSCSP Phase II Basalt Injection Pilot Location. (Courtesy of BSCSP Website)

MGSC Finds New Use for Unmined Coal (FY2008). With this Phase II pilot project in Wabash County, Illinois, MGSC became the first RCSP to inject CO_2 into a coal seam in the United States. The project tested the viability of turning unmined coal deposits into a source of useable energy by extracting natural gas, specifically CBM, trapped in the coal. The Wabash County project eliminated the need for dewatering, as it was designed to use one injection well and three production wells. Trucked-in CO_2 was pumped through a heater and injected into the coal seam as a gas, increasing the pressure underground and desorbing the CBM. The Wabash County project monitored the injected CO_2 in the lab and in the field, and measured changes in CO_2 injectivity, the amount of CO_2 that was retained by the coal, and the amount of CH_4 gas that was displaced by CO_2. The Illinois State Geological Survey (ISGS) estimates that the unmined coal seams of the Illinois Basin have up to 3.6 billion tons of storage capacity and more than 10 trillion cubic feet of recoverable CBM.

Midwest Regional Carbon Sequestration Partnership
(http://www.netl.doe.gov/publications/factsheets/project/Proj445.pdf)

New Jersey Joins DOE's RCSP Initiative (FY2009). New Jersey became the 43rd state to join the RCSP Initiative, helping to strengthen U.S. efforts to reduce GHG emissions and mitigate climate change. New Jersey is a regional partner and a participant in the MRCSP's Phase II projects. Contributions from the New Jersey Department of Environmental Protection and Rutgers University include building and refining the state's geologic and terrestrial storage frameworks, as well as a terrestrial demonstration of forested wetlands. Efforts in New Jersey focus on developing and integrating data on the state's potential geologic and terrestrial storage capacity. Due to the prevalence of offshore storage opportunities believed to exist in New Jersey, MRSCP will eventually include offshore reservoirs in its database (http://www.netl.doe.gov/publications/press/2009/09040-New_Jersey_Joins_Regional_Partners.html).

Small-Scale Carbon Sequestration Field Test Yields Significant Lessons Learned (FY2009). A preliminary geologic characterization and storage field test was completed by MRCSP at FirstEnergy's R.E. Burger Plant near Shadyside, Ohio. The project provided significant geologic understanding and "lessons learned" from a region of the Appalachian Basin with few existing deep well penetrations for geologic characterization. The purpose of this test is to assess the suitability of regional geologic formations for permanently storing CO_2 emissions from the power plant. The targets for the geologic storage of CO_2 at the site were the Oriskany and Clinton Sandstones at depths in the range of 5,500 feet to 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. Since the nearest well penetrations are more than 20 miles away from the Burger injection well, any and all data collected from the region is useful in determining the suitability of potential field test locations for CO_2 storage in the future. The data compiled from the project evaluation indicated that the porosity, void space, and permeability of the target formations were lower than expected, and that the pressure in the formations increased with low injection rates. These results confirm the complex nature of the formations and demonstrate the importance of extensive drilling, formation evaluation, and testing to properly characterize and identify appropriate formations for CO_2 storage within the Appalachian Basin prior to injection. In addition to providing a significant geologic understanding of the formation, the project also provided several "lessons learned," ranging from practices regarding site selection; design of robust formation imaging, evaluation, and testing programs; formation simulation(s); well completion; and communication with stakeholders (http://www.netl.doe.gov/publications/press/2009/09031-CCS_Test_Yields_Valuable_Informati.html).

CO_2 Injection Extended for Michigan Field Test (FY2009). MRCSP injected an additional 50,000 metric tons of CO_2 into a permeable interval of the Bass Islands Dolomite where 10,000 metric tons had already been successfully stored approximately 3,200 to 3,500 feet below the Earth's surface near Gaylord, Michigan. Working in cooperation with NETL, the project team anticipated detecting breakthrough at a monitoring well located approximately 480 feet from the injection well and recording geochemical changes as well as the vertical distribution of CO_2 along the wellbore. Extending the injection phase over a period of six to seven months at an average rate of 250 metric tons per day allowed seasonal effects and the long-term temperature and pressure response within the Bass Island Formation to be analyzed (http://www.netl.doe.gov/publications/press/2009/09012-DOE_Partners_Begin_CO_2_Injection.html).

Figure 14. MRCSP Conducting Crosswell Seismic Imaging near Gaylord, Michigan, in October 2007. (Courtesy of MRCSP Website)

Plains CO_2 Reduction (PCOR) Partnership

(http://www.netl.doe.gov/publications/factsheets/project/Proj446.pdf)

PCOR Partnership's Decision Support System Used in Development of Carbon Management Plan (FY2009). The PCOR Partnership's Decision Support System (DSS), a web-based GIS that contains estimated storage capacities of regional geologic carbon sinks, was used to prepare a carbon management plan for Excelsior Energy's Mesaba Energy Project. The plan examines potential options for reducing the project's CO_2 emissions. The PCOR Partnership's DSS allows partners to browse, query, analyze, and download data regarding CO_2 storage in the PCOR Partnership region. Most of the characterization information that is used for a carbon management plan can be inspected through the DSS, which contains tools for the interactive data analysis of the PCOR Partnership region, with both text- and map-based approaches. This information, as well as regulatory issues, pipeline transportation of CO_2, carbon markets, and MVA requirements, was included in the Mesaba carbon management plan (http://www.netl.doe.gov/publications/press/2009/090817-Regional_Partners_Decision_Support_System.html).

FE-Supported Carbon Storage Documentary Recognized for Excellence (FY2009). The environmental documentary, titled, "Out of the Air – Into the Soil: Land Practices That Reduce Atmospheric Carbon Levels," won a 2009 Communicator Award of Excellence and a 2009 Golden Aurora Award recognizing film and video excellence (http://www.undeerc.org/pcor/documentary/outofair.aspx). Produced for a general audience by Prairie Public Broadcasting (Fargo, North Dakota) in collaboration with the PCOR Partnership, the 30-minute program introduces terrestrial CO_2 storage as a way to reduce a carbon footprint by using the natural ability of plants to absorb CO_2 from the atmosphere and store the carbon in roots, stems/trunks, leaves, and soils. Other PCOR Partnership documentaries,

titled, "Nature in the Balance" and "Reducing our Carbon Footprint: The Role of Markets," were released in 2005 and 2008, respectively (http://www.undeerc.org/PCOR/documentary/natureinbalance.aspx and http://www.undeerc.org/PCOR/documentary/reducecarbonfootprint.aspx). The educational series is part of an extensive PCOR Partnership outreach effort to raise awareness of the benefits and opportunities of carbon storage both regionally and globally. The awards presented are the highest honor among the Communicator Awards, the leading international awards program honoring creative excellence among communications professionals. The Aurora Awards are an international competition designed to recognize excellence in the film and video industries (http://www.netl.doe.gov/publications/press/2009/09061-CCS_Documentary_Wins_Award.html).

PCOR Partnership Injects CO_2 for North Dakota Project (FY2009). The PCOR Partnership injected nearly 500 tons of CO_2 approximately 1,200 feet underground into an unmineable lignite seam in Burke County, North Dakota, to determine the long-term effect the CO_2 will have on the lignite and the potential for EOR. Previous characterization activities suggest the region's low-rank coal seams could store up to 8 billion tons of CO_2, while releasing more than 17 trillion cubic feet of CH_4. The first to focus on lignite coals, the demonstration has provided previously unavailable insights broadly applicable not only within the region but throughout western North America where low-rank coal seams are prevalent. PCOR began drilling operations in FY2007. Overall, the project focused on the following factors: CH_4 content, CO_2 storage capacity, and methodology; the features of fluid transport in lignite; the stability of CO_2 stored within lignite coal seams; factors controlling the success of storage and production in lignite; and economics. During the drilling operation, researchers used sampling techniques to indicate the presence of gas in the vicinity of the coal seam (http://www.netl.doe.gov/publications/press/2009/09015-CO_2_Injection_Begins.html).

Southeast Regional Carbon Sequestration Partnership
(http://www.netl.doe.gov/publications/factsheets/project/Proj442.pdf)

Injection Phase for FE Carbon Sequestration Project Begins in Central Appalachian Basin (FY2009). SECARB initiated CO_2 injection into coal seams in Russell County, Virginia, on January 15, 2009 (Figure 16). The project site is representative of an area that could store an estimated 1.3 billion tons of CO_2 while producing up to 2.5 trillion cubic feet of natural gas from unmineable coal seams. SECARB has since finished the injection of 1,000 tons of CO_2 into a donated CNX Gas CBM well and monitoring activities at the test site and data analysis from the injection operations remain ongoing. Prior to injecting 1,000 tons of CO_2 into unmineable coal seams in Russell County, Virginia, the seams were hydraulically fractured to increase the number and size of CO_2 pathways into the coal. The hydrofrac procedure doubled to 40 tons of

Figure 15. PCOR Partnership's Burke County, North Dakota, Field Test Site. (Courtesy of PCOR Partnership Website)

CO_2 per day, allowing the planned 45-day injection phase to be completed 19 days early on February 9, 2009. Monitoring of the CO_2 injection through instrumented wells drilled within 300 feet of the injection well will verify retention of CO_2 in the injection zone, quantify storage capacity, and establish the quantity and quality of the natural gas produced. The project is designed to demonstrate the cost effectiveness of utilizing the immediate commercial benefits of CH4 recovery to offset infrastructure development costs for the safe, permanent storage of larger volumes of CO_2 (http://www.netl.doe.gov/publications/press/2009/09006-Coal_Seam_Injection_Begins.html).

Underground Monitoring of Carbon Storage Site Begins in Mississippi (FY2008). SECARB is using innovative, real-time monitoring equipment installed two miles beneath the Earth's surface to track the movement of CO_2 injected for oil recovery. The project includes downhole pressure and temperature measurements conducted by the Gulf Coast Carbon Center (GCCC) at the Bureau of Economic Geology, University of Texas at Austin. The effort examines the instrumentation necessary to ensure safe CO_2 storage by verifying CO_2 retention in the injection zone, quantify storage capacity, and quantify near- and far-field pressure response to injection. SECARB began injecting CO_2 on July 15, 2008, at a depth of 10,300 feet for EOR at the Cranfield oilfield near Natchez, Mississippi. The naturally occurring CO_2 is obtained from Jackson Dome and transported by pipeline to the injection site. SECARB plans to inject CO_2 at a rate of 250,000 to 500,000 metric tons per year over the next several years into the lower Tuscaloosa Formation. The Tuscaloosa Formation lies beneath an area of approximately 46,000 square miles in southern Alabama and Mississippi, the Florida Panhandle, and Louisiana.

Figure 16. SECARB's Russell County Injection Site. (Courtesy of SECARB Website)

Southwest Regional Partnership on Carbon Sequestration

(http://www.netl.doe.gov/publications/factsheets/project/Proj443.pdf)

SWP Starts CO_2 Injection in New Mexico Coalbed (FY2008). SWP began injecting a planned 35,000 tons of CO_2 in an ECBM recovery project to develop methods to maximize permanent storage of CO_2 at the San Juan Basin near Navajo City, New Mexico. The San Juan Basin, which contains coal at approximate depths of 3,000 feet, was chosen for the six-month demonstration project because it is regarded as one of the top basins in the world for CBM recovery due to its favorable geology, high CH_4 content, nearby availability of CO_2 from power plants, low capital and operating costs, and well-developed natural gas and CO_2 pipelines. The basin consists of three CBM-producing wells and a centrally located injection well. The coal seams are approximately 75 feet thick and are split among three seams over a 175-foot interval. In addition, the San Juan Basin contains highly permeable coal that is required for maintaining effective CO_2 injection rates over time. DOE established the maintenance of high injection rates as a goal for large-scale CO_2 storage in coal.

Figure 17. San Juan Basin Test Site. (Courtesy of SWP Website)

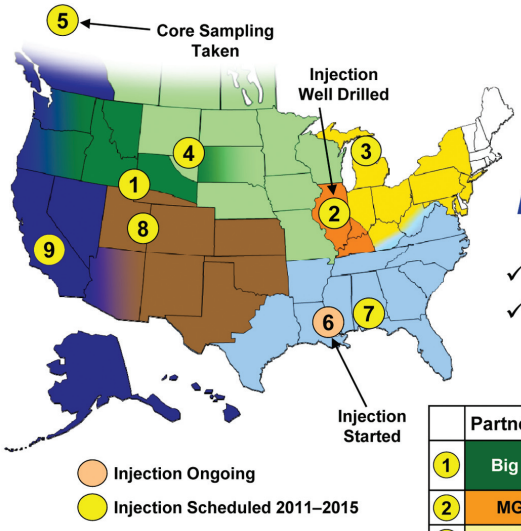
West Coast Regional Carbon Sequestration Partnership

(http://www.netl.doe.gov/publications/factsheets/project/Proj444.pdf)

WESTCARB Completes Drilling Operations at Arizona CO_2 Injection Site (FY2009). WESTCARB completed drilling an approximately 4,000-foot deep well for the injection of 2,000 tons of CO_2 from an Arizona Utilities coal-fired power plant to test the safety and feasibility of CO_2 storage in the saline formations of Arizona's portion of the Colorado Plateau region. WESTCARB provided a daily blog update of drilling activities on their partnership website. Although this injection was not completed for several technical reasons, a significant amount of information about this geological formation was obtained.

Hawaii Joins DOE's RCSP Initiative (FY2008). Hawaii became the 42nd state to join DOE's RCSP Initiative, becoming a member state of WESTCARB. Hawaii was included as a regional partner for the first time when WESTCARB was awarded DOE funding for a Phase III large-scale storage test. Efforts in Hawaii will focus on site characterization or "source-sink matching" of CO_2 emission sources, such as power plants, and terrestrial and geologic sinks.

Figure 18. WESTCARB Test Drilling Site. (Courtesy of WESTCARB Website)



Large-Scale Geologic Tests

- ✓ *Nine large-volume tests*
- ✓ *Injections scheduled 2011–2015*

	Partnership	Geologic Province	Type
1	Big Sky	Triassic Nugget Sandstone / Moxa Arch	Saline
2	MGSC	Deep Mt. Simon Sandstone	Saline
3	MRCSP	St. Peter Sandstone	Saline
4	PCOR	Bell Creek Field	Oil Bearing
5		Devonian Age Carbonate Rock	Saline
6	SECARB	Lower Tuscaloosa Formation	Saline
7		Paluxy Formation	
8	SWP	Regional Jurassic & Older Formations	Saline
9	WESTCARB	Central Valley	Saline

Figure 19. RCSP Development Phase Projects (as of May 2010).

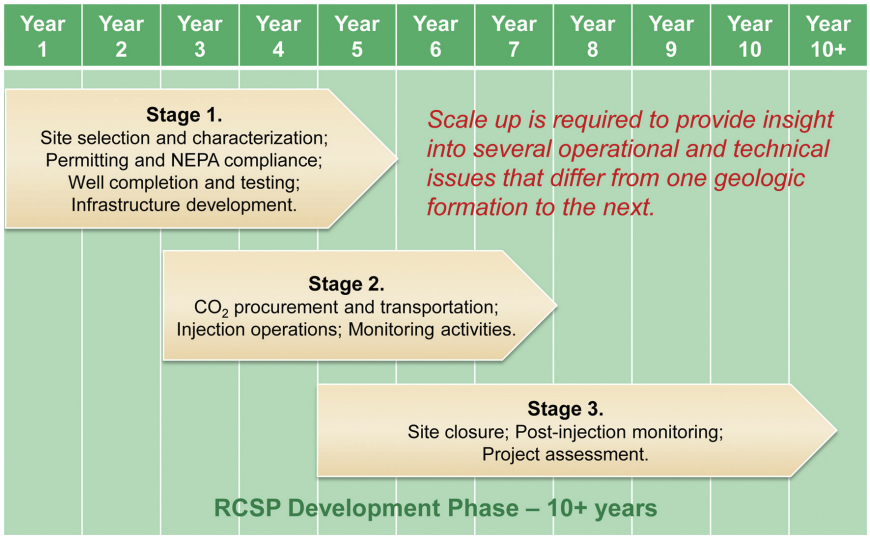


Figure 20. Development Phase Timeline.

Development Phase

The Development Phase (Phase III) builds on the experience obtained in the Characterization and Validation Phases and involves the injection of 1 million tons or more of CO_2 by each RCSP into regionally significant geologic formations of different depositional environments (Figure 19). These large-volume injection tests are designed to demonstrate that CO_2 storage sites have the potential to store CO_2 emissions safely, permanently, and economically for hundreds of years.

These large-scale injection tests will occur over several years (Figure 20). The RCSPs will be expected to maximize CO_2 injection volumes that fully utilize the infrastructure of their respective regions. Sources of CO_2 may include natural deposits, ethanol facilities, natural gas processing plants, and eventually CO_2 captured from power plants.

Results obtained from these efforts will provide the foundation for CCS technology commercialization throughout the United States, including providing experience that can be used to implement additional demonstration projects.

Development Phase Accomplishments

DOE Awards Seven RCSPs Funding for Large-Scale, Development Phase Activities (FY2008 [BSCSP FY2009]).

- ***BSCSP*** – BSCSP will conduct a large-volume test in the Northwest Region. BSCSP plans to drill a CO_2 injection well and then inject up to 1 million tons of CO_2 per year into a sandstone or limestone formation at a depth of approximately 11,000 feet. It is expected that CO_2 for the project will be available via an operating petroleum or natural gas processing facility in the vicinity of the selected injection site (http://www.netl.doe.gov/publications/press/2008/08059-DOE_Makes_Sequestration_Award.html).

- ***MGSC*** – MGSC has partnered with ADM, an agricultural product processing company, to conduct a large-volume, saline storage test at ADM's ethanol facility located in Decatur, Illinois. The test will involve the injection of 367,000 tons of CO_2 per year for three years from the fermentation plant into the Mt. Simon Sandstone, a major regional saline formation in the Illinois Basin (http://www.netl.doe.gov/publications/press/2007/07084-Illinois_Basin_Sequestration_Proje.html).

- ***MRCSP*** – MRCSP will inject a total of 1 million tons of CO_2 into the Mt. Simon Sandstone over a four-year period (http://www.netl.doe.gov/publications/press/2008/08012-DOE_Funds_Large-Scale_Projects.html).

- ***PCOR Partnership*** – The PCOR Partnership will conduct two projects: (1) the Williston Basin demonstration will transport 1 million tons of CO_2 per year and inject the CO_2 into an oil reservoir in the Bell Creek Field located in eastern Montana, and (2) the Fort Nelson project in British Columbia will utilize more than 1 million tons of CO_2 per year captured from one of the largest gas processing plants in North America, transport the CO_2 in a supercritical state via pipeline, and inject it into Devonian-age Elk Point carbonate rock formation at a depth of greater than 5,000 feet (http://www.netl.doe.gov/publications/press/2007/07072-DOE_Awards_Sequestration_Projects.html).

- ***SECARB*** – SECARB will conduct a two-step, large-volume injection test in the lower Tuscaloosa Formation. The first step, or "Early Test," has already injected over 1 million tons of CO_2 and will eventually complete the injection of 1.65 million tons of CO_2 per year for 18 months. The CO_2 will come from a naturally occurring source. The second step, or "Anthropogenic Test," will inject 110,000 to 275,000 tons of CO_2 per year for four years. The CO_2 will be supplied by a pilot unit capturing CO_2 from flue gas produced from a Southern Company power plant located near the injection site (http://www.netl.doe.gov/publications/press/2007/07072-DOE_Awards_Sequestration_Projects.html).

- ***SWP*** – SWP will follow a four-year injection schedule that will eventually lead up to 1 million tons of CO_2 per year. The target formations for this deployment include deep Jurassic-, Triassic-, and Permian-aged sandstones; secondary targets include Mississippian-aged carbonates. SWP plans include a "dual completion" with injection in two different formations at the same time (http://www.netl.doe.gov/publications/press/2007/07072-DOE_Awards_Sequestration_Projects.html).

- ***WESTCARB*** – WESTCARB will conduct a large-volume, saline test in Northern California (http://www.netl.doe.gov/publications/press/2008/08012-DOE_Funds_Large-Scale_Projects.html).

First U.S. Large-Scale CO_2 Storage Project Advances (FY2009). Drilling operations organized by the MGSC were completed upon reaching the Precambrian granite basement rock underlying the Mt. Simon sandstone formation near Decatur, Illinois. The injection well was drilled into the Mt. Simon Sandstone to a depth more than one mile beneath the surface (Figure 21). No wells within 50 miles have been drilled to the bottom of the sandstone, which the storage well plans to complete. The project will obtain core samples of the Mt. Simon Sandstone during drilling that will be used in analysis to help determine the best section for injection. From 2011 to 2013, up to 1 million metric tons of captured CO_2 from ADM's ethanol production facility in Decatur, Illinois, will be injected more than one mile beneath the surface into a deep saline formation. Following injection, the site will be monitored to ensure safe, permanent CO_2 storage. A core sample of the overlying Eau Claire shale formation was recovered to evaluate the sealing properties of the 500-foot thick caprock. Results of the project will provide important information on the future of carbon storage as a viable option for GHG mitigation. ADM was issued an Underground Injection Control (UIC) permit in January 2009 by the Illinois EPA for the injection well (http://www.netl.doe.gov/publications/press/2009/09022-Large-Scale_CCS_Advances.html).

Figure 21. MGSC Phase III Injection Well. (Courtesy of MGSC Website)

PCOR Partnership Begins Core Sampling for Large-Volume Storage Test (FY2009). The PCOR Partnership collected core samples from a new characterization well near Spectra Energy's Fort Nelson natural gas processing plant in British Columbia, Canada. The Fort Nelson project is on track to become one of the first commercial-scale CCS projects in a saline formation in North America. With plans to inject more than 2 million tons of CO_2 per year, the project will also be one of the largest carbon storage projects in the world. Core sampling and well logging help to determine a site's geologic suitability for safe, permanent CO_2 storage. Coring of the Elk Point rock formations at Fort Nelson will provide researchers, geologists, and reservoir experts with characterization data of the carbonate formations that will be used to store the CO_2 and the impermeable shale layers above that will act as a caprock to contain the CO_2. As part of these activities, numerous geomechanical and geochemical tests designed to evaluate the performance of the reservoir and containment rocks will be performed. The project is expected to involve the eventual transportation of CO_2 from Spectra Energy's Fort Nelson natural gas processing plant to the injection site. To ensure the safe storage of CO_2, PCOR will implement a comprehensive MVA plan for the project (http://www.netl.doe.gov/publications/press/2009/09033-CCS_Core_Sampling_Begins.html).

SECARB Announces Plans for Carbon Storage Project Using CO_2 Captured from Coal-Fired Power Plant (FY2009). Southern Company and SECARB announced plans to inject CO_2 captured from Alabama Power's Plant Barry into a deep saline reservoir 9,000 feet beneath the surface in the Citronelle Oilfield north of Mobile, Alabama. Beginning in

2011 and continuing for at least four years, 110,000 to 275,000 tons of CO_2 per year will be captured at the plant, transported via pipeline, and injected into the saline formation, which has oil-bearing formations above and below. A thorough monitoring process will be used to track the movement of the injected CO_2 and ensure that it is safely and permanently stored. The test site was selected because it is representative of similar saline formations that are believed to have great potential for carbon storage in the Southeast United States (http://www.netl.doe.gov/publications/press/2009/09047-SECARB_Announces_CCS_Plans.html).

Global Collaborations

The Global Collaborations component of the Carbon Sequestration Program benefits from technology solutions developed in the Core R&D and Infrastructure elements. The collaborative learning will help to advance overall CCS efforts at a lower cost and within a quicker timeframe. As aforementioned, the program includes work performed with various international groups and major international CO_2 storage projects that DOE is supporting either directly or through funding to researchers (Table 2). Collectively, these integral elements will guide the program toward the demonstration of commercial-scale projects and the ultimate deployment of CCS.

Global Collaborations Accomplishments

North America Carbon Atlas Partnership (NACAP) Sets Timetable (FY2009). NACAP participants agreed on the action items needed to facilitate mapping of CO_2 sources and geologic storage sites in Canada, Mexico, and the United States by late 2012 at an NETL-hosted meeting. The first NACAP meeting was hosted by Canada in December 2008, and the next meeting took place in Mexico in March 2010. NACAP, an initiative of the NAEWG, serves to foster collaboration among the three countries in the area of CCS.

CO_2 Stored in DOE Co-Sponsored Canadian Study Tops 10 Million Tonnes (FY2009). More than 10 million tonnes of CO_2 has been stored as part of EOR operations in the Weyburn and Midale oilfields in southern Saskatchewan, Canada. The Weyburn commercial oilfield operator, Encana Corporation, is injecting almost 2 million tonnes of CO_2 per year received through a 320-kilometer pipeline from Dakota Gasification Company in Beulah, North Dakota. At 28,000 barrels of oil per day, Weyburn production has nearly tripled as CO_2 floods the carbonate reservoir 1,500 meters underground. NETL represents the DOE's interest in the Weyburn-Midale CO_2 Monitoring and Storage project that is determining the permanency and best practices of geological storage in conjunction with the world's largest EOR and carbon storage operations. The research project is conducted by the Petroleum Technology Research Centre (PTRC) with sponsorship from Canada's Federal and provincial governments, IEA GHG, the European community, and other industry and research organizations in addition to DOE.

FE Project Monitors Subsurface Conditions at North Sea CO_2 Storage Site (FY2009). Researchers from world-acclaimed U.S. marine institutes working with NETL partnered with European scientists to track the injected CO_2 plume distribution, plume migration, and other related reservoir and subsurface conditions at the site of the world's first and longest running carbon storage operation – the Sleipner gas field in the North Sea. Because the injected gas is displacing pore space water in the Utsira Formation 1,000 meters under the seabed, the bulk density of the sandstone formation is decreasing, allowing changes in local gravity field strength to be detected by instrumentation developed at Scripps Institution of Oceanography for reservoir management in the oil industry. Scientists aboard the research vessel will receive data transmitted from sensitive gravity instruments positioned on the seafloor. With more than 10 million tonnes of CO_2 stored to

Table 2. DOE's Global CCS Project Involvement

Location	Operations	U.S. Involvement	U.S. Participant(s)	Reservoir	Operator/Lead	International Recognition
North America, Canada Saskatchewan Weyburn-Midale	1.8 Mt CO_2/yr Commercial 2000	2000-2011	Lawrence Livermore National Laboratory, Schlumberger, Fugro, University of Columbia	Oil field Carbonate EOR	Cenovus, Apache	US-Canada Clean Energy Dialogue, IEA GHG R&D Programme, CSLF
North America, Canada – Alberta Zama Oil Field	250,000 tons CO_2, 90,000 tons H_2S Demo	2005-2009	PCOR Partnership	Oil field Carbonate EOR	Apache (Reg. Part.)	CSLF
North America, Canada – British Columbia Fort Nelson	> 1 Mt CO_2/yr, 1.8 Mt acid gas/yr Large-scale Demo	2009-2015	PCOR Partnership	Saline Formation	Spectra Energy (Reg. Part.)	CSLF
Europe, North Sea, Norway Sleipner	1 Mt CO_2/yr Commercial 1996	2002-2011	Scripps, University of California, Lamont-Doherty, Columbia University	Marine Sandstone	StatoilHydro	CSLF, European Commission, IEA GHG R&D Programme
Europe, North Sea, Norway Snovhit CO_2 Storage	700,000 tonnes CO_2 Commercial 2008	2009-TBD	LLNL	Marine Sandstone	StatoilHydro	—
Europe, Germany CO_2SINK, Ketzin	60,000 tonnes CO_2 Demo 2008	2007-2010	Lawrence Berkeley National Laboratory	Saline Sandstone	GeoForschungsZentrum, Potsdam (GFZ)	CSLF, European Commission, IEA GHG R&D Programme
Iceland CarbFix	CO_2 stream from geothermal power plant	2009-2012	Columbia University	Hellisheidi Geothermal Power Plant	Reykjavik Energy	Icelandic, French, and U.S. (Columbia University) collaboration
Australia – Victoria Otway Basin	100,000 tonnes CO_2 Demo 2008	2005-2010	LBNL	Gas Field Sandstone	CO_2CRC	CSLF
Africa, Algeria In Salah Gas	1 Mt CO_2/yr Commercial 2004	2005-2010	LBNL, LLNL	Gas Field Sandstone	BP, Sonatrach, StatoilHydro	CSLF, European Commission
Asia – China Ordos Basin	Assessment Phase CCS	2008-TBD	LLNL, West Virginia University	Ordos Basin	Shenhua Coal	—

date and a timeframe greater than a decade, Sleipner operations are seen as analogous to future coal-based power plants with CCS capabilities (http://www.fossil.energy.gov/news/techlines/2009/09032-DOE_Study_Monitors_CO_2_Storage.html).

International Community Updated on U.S. Carbon Storage Activities (FY2009). NETL staff presented overviews of the RCSPs and the carbon capture component of FE's Innovations for Existing Plants (IEP) Program to the International Scientific Congress on Climate Change on March 10-12, 2009 (http://www.netl.doe.gov/technologies/coalpower/ewr/). Hosted by the University of Copenhagen, more than 2,500 delegates from nearly 80 countries participated in the Congress. The Congress supplements the work of the Intergovernmental Panel on Climate Change (IPCC) by identifying and synthesizing science, technology, and policy advances important to the sustainability of global communities in the current and coming decades.

IEA Finds U.S. CO_2 Sequestration Program World's Most Ambitious (FY2008). 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; no other country or region is undertaking such an ambitious program; and that Phase III is an excellent program that will achieve major results for the United States, Canada, and the world (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/Expert_Review_of_DOE_Regional_Patrnerships_Phase_III_-_ExecS.pdf).

DOE Technology Monitors CO_2 Injection in Australian Gas Field (FY2008). Australia launched the first carbon storage project in the Southern Hemisphere with the help of technology developed by DOE researchers. The $36 million Otway Basin Pilot Project, which is endorsed by the CSLF, will inject up to 100,000 metric tons of CO_2 more than one mile beneath the Earth's surface and monitor CO_2 in a depleted gas field in southeastern Australia to demonstrate the feasibility of storing the GHG in the Waarre Formation of the Otway Basin, as well as similar formations worldwide. With the injection expected to last one to two years, the reservoir will be monitored before, during, and after the CO_2 is injected. The Otway Basin was selected as a test site because of its large source of natural CO_2 and its abundance of now-depleted gas fields containing rock formations with geologic history of storage permanence. Cutting edge instrumentation, which was developed by the Lawrence Berkeley National Laboratory (LBNL) and research sponsored by NETL, will be used to track the CO_2 plume during and after the injection. Sophisticated seismic techniques will provide data about the location, migration, and permanent storage of the CO_2 plume, which will be more than one mile deep.

DOE Technology Deployed at European Showcase Project for Onshore CO_2 Storage (FY2008). A Distributed Thermal Perturbation Sensor (DTPS) developed in cooperation with NETL at LBNL was utilized to monitor the CO_2 plume and determine other reservoir properties at the CO_2SINK site outside Berlin, Germany. The technique uses a heat source and temperature sensors to measure the rate of fluid/CO_2 migration at numerous locations along a borehole. A planned injection of 60,000 to 90,000 tons of CO_2 over the next several years began June 30, 2008. With NETL support, LBNL researchers conduct storage technology transfer through participation in several international CO_2 storage demonstrations including those at Otway, Weyburn-Midale, and In Salah.

American Recovery and Reinvestment Act of 2009

The Carbon Sequestration Program will use Recovery Act funding to stimulate private sector investment that will significantly advance several important ongoing Carbon Sequestration Program activities (http://www.netl.doe.gov/publications/press/2009/stimulus.html). Recovery Act activities will accelerate commercial-scale demonstrations of CCS technology, thus increasing potential public benefits and reducing program risk in the process.

American Recovery and Reinvestment Act of 2009 Accomplishments

DOE Announces Regional Sequestration Technology Training Projects (FY2009). DOE announced $8.47 million in funding over three years to develop seven RCSP technology training projects that will facilitate the transfer of knowledge and technologies required for site development, operations, and monitoring of commercial CCS projects. The funding, which includes $6.9 million in Recovery Act funding, will advance the United States in its position as the leader in CCS technology for addressing climate change. The training activities will focus on the applied engineering and science of CCS for site developers, geologists, engineers, and technicians, providing a technology transfer platform for CO_2 storage. The selected projects will produce the workforce necessary for the CCS industry with skills and competencies in geology, geophysics, geomechanics, geochemistry, and reservoir engineering disciplines. The selected projects successfully addressed five activity areas: implement an organized sponsorship development program; develop short courses on CCS technologies; conduct regional training – outreach and networking; perform regional/basin technology transfer services; and plan and manage the recipient's regional program (http://www.netl.doe.gov/publications/press/2009/09062-DOE_Awards_CCS_Training_Projects.html).

DOE Advances CCS Research (FY2010). On September 16, 2009, DOE announced $12.7 million in funding for 43 research projects to advance CCS technologies by providing graduate and undergraduate student training opportunities at universities across the United States (http://www.fossil.energy.gov/recovery/projects/geologic_sequestration_training.html). The projects will provide advanced research training in simulation and risk assessment; MVA; geological-related analytical tools; methods to interpret geophysical models; and CO_2 capture. The three-year projects, which are funded through the Recovery Act, will be managed by NETL's Carbon Sequestration Program (http://www.fossil.energy.gov/news/techlines/2009/09066-DOE_Advances_CCS_Training.html).

DOE Research Projects to Examine Promising Geologic Formations for CO_2 Storage (FY2010). DOE will contribute $49.75 million for 10 projects aimed at significantly increasing scientific understanding about the potential of geologic formations to safely and permanently store CO_2 (http://www.fossil.energy.gov/recovery/projects/site_characterization.html). The projects will examine the usefulness of potential geologic storage sites and supplement existing data; in addition, project participants will participate in technical working groups on best practices for site characterization and storage site selection. Upon completion, the data obtained from these projects will be integrated into the NATCARB database. Funding for the projects comes from the Recovery Act to promote employment opportunities for local and regional organizations over the next three years (http://www.fossil.energy.gov/news/techlines/2009/09065-DOE_Awards_Site_Characterization_P.html).

For More Information

The NETL website (http://www.netl.doe.gov) offers extensive information about the components of DOE's Carbon Sequestration Program. The website provides an extensive program overview webpage with details about the five technical Core R&D focus areas, Systems Analyses capabilities, an FAQ information portal, information about the RCSPs with links to their websites, and an extensive reference shelf. Links to numerous resources can be accessed via the Carbon Sequestration Reference Shelf on the NETL website. Each of the categories on the Carbon Sequestration Reference Shelf has a variety of documents posted for easy access to current information. Once at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/refshelf.html, click on a category to view all materials related to the following:

- The Carbon Sequestration Newsletter (http://listserv.netl.doe.gov/mailman/listinfo/sequestration)
- Major Carbon Sequestration Educational Resources
- Program Overview Presentations
- Program Reports, Plans, and Roadmaps
- Journals and Scientific Articles
- Conference Proceedings and Presentations
- Project Descriptions
- Program Fact Sheets
- Regulatory and Policy Issues
- Systems Analysis
- Peer Review
- Best Practice Manuals

To learn more about DOE's Carbon Sequestration Program, please contact Sean Plasynski at Sean.Plasynski@netl.doe.gov, John Litynski at John.Litynski@netl.doe.gov, or Beth Tori at Beth.Tori@netl.doe.gov.

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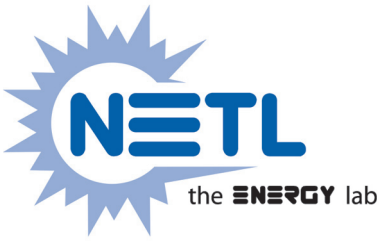

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